Technical Report No. 14

THE INFLUENCE OF SO_2 FUMING ON THE VEGETATION SURROUNDING THE KAHE POWER PLANT ON OAHU, HAWAII

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U. S. International Biological Program

October 1972

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PREFACE

The following investigation was done as part of an integrated environmental impact study. The request for this investigation was directed to the ISLAND ECOSYSTEMS program of IBP as a service job. For this reason it is presented here as a technical report.

ABSTRACT

The study relates to an investigation of the vegetation around Kahe power station, a recently established electricity generating plant at Kahe Point on SW Oahu. A vegetation map was prepared from aerial photographs at 1:5,000 and a search was made for possible SO_2 damage manifestations from the fumes emitted by the plant. Three major communities were identified, (1) closed forest of *Prosopis pallida*, (2) open forest-scrub dominated by *Leucaena leucocephala* and *Acacia farnesiana* and (3) open scrub-grassland dominated by the native pili grass (*Heteropogon contortus*). Within each of these major units, two to three floristic and structural subunits were mapped. No SO_2 damage was noted in the vascular plants. A separate survey of rock-lichens on identically sea-breeze-exposed ridges, north and south of the power plant, showed a considerably lower abundance of foliose rock-lichens in the southern area which receives much of the SO_2 plume. It was concluded that a beginning influence is shown by the lower abundance of lichens and that SO_2 damage in the vascular plants may show up only during the rainy season when the vegetation is actively growing. The investigation was done during the dry season in September.

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by Dieter Mueller-Dombois and Günter Spatz

The power plant at Kahe Point emits fumes that are constantly visible. The fumes contain SO_2, which can be smelled in the surrounding area of the plant. A study was initiated through Stearns-Roger, Inc. Engineering firm (Colorado) to investigate the vegetation around the power plant for possible manifestations of this SO_2 fuming. The first power plant unit began to operate in 1963. Since then the plant gradually increased its power output with installation of a fourth unit in 1972. Following a proposal by the writers, a plan was stipulated in a contract (R900 C10637, dated August 23, 1972), which called for identification and mapping of the present plant communities surrounding the Kahe Point power plant and for a comparative analysis of another area showing the same environmental conditions, but not being influenced by SO_2 containing fumes. In addition, lichens, known to be most sensitive to SO_2 fuming, were to be analyzed separately.

The present report is the fulfillment of this contract. The vegetation map and a phytosociological table are appended.

THE AREA

Geographic location

The Kahe Point power plant of Hawaiian Electric Company is located at the SE coast of Oahu. It is situated on the inland side (mauka) of the coastal highway and at the bottom of a steep bowl rising to 800 feet behind the station. The rim of this bowl extends in an approximate semi-circle around the plant. The seaward boundary of the area is defined by the coastline from Kahe Point to approximately where Pili o Koe Gulch empties into the ocean.

Climate

The area is in a tropical summer-drought climate (Kartawinata and Mueller-Dombois 1972: 402), with an approximate mean annual rainfall of 500-600 mm. The mean air temperature ranges from 21°C in January to 27°C in September. The drought-months extend from April through early October. During these months, the vegetation is in a state of dormancy, as similarly is the temperate zone vegetation during the winter months.

PROCEDURE

Reconnaissance

The Kahe site and its neighboring areas (Nanakuli Valley to the north and Waimanalo Gulch and Makuwa Gulch to the south) were visited with the intention of analyzing an area comparable to the Kahe site without the fuming influence. However, it was found that all of the neighboring areas differed sufficiently in both physiography and current vegetation structure that a comparative analysis would not have allowed to draw satisfactory conclusions. Moreover, an interference of fuming from Barber's Point Industrial Park was noted in the area south of Kahe Point. It was therefore decided to rely merely on an intensive search for signs of SO_2 damage in the Kahe area itself, and to compare the phytosociological data obtained with an earlier investigation of Oahu's dry-zone grasslands (Kartawinata and Mueller-Dombois 1972). In contrast, areas, for a reasonable comparison of rock-lichens in the SO_2 fuming range and away from it, are found. This will be further explained below.

