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Ecological and floristic studies in Kipapa Gulch, Oahu*

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INTRODUCTION

This investigation concerns the ecological and floristic features of Kipapa Gulch, Koolau Range, a mountain valley extending from near the middle of the range at an elevation of 860 meters, to sea level at Pearl Harbor, a distance of about 21 kilometers. It was chosen as typical of approximately one quarter of the island. It is one of the larger gulches and has a well preserved mountain flora. More specifically, the objects of study have been to determine the species of plants which are growing naturally at different elevations in this valley, together with an experimental investigation of environmental conditions, as well as a survey of the composition, distribution, and successional relations of the various plant communities. The work was initiated in the fall of 1931 and carried on during the following four years. The climatic and edaphic data were gathered in 1933.

Very few ecological studies of vegetation have been made in Hawaii. Early explorers, Wilkes (66),[1] Bloxam (5), Byron (7), Chamisso (11), Menzies (37), and Seemann (53), give only short observational accounts of the vegetation. Hillebrand (23) takes up the ecology of the Hawaiian islands in general and divides the plants into groups occupying different elevations. The more recent workers are Forbes (19), Rock (44), Campbell (10), and MacCaughey (30). Forbes deals with plant succession on new lava flows, Rock with vegetational zones, Campbell with environment, and MacCaughey with associations.

* Presented in partial fulfillment of the requirements for the degree of Master of Science, University of Hawaii, 1935.

[1] Numbers in parentheses refer to Bibliography, p. 230.

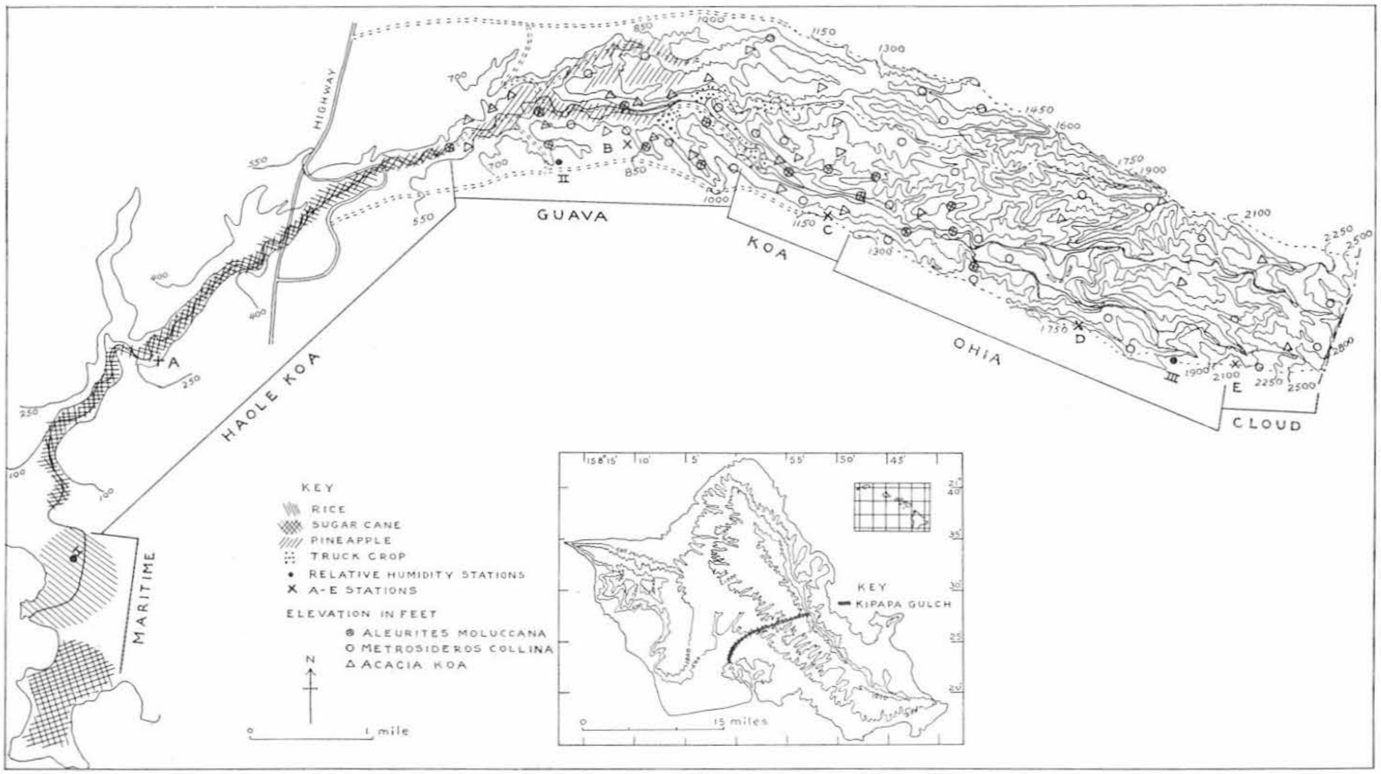

FIGURE 1.—Map of Kipapa Gulch showing topography, stations where data were collected, and distribution of important trees.

The only detailed ecological study of a specific area in Hawaii was made by MacCaughey (30). Before this study, the ecological investigations comprised only a general description of the vegetation.