The field work was done in September 1972, which is during the height of the drought season. As mentioned before, the perennial vegetation at this time is in a state of dormancy and the annual plants have disappeared.

Vegetation sampling and mapping

Vegetation sampling was done in 20 plots interspersed along six transects.

The transects extendedinland from the base of the bowl, from behind Kahe power plant up the slope to the rim of the bowl. The transects were approximately evenly distributed through the semi-circle of the bowl from one side to the other.

Mapping was done from a recent large-scale air photo (approx. 1:5000) simultaneously with the vegetation sampling. Structural vegetation units, such as forest, open forest, scrub and grass cover were easily mappable, because they formed a rather clear elevational zonation in the bowl. The vegetation samples were placed in the zones. The floristic analysis was used to verify and adjust the map-boundaries, where necessary. In forest vegetation, the sample plot sizes were 20 x 20 m, in scrub and grass vegetation they were 10 x 10 m. All species were listed in each plot. Species quantities were estimated with the Domin-Krajina abundance-cover scale (bottom of TABLE 1). Careful observations were made on possible fume damage to vascular plants in each sample plot and along the transects. We will first report on the general vegetation analysis and subsequently on the lichen study.

THE PLANT COMMUNITIES OF KAHE BOWL

General vegetation-substrate zonation

As mentioned above, the vegetation in Kahe bowl forms a relatively distinct zonation. A closed, low-stature forest, dominated by *Prosopis pallida* (kiawe) occurs inland of the power plant and up the lower part of the surrounding slope. Upslope, *Prosopis* trees become more scattered and smaller. Here, they are interspersed with another low-stature tree species, *Leucaena leucocephala* (koa-haole). Further up, these trees give way to a shrub species, *Acacia farnesiana* (klu) which forms a scrub vegetation on the upper midslope. Still higher up the shrub individuals become more scattered and near the upper part of the rim the woody vegetation is replaced by a closed grass cover dominated by *Heteropogon contortus* (pili grass).

This vegetation zonation is generally well correlated with the substrate, although historical factors, such as fire and grazing, have undoubtedly contributed to the present vegetation pattern. The substrate shows a colluvial sequence. The bottom and lower slope of the bowl is covered with coarse broken rock, which forms the substrate of the closed forest. Upwards, the rocks decrease in size and more fine soil occurs in pockets between the rocks. The closed grass cover on the upper more gently sloping part of the bowl occurs on shallow soil. But, there are still many rocks that crop out among the grass covered soil.

These general relationships are shown on the profile diagram (FIG. 1).

FIG. 1 General vegetation-substrate relationships along slope transects from bottom to ridge in Kahe bowl

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The general elevational zonation described is often interrupted by rock slides of various sizes that extend perpendicular to the contour lines. These rock slides indicate that geomorphological development is still quite active in Kahe bowl. For this study, this was of significance in so far as some of the exposed rocks that showed a conspicuous absence of lichens were rocks that had moved recently.

The map units

The plant communities outlined on the map (FIG. 2) will be discussed in four categories. More detail is shown in the synthesis table (TABLE 1).

1. Closed forest. - This is the *Prosopis pallida* forest occurring at the bottom and on the lower slope of Kahe bowl. The trees are of low stature, i.e., of 5-7 m height, and they grow with interlocking crowns. However, during the