Acknowledgments

These studies have been conducted under the direction of Professor Harold St. John of the University of Hawaii to whom I express my appreciation for the aid and counsel given during the progress of the problem. I also express my appreciation to Dr. Herbert E. Gregory, Director Emeritus of Bernice P. Bishop Museum, for use of the herbarium, and to Mr. Edwin H. Bryan, Jr., Curator of Collections, for his unfailing encouragement. Furthermore, I acknowledge my indebtedness to Mr. E. B. Bartram for naming the mosses, to Dr. Oscar C. Magistad for the use of the organic content determination apparatus, to Dr. Walter Carter for the loan of atmometers and to Mr. J. F. Voorhees for the use of a sling psychrometer. I also thank Mrs. Beatrice M. Hosaka for typing the paper, Mr. Michio Yamaguchi who has been an unselfish field companion and frequent assistant on most of the trips taken during the progress of the study, Mr. F. R. Fosberg who has been a pleasant field companion on some of the trips, and last but not least Dr. G. E. Nichols and Dr. F. E. Egler for reading and commenting on this paper.

Physiography

Kipapa Gulch is located on the west slope of the Koolau Range, which runs northwest to southeast from one end of the island to the other (fig. 1). The gulch extends approximately 21 kilometers from the West Loch of Pearl Harbor to the summit area of the Koolau Range, and is one of the longest gulches on the island of Oahu. The region from the shore of West Loch for about 800 meters to the mouth of the entrenched gulch is of level alluvial land. The larger portion of this section is utilized for rice growing. There are several fish ponds varying in size from a few acres to several acres close to the beach and small patches of taro fields and vegetable gardens along the fringe of the rice fields.

The gulch extends northward for a short distance, turns northeast and then eastward toward the summit range. The width and depth of the gulch vary considerably. The gulch at its mouth is narrow with steep rocky sides, but a few hundred meters inland, it becomes broader with less steep sides. On the gulch bottom are flood plains ranging in size from a few to many acres. This region with nearly level floor and gently sloping sides extends to about 225 meters elevation and is cultivated. The lower third of this agricultural land is planted in sugar cane and the upper two thirds is cultivated in pineapple and truck crops (fig. 2).

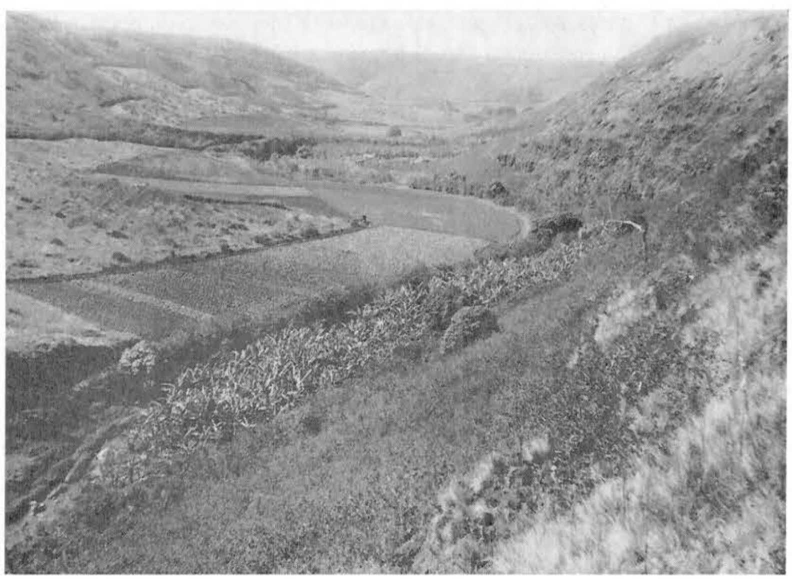

FIGURE 2.—View downstream in the Guava Zone showing cultivated fields, *Psidium Guayava, Heteropogon contortus* on the foreground slope, and banana plantation on the bottom.

Above 225 meters elevation, the slopes are entrenched by many narrow gullies that run obliquely to the main gulch. The few side gullies radiating from the main gulch below the 225 meters elevation are also oblique. This much dissected section is thickly forested with many species of native ferns, shrubs, and tall trees.

The depth of the gulch increases with the increase in elevation up to about 200 meters of the summit where the streams descend as cascades and waterfalls from the slope of the summit range. The side streams are intermittent to semi-intermittent in flow and supply the central stream which is usually permanent in flow. Its lower section, below the forest, occasionally dries up after a long drought.

The central or main stream meanders through the gulch to the West Loch cutting across the alluvial land beyond the gulch proper. The stream at this lower portion is fed by springs, and the flow is permanent. On both sides of the gulch at about half way between the bottom and the rim is a bed of basalt, two to seven meters thick, which outcrops in a continuous line in the lower region of the gulch but becomes intermittent as the forest is approached. This narrow strip of basalt outcrop that extends along the center of the gulch slopes has a conspicuous effect on the height of the plants, due to greater moisture and deeper soil below the outcrop. The plants growing below the outcrop are taller and more vigorous than the same species growing above it.

Plant Zones

In Kipapa Gulch, the plant life shows striking differences in its various parts, due mainly to the wide range of ecological conditions that exist between those of the seaward portion and those of the summit area. Variations occur not only in the composition of the vegetation but also in the habit of individual species. For example, the most common introduced plant, *Psidium Guayava* (guava) thoroughly naturalized in Hawaii, is only a small bush of about 1.2 meters high in the xerophytic lowland region, but it gets much larger in stature and in the diameter of the trunk as the mesophytic region is reached. Here it attains a height of 6.5 to 8.5 meters and a diameter of 15 to 25 cm., but again the species becomes smaller and less common as the wet summit region of the Koolau Range is reached.

For purposes of field investigation and for the presentation of data, six plant zones have been tentatively established in Kipapa Gulch. These are recognized wholly on the basis of existing cover types. Any other classification taking into account the phyto-climate, the pre-existing vegetation, or the ultimate plant cover is not yet possible in the present state of knowledge.

The Maritime Zone vegetation is chiefly composed of salt-loving plants such as *Batis maritima, Sesuvium Portulacastrum,* and *Scirpus maritimus.* On waste places, particularly on drier sites, *Prosopis chilensis* and *Panicum purpurascens* are conspicuous. In the lower section of the gulch, in the Haole Koa Zone, the plants are mostly xeric. Some of the dominating species are *Leucaena glauca* (haole koa), *Opuntia megacantha, Acacia Farnesiana, Lantana Camara,* and *Heteropogon contortus.* Farther up the gulch, in the Guava Zone, *Psidium Guayava* and *Lantana Camara* are most common. Above this region is the Koa Zone, dominated by *Acacia Koa* and *Gleichenia linearis* on the slopes, and by *Aleurites moluccana* in the gully bottoms. The central portion of the native forest, the Ohia Zone, is dominated by *Metrosideros collina* (ohia lehua), a tree towering 15 meters or more above the ground. The Cloud Zone is characterized by low, dwarfed shrubs in more sheltered parts and by mat-forming *Panicum, Paspalum, Isachne,* and mosses in exposed windswept areas. The vegetation of Kipapa Gulch is more fully treated on page 190.

ENVIRONMENTAL FACTORS

The climatic and edaphic factors determine the vegetation of a region. To determine the various environmental conditions that affect the plants of this region, the atmospheric temperature, relative humidity, rainfall, evaporation, soil temperature, soil moisture, soil acidity, and the organic content of the soil were investigated in the different vegetational zones. The stations where these observations were made were designated as Stations A, B, C, D, and E from the Haole Koa to the Cloud Zones respectively. Their location is shown on the map (fig. 1).

The various climatic and edaphic factors at the stations were recorded at certain times of selected days during 1933. The evaporation and rainfall data of Station A were recorded at 6:00 a.m., B at 6:30 a.m., C at 8:30 a.m., D at 10:30 a.m., and E at 11:45 a.m. The atmospheric temperature and soil temperature data of Station A were recorded at 4:30 p.m., B at 4:00 p.m., C at 3:30 p.m., D at 1:45 p.m., and E at 12:00 m. The times of recording the above factors are approximate varying about 30 minutes on either side of the stated hour, since it was often very difficult to travel through the forest. The relative humidity data were recorded simultaneously at three different places.

Station A is in the Haole Koa Zone at 75 meters elevation on a north facing slope. In the immediate vicinity of the station are a few fairly large stands of *Opuntia megacantha* and sparse growth of *Psidium Guayava, Lantana Camara, Heteropogon contortus, Cassia Leschenaultiana,* and *Waltheria indica* variety *americana.*

Station B is in the Guava Zone at 225 meters elevation on a north facing slope. Around the station are a few trees of *Metrosideros collina* and scattered bushes of *Psidium Guayava, Wikstroemia oahuensis, Lantana Camara, Styphelia Tameiameiae*, and low plants of *Chrysopogon aciculatus, Paspalum orbiculare*, and *Stenoloma chinensis*.

Station C is in the Koa Zone at 305 meters elevation on a north facing slope. Around the station is a thick stand of *Stenoloma chinensis* and *Gleichenia linearis*. Several trees of *Metrosideros collina, Psidium Guayava, Styphelia Tameiameiae*, and *Acacia Koa* are also found near by.

Station D is in the Ohia Zone at 485 meters elevation on the north facing slope. Around the station are dense stands of *Metrosideros collina, Straussia kaduana, Bobea elatior, Acacia Koa*, and *Gleichenia linearis*. Also many species of ferns and mosses are found on the ground and on tree trunks.

Station E is in the Cloud Zone at 670 meters elevation on the north facing slope. Around the station are many dwarfed trees of *Suttonia Lessertiana, Metrosideros collina, Straussia kaduana*, and *Fagara oahuensis*. Other plants in the vicinity are *Gahnia Beecheyi, Peperomia membranacea, Vaccinium dentatum, Elaphoglossum reticulatum, Gleichenia emarginata, Hymenophyllum recurvum*, and mosses.

Atmospheric Temperature

The atmospheric temperature was recorded at the A to E Stations on March 19, April 2, 9, 16, July 2, 9, 16, 23, 30, November 5, 12, 19, and 26. The data are presented in table 1. The average temperature readings in degrees centigrade at Station A is 29.2, at B, 25.0, at C, 24.0, at D, 22.0, and at Station E, 21.5. The readings indicate that the temperature at the various stations fluctuates on different days at the same hour. At Stations A, B, and C, the temperature in July is much higher than in March, April, or November, but at Stations D and E there seems to be no indication of a month with decided high temperature. The first three stations are below the native forest while the last two are in the forested region.

Table 1. Atmospheric temperature in degrees centigrade recorded at Stations during 1933.