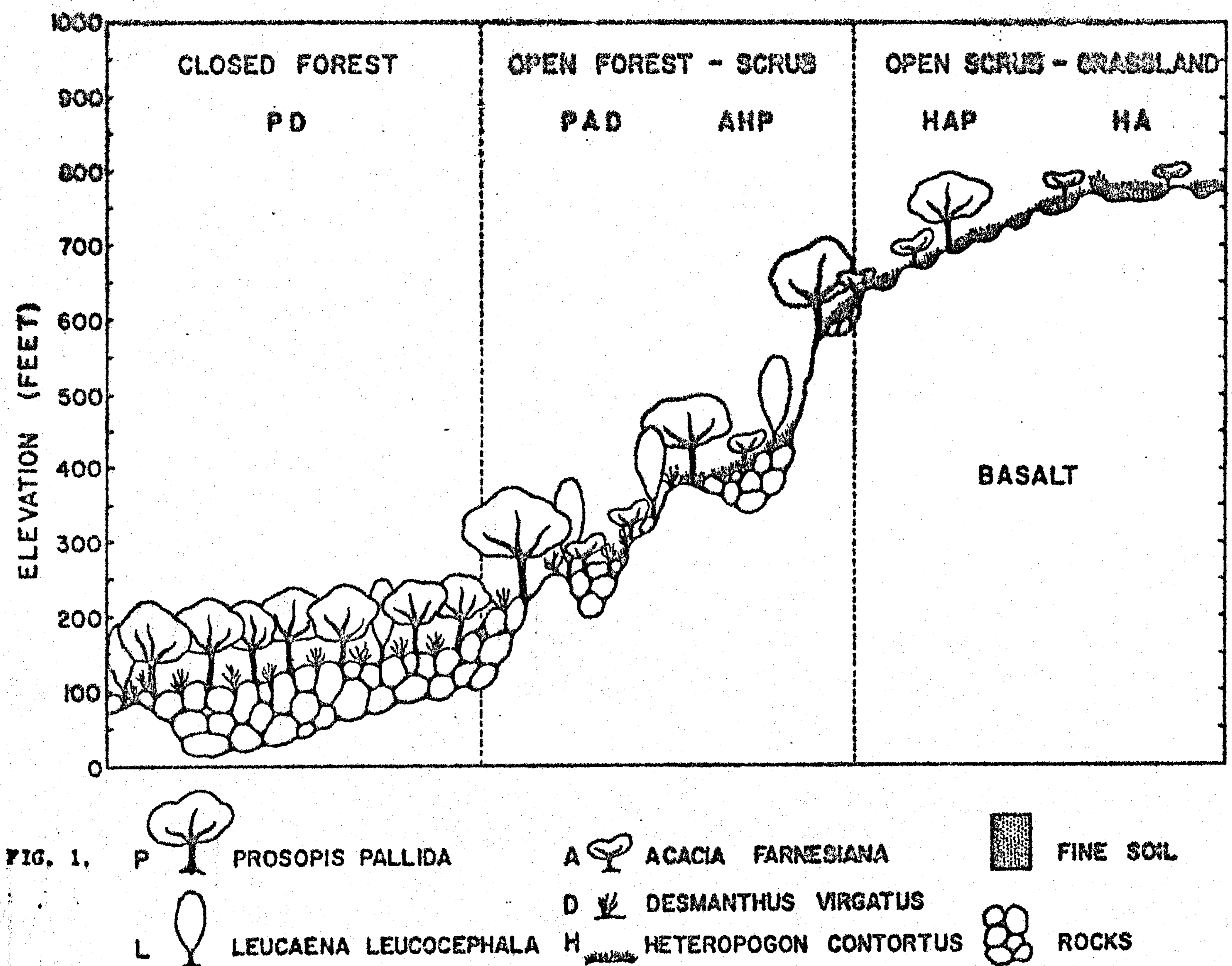
CLOSED FOREST
PD
OPEN FOREST - SCRUB
PAD
AHP
OPEN SCRUB - GRASSLAND
HAP
HA
BASALT
ELEVATION (FEET)
1000
900
800
700
600
500
400
300
200
100
0
P PROSOPIS PALLIDA
L LEUCAENA LEUCOCEPHALA
A ACACIA FARNESIANA
D DESMANTHUS VIRGATUS
H HETEROPOGON CONTORTUS
FINE SOIL
ROCKS

FIG. 1.