Date	Stations				
	A 4:30 p.m.	B 4:00 p.m.	C 3:30 p.m.	D 1:45 p.m.	E 12:00 m.
March 19	25.5	21.5	22.0	19.0	20.0
April 2	25.5	24.0	23.0	20.0	18.0
April 9	26.5	23.0	23.0	26.5	22.5
April 16	25.5	25.0	23.0	24.0	19.5
July 2	32.0	21.0	21.0	19.2	19.0
July 9	29.5	27.5	26.0	25.0	23.0
July 16	32.0	24.5	23.0	20.5	18.5
July 23	36.0	34.0	29.0	28.0	21.0
July 30	30.0	30.0	30.0	22.5	20.0
Nov. 5		23.0	22.0	25.0	24.0
Nov. 12		24.0	23.0	25.0	22.0
Nov. 19		24.0	24.0	23.0	23.0
Nov. 26		24.0	23.0	17.0	16.0

Since 1905, the atmospheric temperature has been recorded by the Oahu Sugar Company at 61 meters elevation (Haole Koa Zone) and at 205 meters (Guava Zone) in Kipapa Gulch. The data of 28 years (1905-1933) show very little difference in the average annual temperature from year to year. At 61 meters elevation the annual mean temperature fluctuated between 22.3 degrees centigrade and 24.6 degrees centigrade. At 205 meters elevation, the temperature record of 28 years (1905-1933) ranged from 21.3 degrees centigrade to 23.0 degrees centigrade.

Atmospheric Relative Humidity

To determine the relative humidity at different vegetative zones of Kipapa Gulch, wet and dry bulb psychrometers were set up in the open in the Maritime, Guava, and Ohia Zones designated as Stations I, II, and III (fig. 1.), and the readings were made simultaneously from August 5 to 9, 1933. Station I is near the mouth of the gulch on an alluvial flat at an elevation of 3 meters; Station II is on the ridge at an elevation of 200 meters, and Station III is on the ridge in the native forest at an elevation of 550 meters. At Station I, readings were taken at 6:00 a.m. and 7:00 p.m.; at Stations II and III, at 6:00 a.m., 12:00 m., and 7:00 p.m. as tabulated (table 2). The readings for the five days show that the average relative humidity at Station I is 85 percent, at Station II, 79.8 percent, and at Station III, 92.9 percent.

The rather high relative humidity of Station I might be due to the large body of water near by. Station II is a typical region above the lowland and below the forest so the readings obtained at this zone can be favorably compared with that of Station III, a typical rain forest. The data indicate the average relative humidity of Station III as 14.1 percent higher than that of Station II. The readings also indicate that there is less fluctuation of the relative humidity in the forest than in the open.

Table 2. Relative humidity readings made from August 5 to 9, 1933, at Stations I, II, and III.

Date	Time	Stations — Relative Humidity		
		I	II	III
Aug. 5	7:00 p.m.	87.0		100.0
Aug. 6	6:00 a.m.		71.0	95.0
	12:00 m.		72.0	90.0
	7:00 p.m.	87.0	91.0	95.0
Aug. 7	6:00 a.m.	82.0	81.0	92.5
	12:00 m.		72.0	92.5
	7:00 p.m.	83.0	91.0	92.5
Aug. 8	6:00 a.m.	86.0	90.0	97.5
	12:00 m.		67.0	82.0
	7:00 p.m.	87.0	73.0	95.0
Aug. 9	6:00 a.m.	82.0	90.0	90.0

Rainfall

The Koolau Range, with an elevation of 800 meters for the greater part of its length, deflects upward the wind that has absorbed much moisture by blowing over the great expanse of ocean and causes it to lose the moisture in the form of rain. The average annual rainfall of Kipapa Gulch varies from 58.57 cm. at 18 meters elevation to 505.49 cm. at 548 meters elevation. The region usually has a slightly greater precipitation during December to March and a slightly drier season during the summer months; otherwise the rainfall is evenly distributed throughout the year.

There are several permanent rainfall gauges set up at various elevations in Kipapa Gulch and the records of these gauges extend over a period of 9 to 35 years. The average annual rainfall record of 36 years (1898-1933) at 18 meters elevations in the Haole Koa Zone is 58.57 cm., of 36 years (1898-1933) at 60 meters elevation in the Haole Koa Zone is 61.80 cm., of 17 years (1917-1933) at 115 meters elevation in the Haole Koa Zone is 121.33 cm., of 29 years (1905-1933) at 205 meters elevation in the Guava Zone is 120.62 cm., of 9 years (1925-1933) at 225 meters elevation in the Koa Zone is 200.83 cm., of 5 years (1929-1933) at 548 meters elevation in the Ohia Zone is 505.49 cm.

Temporary rain gauges were set up on March 19, 1933 at Stations A to E (fig. 1) and measurements were made on March 26, April 2, 9, 16, July 9, 16, 23, 30, November 12, 19, and 26. The readings were made at intervals of seven days and each reading is a record of a seven-day period. The data presented in table 3, and the 9 to 35 years' record indicate a greater rainfall with increase in elevation.

Table 3. Seven-day period rainfall in centimeters recorded at Stations A to E during 1933.

Stations	Date										
	Mar. 26	April 2	April 9	April 16	July 9	July 16	July 23	July 30	Nov. 12	Nov. 19	Nov. 26
A	2.54	0.97	0.00	2.54	0.64	0.64	0.33	0.33	......	......	......
B	4.29	1.42	0.76	2.24	1.75	1.27	1.75	2.39	0.15	0.00	0.30
C	5.08	2.24	0.33	2.24	2.87	2.24	2.54	4.45	1.42	0.00	2.54
D	3.66	7.95	1.12	1.42	3.51	2.69	4.14	3.51	1.75	0.00	1.27
E	3.02	9.53	0.25	1.42	7.62	4.45	9.04	8.89	1.27	0.15	5.08

Evaporation

To determine the amount and rate of evaporation in the different vegetational zones, Livingston white sphere atmometers were set up at Stations A, B, C, D, and E (fig. 1). At each station two atmometers were set up, each eight inches above the ground, one in full sunlight and the other in the shade to get the rate of water loss under the two conditions. The atmometers were set up according to Livingston-Thone (28) method, except that the joints of the rubber stopper were coated with melted paraffin. These atmometers were operated from March 19 to April 16, from July 2 to 30 and from November 5 to 26, and the evaporation was recorded every seven days. During the period of operation, an average of 157.93, 124.83, 91.00, 32.07, and 25.67 cc. of water evaporated from the atmometers placed in the sun at Stations A to E respectively, and an average of 109.61, 107.12, 66.17, 27.14, and 11.97 cc. of water evaporated from the atmometers placed in the shade at the stations in the same order (fig. 3). The following average evaporation in the sun and shade together were obtained at the stations: A, 133.77 cc.; B, 115.97 cc.; C, 78.58 cc.; D, 29.60 cc.; and E, 18.82 cc.

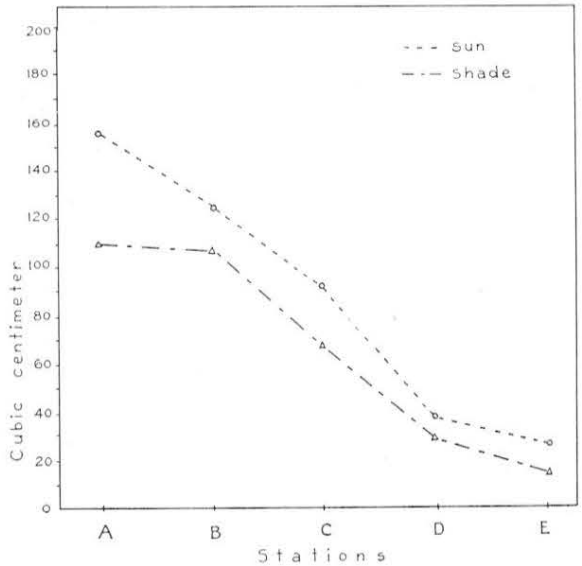

FIGURE 3.—Average evaporation in cc. from bulb atmometers placed in sun and shade at different stations during 1933.

The evaporation from the atmometers in the sun was much greater than that from the atmometers placed in the shade, and the evaporation outside the forest was decidedly greater than evaporation in the forest. The average evaporation for the three Stations, A, B, and C, which are below the native forest was 109.43 cc. while the average evaporation of Stations D and E which are in the native forest, was 24.21 cc.; a ratio of 4.5:1.

SOIL TEMPERATURE

Soil temperatures were taken at Stations A, B, C, D, and E on March 19, 26, April 2, 9, 16, July 2, 9, 16, 23, 30, and November 5, 12, 19, and 26, 1933. The soil temperature reading of Station A was made at about 4:30 p.m., of Station B at 4:00 p.m., of Station C at 3:30 p.m., of Station D at 1:45 p.m., and of Station E at 12:00 m. The soil temperature was recorded with a thermometer tied to a rod and inserted to 15, 30, 60, and 90 cm. depth in a vertical hole made with a soil auger. The soil auger was screwed in vertically until the 15 cm. mark was reached, then taken out and the thermometer placed in the cavity for approximately three minutes with the bulb of the thermometer in the soil. Then the thermometer was quickly pulled out and the temperature recorded. The same hole was deepened with the soil auger until the 30 cm. mark was reached and again the temperature was recorded in the same manner. The temperature for the 60 and 90 cm. depths was similarly recorded. Each week a new hole was dug with the soil auger and the temperature recorded. The average soil temperature of the readings made on selected days during 1933 of Stations A, B, C, D, and E at 15 cm. depth, were 30.6, 24.0, 22.9, 20.0, and 18.8 degrees centigrade, respectively; at 30 cm. depth, 27.9, 22.8, 22.0, 19.6, and 18.9 degrees centigrade respectively; at 60 cm. depth, 27.3, 22.6, 21.8, 19.7, and 18.8 degrees centigrade, respectively; at 90 cm. depth, 26.7, 22.5, 21.6, 19.5, and 18.0 degrees centigrade, respectively (fig. 4).

The average soil temperature readings of the depths from 15 to 90 cm. at Station A was 28.1, at B, 22.9, at C, 22.1, at D, 19.7, at E, 18.8 degrees centigrade.

On July 23, 1933, the highest temperature of 36.0 degrees centigrade and on November 26, 1933, the lowest temperature of 17.0 degrees centigrade were recorded for the 15 cm. depth at Stations A and E, respectively.