FIG. 2. VEGETATION MAP OF KAHE BOWL, OAHU, HAWAII

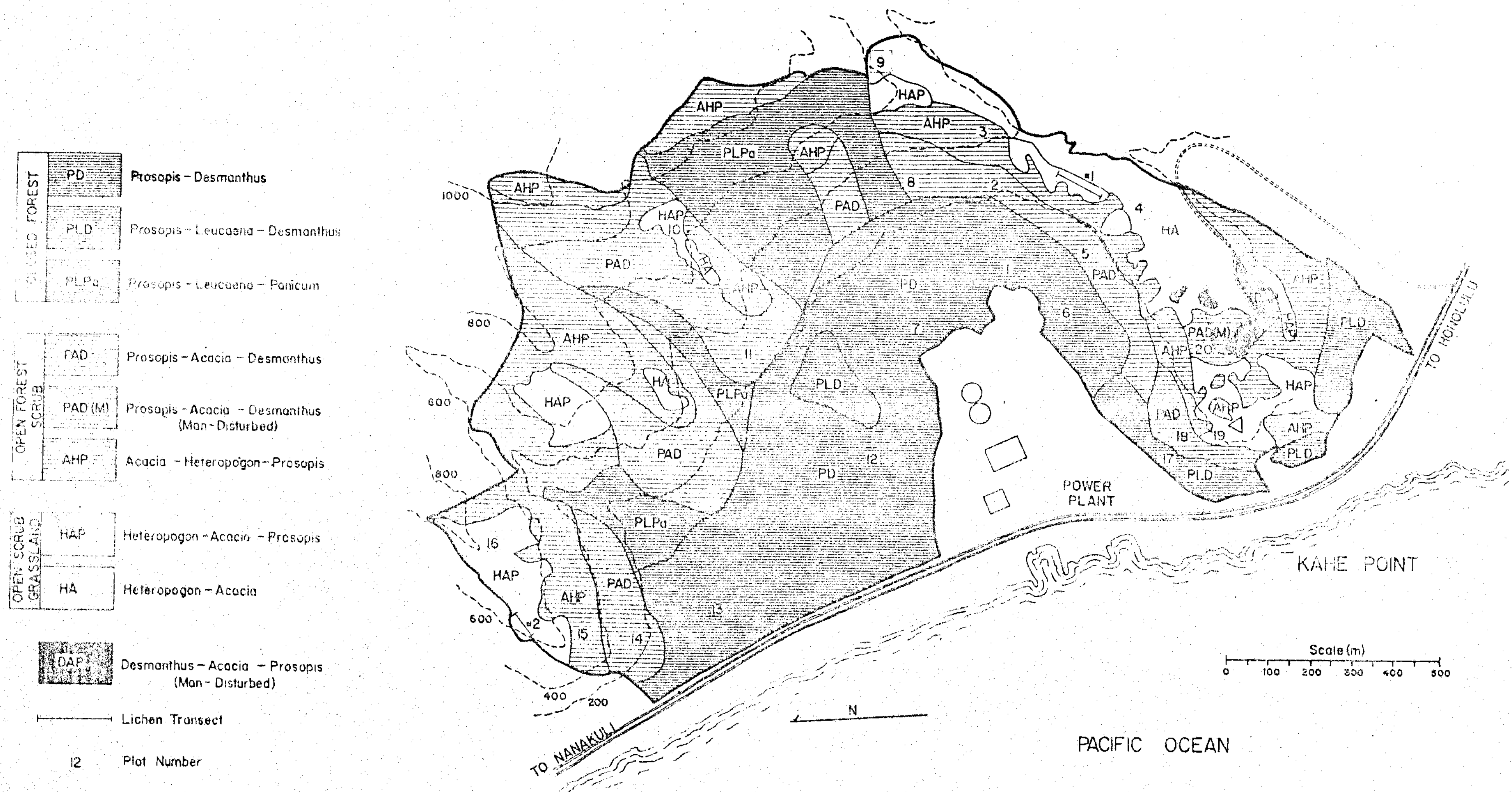

TABLE I: PLANT COMMUNITIES OF KAHE BOWL

	CLOSED FOREST •						OPEN FOREST —						SCRUB •			OPEN SCRUB-GRASSL.					
	PD					PLD	PAD						PAD (m)	AHP		HAP		HA			
relevé	12	7	13	6	1	17	2	8	11	5	18	14	20	3	15	19	10	16	9	4	frequency
date	23.9	23.9	30.9	23.9	23.9	30.9	23.9	23.9	23.9	23.9	30.9	30.9	30.9	23.9	30.9	30.9	23.9	30.9	23.9	23.9	
elevation feet	40	100	80	100	100	60	200	300	220	150	120	240	300	430	600	270	780	760	680	350	
slope	5%	11%	5%	10%	20%	20%	30%	30%	45%	35%	60%	40%	30%	40%	40%	30%	25%	55%	flat	flat	
exposure	190°	210°	170°	280°	230°	320°	230°	206°	180°	312°	280°	180°	300°	240°	140°	340°	160°	150°			
number of species	8	7	9	10	11	11	9	12	10	14	12	14	11	14	10	14	13	10	13	8	
species limited to closed forest																					
C_1 Ocimum basilicum	1	·	2	2	3	1	·	·	·	·	·	·	·	·	·	·	·	·	·	·	5
species avoiding open scrub-grassl.																					
B_2 Malvastrum coroman.	·	·	3	3	1	2	2	3	3	2	·	1	·	·	·	·	·	·	·	·	9
C_1 Chloris virgata	4	2	3	5	3	2	·	3	·	4	2	3	3	4	·	·	·	·	·	·	12
Setaria verticillata	1	·	1	3	3	3	2	·	·	·	1	2	2	·	·	·	·	·	2	·	10
species avoiding closed forest																					
B_2 Acacia farnesiana	··	·	·	·	·	·	6	3	5	6	7	2	4	6	7	5	5	4	4	5	14
Waltheria americ.	·	·	·	·	·	·	·	3	3	2	·	+	1	3	3	3	3	3	3	3	12
C_1 Heteropogon contor.	·	·	·	1	+	·	·	2	4	5	2	3	4	8	7	9	8	9	8	9	15
Rhynchelytrum rep.	·	·	·	·	·	·	·	·	2	4	1	·	2	4	2	3	4	3	6	3	11