At 30 cm. depth, the highest temperature of 32.0 degrees centigrade was recorded on July 23 at Station A and the lowest temperature of 17.5 degrees centigrade was recorded on November 26 at Station E. At 60 cm. depth, the highest temperature of 31.0 degrees centigrade and the lowest temperature of 17.0 degrees centigrade were recorded on July 23 and April 9, respectively at Stations A and E. At 90 cm. depth, the highest temperature of 30.0 degrees centigrade and the lowest temperature of 17.0 degrees centigrade were recorded on July 2 and April 9 respectively at Stations A and E.

The data were collected at various times in a single year so they do not justify any definite conclusion on the range of variation of soil temperature at Kipapa Gulch. However, the data presented here show that the soil temperature decreases with depth and elevation.

Soil Moisture

To obtain data on the moisture content of the soil, soil samples were collected with a soil auger at depths of 0-15, 30, 60, and 90 cm.,

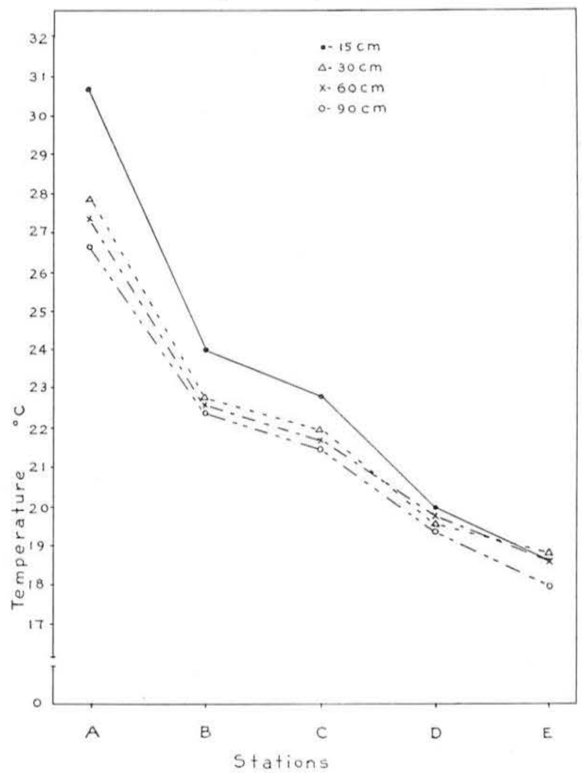

FIGURE 4.—Average soil temperature in degrees centigrade at 15 to 90 cm. depths at different stations recorded in 1933.

at Stations A, B, C, D, and E on March 19, 26, April 2, 9, 16, July 2, 9, 16, 23, 30, November 5, 12, 19, and 26, during 1933. In taking the soil samples, the area was first cleared of leaves and branches; then the soil auger was screwed in vertically to a depth of 90 cm., taking samples at 0-15, 30, 60, and 90 cm. The soil was placed in air-tight cans and brought back to the laboratory, weighed, placed in the oven for 40 hours at 105 to 110 degrees centigrade, then reweighed and the percent of soil moisture was calculated on dry weight basis by using the formula:

$$\text{Percent moisture} = \frac{\text{loss of weight}}{\text{weight of dried sample}} \times 100$$

The average percentage of soil moisture of all depths from 0 to 90 cm. at Station A was 27.10, at Station B, 45.19, at Station C, 58.94, at Station D, 84.93, and at Station E, 125.79 percent. At Station A, the soil moisture increased from 22.44 percent at 0-15 cm. depth to 31.30 percent at 90 cm. depth, an increase of 8.86 percent. At Station B the soil moisture increased from 39.31 percent at 0-15 cm. depth to 47.09 percent at 60 cm. depth and then dropped to 43.81 percent at 90 cm. depth, an increase of 7.78 percent and a decrease of 3.28 percent. At Station C, the soil moisture increased from 62.48 percent at 0-15 cm. depth to 66.73 percent at 30 cm. depth, and then dropped to 52.67 percent at 90 cm. depth, an increase of 4.25 percent and a decrease of 14.06 percent. At Station D, the soil moisture decreased from 110.00 percent at 0-15 cm. depth to 68.99 percent at 90 cm. depth, a decrease of 41.01 percent. At Station E, the soil moisture decreased from 209.64 percent at 0-15 cm. depth to 82.47 at 90 cm. depth, a decrease of 127.17 percent (fig. 5).

The soil moisture at Stations A and B increased with depth but the moisture at Stations C, D, and E decreased with increase in depth, with the exception of a slight rise in moisture at 30 cm. depth at Station C. The increase and decrease of soil moisture at Stations A, B, and C was slight, but the decrease of moisture at Station D and E was very great. The top layer of soil around Stations D and E constitute dead leaves and branches of plants that can absorb and retain more water than the soil below that contains less organic matter (table 4) and this accounts for the rapid decrease in moisture content from the top to the lower layers. The soil moisture of Kipapa Gulch increased with the increase in elevation.

Soil Acidity

To find out to what extent the soil acidity in Kipapa Gulch controls the distribution of plants, the hydrogen-ion concentration of the soils in the various plant zones was investigated. Soil samples at depths of 0-15, 30, 60, and 90 cm. were collected with a soil auger in Haole Koa, Guava, Koa, Ohia and the Cloud Zones (fig. 1) on

March 19 and 26, 1933. The samples were brought back to the laboratory in air-tight cans and were tested by the Hellige Colorimeter test. The soil acidity ranged from pH 7.0 to pH 4.0 in the different zones at various depths. Attempts to correlate these different acidities with the plant distribution were unsuccessful. A further detailed investigation of the hydrogen-ion concentration of the soil might reveal a relationship between plant associations and soil acidity.

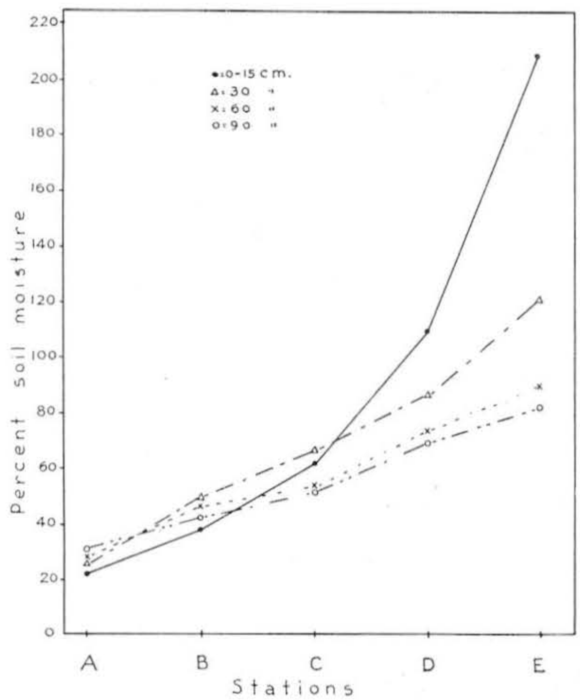

FIGURE 5.—Average percentage of soil moisture of samples collected at depths of 0-15, 30, 60, and 90 cm. on selected days during 1933 at Stations A to E.

ORGANIC CONTENT OF SOIL

The organic content of the soil was determined by the wet combustion method (38) and the samples used for this analysis were those collected for soil moisture determination. One hundred samples were analyzed. The samples were oven-dried for 40 hours at 105 to 110 degrees centigrade and in each case a 3-gram sample was used for the organic content determination. The total percentages of organic matter found in the samples from 0 to 90 cm. depths at the various stations show that Station D has the highest organic content with 16.59 percent, Stations B, C and E comparatively equal amounts with 10.85 percent, 10.89 percent, 11.48 percent, respectively, and Station A the lowest with 2.75 percent (table 4). Station D is in the moist, wooded native forest where the ground is covered with dead plant products while Station A is in the dry, poorly vegetated region. The amount of organic content of the soil decreased with depth at every station investigated with the exception of Station A. The average percentages of the different depths of all the stations show that the greatest amount of organic matter is found in the first 15 cm. of soil.

Table 4. Average percentage of organic matter of five-soil samples taken at Stations A to E at depth from 0-90 centimeters.

Depth	Stations				
	A	B	C	D	E
0-15 cm.	0.77	3.63	5.09	9.85	7.95
30 "	0.68	3.16	3.15	4.51	1.46
60 "	0.61	2.47	1.39	1.35	1.23
90 "	0.69	1.59	1.26	0.88	0.84
Total	2.75	10.85	10.89	16.59	11.48

VEGETATION

Phenology

Observations indicate that many native species have definite flowering periods and that in some months there are more plants in flower than in others. In order to obtain a statistical statement on flowering periods, a phenological record was kept as shown in the species record under Taxonomy (p. 211). The data cover three years of observation, during which time about 90 field trips were made into the native forest. July has the greatest number of plants in flower with 70 species, and December the least with 14 species (fig. 6). The number of plants in flower increases sharply from January with a slight drop in March to the maximum in July, and then drops sharply to December. July has the greatest number of plants in fruit with 52 species; January has the least with 6 species. Data for all the species found in the region were not recorded on a single trip since not all of the species were seen in the course of a day's observation; but most of the species were observed during the three or four trips made in a month. In the native forest of Kipapa Gulch there are two groups of species of flowering plants, those with long and those with short periods of flowering.

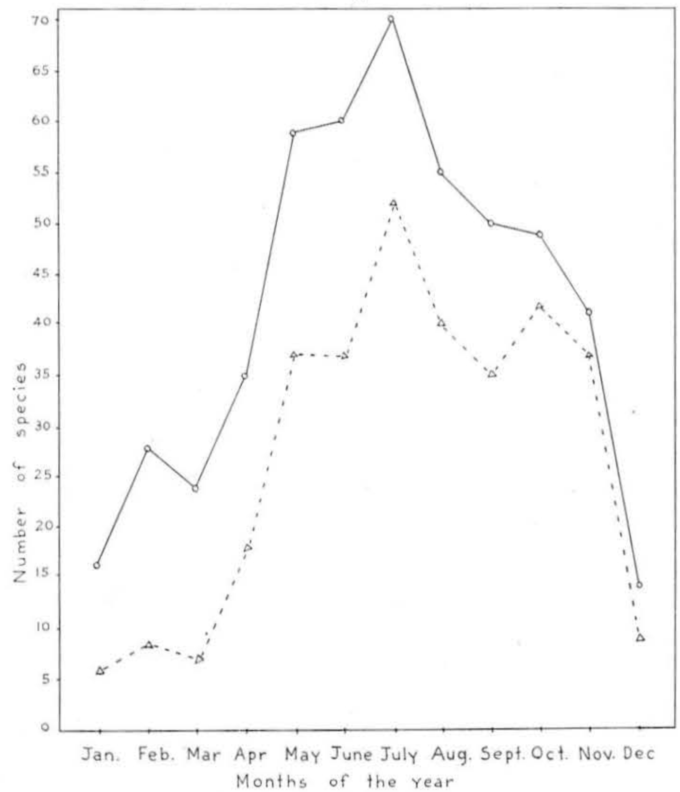

FIGURE 6.—Number of native species in flower and fruit throughout the year.