species limited to scrub + grassland																					
C_1 Passiflora foetida	·	·	·	·	·	·	·	·	·	·	·	+	·	1	+	1	·	3	3	1	7
species limited to open scrub-grassl.																					
B_2 Cassia leschenault.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	2	2	1	·	3
Indigofera suffrutic.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	2	·	2
C_1 Chloris barbata	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1	4	·	·	3	3
species occurring throughout the bowl and rare ones																					
B_1 Prosopis pallida	8	8	8	8	8	7	5	7	6	4	6	7	7	4	3	2	1	·	1	·	18
Leucaena leucoceph.	·	4	·	·	·	6	4	6	4	3	4	5	5	3	2	·	·	·	·	·	11
B_2 Desmanthus virgat.	8	7	8	8	7	2	8	4	·	7	·	2	7	2	·	·	2	·	1	4	15
Sida cordifolia	4	3	6	4	3	5	3	5	4	5	3	7	·	4	5	2	2	·	3	·	17
Leucaena leucoceph.	3	3	·	·	3	4	4	3	3	4	5	3	4	4	6	3	4	3	5	·	17
Opuntia megacan.	·	·	1	+	·	1	·	2	·	2	·	1	·	3	·	2	3	1	·	2	11
Verbesina spec.	·	4	·	·	6	·	6	·	·	·	3	·	·	·	·	·	·	·	·	·	4
Lantana camara	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1	·	1
Dodonaea viscosa	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	3	·	·	·	·	1
Gossypium sandvic.	1	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1
C_1 Trichachne insular.	4	7	1	3	1	3	2	3	6	3	5	2	·	4	3	2	3	2	·	·	17
Bidens pilosa	·	·	·	·	·	·	·	·	·	3	1	·	1	3	·	1	3	·	4	·	7
Merremia aegypt.	·	·	·	·	·	1	·	1	·	·	1	1	1	·	2	·	·	·	·	·	6
Phaseolus lathyr.	·	·	·	·	·	·	·	·	+	+	·	·	·	·	·	1	·	·	·	·	3

B_1 = Woody species 2-6 m tall, B_2 = Woody species 0.2-2 m tall, C_1 = Herbaceous species > 0.2 m tall

The numbers refer to cover estimates as follows:
+ = solitary, small cover; 1 = seldom, small cover; 2 = very scattered, small cover; 3 = scattered, less than 5%; 4 = cover 5-10%; 5 = cover 10-20%; 6 = cover 20-33%; 7 = cover 33-50%; 8 = cover 50-75%; 9 = cover more than 75%, but less than complete.

dry season, the ground area receives much light because a large proportion of the foliage is shed. A second small tree species, Leucaena leucocephala is commonly admixed. The understory is dominated by the shrubs Desmanthus virgatus (acuan) and Sida cordifolia (= S. fallax) (ilima). The herb Ocimum basilicum was limited to this community. Except for Sida cordifolia and rare specimens of Gossypium tomentosum (= G. sandwicense), the endemic cotton, all species in this community are introduced. The community contains remarkably few species. It is possible that a number of annuals occur during the rainy season. Lichens on rocks were found to be generally abundant.

Three subcommunities could be distinguished, which are mapped as:

PD = The Prosopis-Desmanthus facies.
This community is limited to the bottom of the bowl. Here the canopy of Prosopis pallida is denser than in the other subcommunities, and rarely do we find Leucaena leucocephala.

PLD = The Prosopis-Leucaena-Desmanthus facies. This subcommunity is limited to a small area. It contains considerably more Leucaena, and the canopy is somewhat more open than in PD.

PLPa = The Prosopis-Leucaena-Panicum maximum facies. This subcommunity extends upslope in a few narrow gulches, which apparently receive additional moisture after rains by seepage. Dense undergrowth of the tall bunchgrass, Panicum maximum forms an almost impenetrable jungle.

2. Open forest-scrub.- This community forms the next major woody vegetation zone upslope above the closed forest. The overstory trees are still Prosopis pallida and Leucaena leucocephala, but they are more widely spaced or grow in small clumps (Leucaena). The spaces between the tree crowns and beneath

the crowns are filled by shrubs. Here particularly the 1-3 m tall Acacia farnesiana (klu) is common and forms a good differential species to the previous community. Another frequent shrub, not found in the previous type, is Waltheria americana (hi'aloa). Sida cordifolia is still as common as in the closed forest. Three perennial, scattered grasses are often found here, Chloris virgata (finger grass), Setaria verticillata (bristly foxtail) and Trichachne insularis (sourgrass).

This community occurs generally on steeper slopes. The substrate is still mostly colluvial rock, but the proportion of exposed rock and soil is quite variable from place to place. Generally, fine material increases upslope.

Two subcommunities were mapped:

PAD = Prosopis-Acacia-Desmanthus facies. In this subcommunity Prosopis is still the dominant in cover, and Desmanthus occurs as its undergrowth in patches. But the spaces between Prosopis are occupied by Acacia farnesiana. In some openings of the woody plants occur scattered grasses of Heteropogon contortus (pili) and Rhynchelytrum repens (natal redtop).

AHP = Acacia-Heteropogon-Prosopis facies. As indicated in the name order, Acacia dominates in cover, while Prosopis is merely present as a scattered tree. But the grass Heteropogon contortus occurs also in larger patches of one to several square meters. Here it is often admixed with Rhynchelytrum repens and the herbaceous vine Passiflora foetida (passion flower).

Certain undergrowth species that are more associated with the woody species (such as the grasses Chloris virgata, Setaria verticillata and the small shrub Malvastrum coromandelianum) are mostly absent here.

3. Grassland. - This community occurs where the grass Heteropogon contortus

forms coherent mats above the woody plant communities. Grassland occupies the upper slopes and level areas near the ridge. There are still many outcropping rocks dispersed throughout the grassland, but soil usually covers more than 75% of the surface. Its depth, however, is usually less than 50 cm. Important associated species are Rhynchelytrum repens, Chloris barbata, and the small shrubs Cassia leschenaultiana and Indigofera suffruticosa (indigo). Two subcommunities were mapped:

HAP = Heteropogon-Acacia-Prosopis facies. This was distinguished by the presence of scattered, shrubby Prosopis pallida.

HA = Heteropogon-Acacia facies. This is the more wide-spread form of the Heteropogon grassland distinguished by the absence of Prosopis.

4. Man-disturbed woody communities. - The southeast side of the bowl showed some disturbances from World War II military activities. Since the floristic pattern did not quite fit into the established categories, these man-disturbed communities were mapped as:

PAD(m) = Prosopis-Acacia-Desmanthus (m for man-disturbed) community. Nearly all species found in the "normal" community of this type were present, but Sida cordifolia and Trichachne insularis were notably absent.

DAP = Desmanthus-Acacia-Prosopis community. This community occurred in the same general area. It is recognized by the extremely dense growth of Desmanthus virgatus, which suppresses almost all other shrub and herb species in this community. This facies probably represents an earlier seral stage after fire disturbance of the PAD community.

THE LICHEN SURVEY

Reconnaissance

Observations and notes on lichen distribution were made throughout the transect walks and plot analyses. Foliose and crustose lichens occurred on two substrates; on the stems and branches of Prosopis pallida and on exposed rocks. On Prosopis their abundance was definitely correlated with size and age of trees. The oldest trees seemed to have the most lichens. These trees occurred scattered throughout the bottom and the lower slope area of the bowl. There was no obvious pattern of increasing lichen abundance with distance from the power plant. Also no distinct variation could be ascertained between areas around the semi-circle of the bowl.

The distribution of lichens on rocks seemed to be more abundant at the base and slope-bottom, somewhat less abundant at midslope and again somewhat more abundant on the upper slope, on rocks exposed in the grassland. Rocks lacking lichens in the midslope section were often those that had recently moved, probably by gravitation. Several rock slopes in the open forest-scrub zone (type 2) were practically barren of woody plants. On these slopes lichens were completely absent. Obviously, here colluvial activity has recently occurred. For this reason, it was necessary to look for lichens on stable rocks. Near the top of the ridge in the grassland, the slopes are more gentle on both sides of the ridge, and the outcropping larger rocks are stable.

Here it was noted that the lichens were definitely more abundant on the NW seaward facing side of the ridge than on the SW inland facing side.

This difference in lichen abundance on the two sides of the gently sloping ridge top has nothing to do with the SO_2 fuming, but can be explained as related to the prevailing moisture-laden sea breeze, which on the lee side of the island seems to come from the NW. This wind also seems to channel the plume of the power plant much of the time in the SE direction.

The two seaward ridge tops that form the ends of the semi-circular bowl are comparable in physiography, wind exposure and vegetation. The ridge at the N-end is south of Pili o Koe Gulch and the S-end ridge begins right above Kahe Point. Both ridge tops have areas of gentle NW facing slopes which show numerous outcropping, stable rocks in the *Heteropogon* grassland. General observation indicated that lichens were less abundant on the ridge southeast of the electric plant, *i.e.*, on the ridge above Kahe Point.

Abundance measurements

Two parallel point-frequency transects were run, one on the ridge (above Kahe Point) to the southeast of the power plant (transect 1), the other on the ridge (at Pili o Koe Gulch) to the north (transect 2). Both transects were run on the upper gentle NW facing slopes of these ridges, which can be assumed to receive equal amounts of moisture-laden sea breezes. Rocks to be sampled were required to stand at least 25 cm above the soil surface and to have a minimum diameter of 50 cm. Any such rock encountered in a 5 meter wide belt-transect running roughly parallel and 3 m below each ridge was sampled across its center. A minimum of 1000 points were sampled on each ridge with a point-frequency frame in which the pointed steel rods were 10 cm apart (i.e., 10 per meter). Consequently the length of transect 1 was about 120 m and that of transect 2 about 60 m. This difference in length was the result of large outcropping rocks being more abundant along transect 1. The results are shown in TABLE 2.

TABLE 2 shows that the total lichen cover on rocks on the side receiving much of the fume (transect 1) is only half that on the slope away from the plant (transect 2). When examining the kinds of lichens, it is seen that the foliose lichens (no. 2 and 3) are reduced to 40% of those on the side away from the power

TABLE 2. Lichen cover on rocks on ridges at each side of Kahe power plant. Transect 1 occurs in the area receiving much of the SO_2 fuming.

	TRANSECT 1		TRANSECT 2		TR1/TR2
	Points	% cover	Points	% cover	ratio
Total no.	1070	100.0	1260	100.0	1.0
Barren rock	1016	95.0	1135	90.1	1.1
Lichen 1	21	2.0	31	2.5	0.8
Lichen 2	16	1.5	51	4.1	0.4
Lichen 3	10	0.9	32	2.5	0.4
Lichen 4	7	0.7	11	0.9	0.8
Total lichen points	54	5.1	125	10.0	0.5

Lichen 1 = *Lecanora* sp. (a light yellow crustose form)

Lichen 2 = *Parmelia plittii* Gyal. (a light green foliose form)

Lichen 3 = *Physcia ?subtilis* Degel. (a light gray foliose form)

Lichen 4 = *Caloplaca* sp. (an orange crustose form) plant. The two crustose lichens (no. 1 and 4) are less strongly reduced.

CONCLUSIONS

It seems reasonable to conclude that there is indeed a toxic effect manifested in the foliose lichens because they are less abundant along the southern rim of the bowl.

With regard to the vascular plants, there is no evidence as yet of SO_2 damage manifestation. This conclusion is based on the present phytosociological analysis and a comparison with earlier data taken by Kartawinata and Mueller-Dombois (1972). In 1965-67, the dry-grass community above Kahe Point was studied in seven vegetation samples (plots 49, 50, 96-100, p. 377 and Appendix Table 1 in the above cited publication). Examination of the floristic composition at that time in the *Heteropogon* grassland and at this time shows no important difference.

However, it must be emphasized that the present study was done at the most inopportune time for detecting any foliage damage on vascular plants, because they were all dormant during September. Certainly, a loss in the more abundant perennial species requires a rather drastic SO_2 effect. First, one would expect a discoloration of green leaves during the growing season, such as shown by Hindawi (1970). As a next stage, one would expect necrosis and perhaps abortion of leaves and shoots. These symptoms cannot be detected during the season of dormancy. It is of relevance here to draw attention to a recent paper on effects of sulphur oxides on vegetation by Linzon (1972), who gives SO_2 threshhold levels for vegetation damage. In view of Linzon's data, it would seem advisable to monitor the SO_2 emission into the bowl for at least 3-4 months during the growing season (December through April) and then to make simultaneous observations on foliage effects in permanent plots.

A periodic reanalysis of the rock-lichens once every 6 months may indicate a rate of lichen disappearance, which may serve as a biological hazard index.

ACKNOWLEDGEMENTS

We wish to thank Dr. C. W. Smith for the identification of the four lichens and Richard Becker for suggesting literature.

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