Some of those with an extended flowering season are *Phyllostegia glabra* variety *Macraei, Phyllostegia grandiflora, Scaevola Gaudichaudiana, Lantana Camara, Ilex anomala, Aleurites moluccana,* and *Psidium Guayava.* These species are found in flower during most of the months of the year.

Some of the short season indigenous species found in the native forest are *Rollandia angustifolia, Hesperomannia arborescens, La-*

bordia glabra, Labordia Cyrtandrae, Gardenia Remyi, Cheirodendron platyphyllum, Dubautia plantaginea, Lobelia oahuensis, Boehmeria grandis, and *Cordyline fruticosa.* During the three years of observation, these species were seen in bloom at about the same time each year.

LEAF SIZES

Leaf size varies within certain limits in plants of the same species and varies between different species, but in general, plants with large leaves are more numerous in the rain forests of the tropical regions.

In working out the leaf-size classes of Kipapa Gulch, Raunkiaer's system (43) was followed.

His classes are:

Class 1—Leptophylls up to 25 sq. mm.

Class 2—Nanophylls up to 225 sq. mm.

Class 3—Microphylls up to 2,025 sq. mm.

Class 4—Mesophylls up to 18,225 sq. mm.

Class 5—Macrophylls up to 164,025 sq. mm.

Class 6—Megaphylls larger than Class 5.

To get an idea of the number of leaf-size classes found in Kipapa Gulch, many leaves of each species were examined and the average recorded. In taking the measurement for the leaf-size classes, the entire compound leaf was considered as a unit. The author is in agreement with Withrow (67), who claims that "Parallel results are not obtained when the lobe of a leaf of one plant is measured, the leaflet of a second and the entire leaf of a third, since a part of one leaf is not comparable to another leaf in its entirety in dealing with area limits. However, by measuring the whole leaf in all cases comparable classification results."

In Kipapa Gulch are found all the leaf-size classes of Raunkiaer but most of the plants fall in Classes 3 and 4 and least in Class 6. Each plant zone (fig. 1 and p. 201, Plant Zones) was studied and the number of the various leaf-size classes of the higher flora including both indigenous and introduced species in each is shown in table 5.

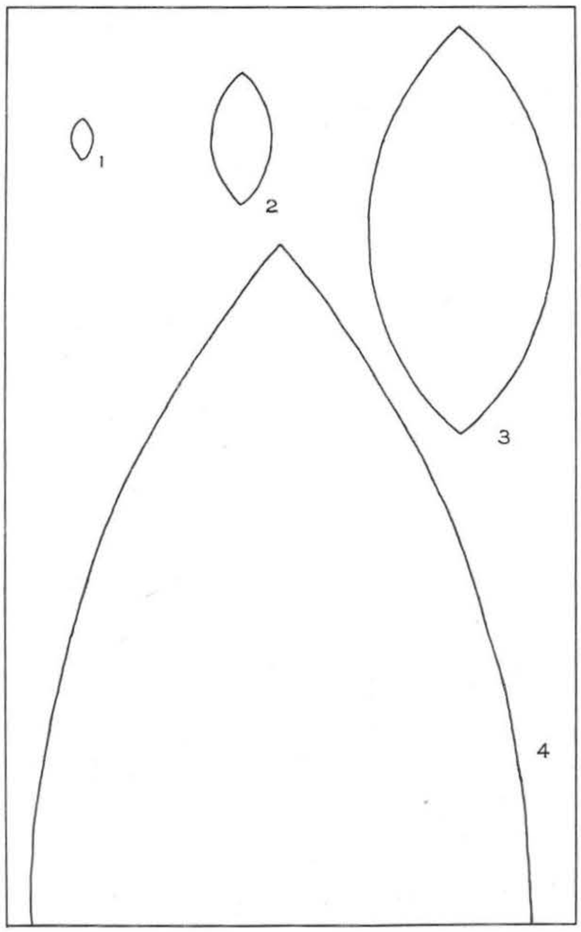

FIGURE 7.—Graphical representation of limits between leaf-size classes, after Raunkiaer: less than 1=leptophyll; between 1 and 2=nanophyll; between 2 and 3=microphyll; between 3 and 2x4=mesophyll; between 2x4 and 8x the size of diagram as bounded by black line=macrophyll; more than 8x the size of diagram as bounded by black line=megaphyll.

Table 5. Leaf-size classes of indigenous and introduced species of the various vegetational zones; data for introduced species in parentheses.

Zones	Leaf-Size Classes 1	2	3	4	5	6
Maritime No. of species	1 (4)	2 (7)	3(16)	1 (5)	— (1)	— (1)
Haole Koa No. of species	— (3)	3(17)	10(33)	4(12)	1(—)	— (1)
Guava No. of species	3 (4)	3(19)	16(37)	3(14)	3 (3)	— (2)
Koa No. of species	5 (1)	2 (3)	21(11)	20(11)	3 (4)	2 (1)
Ohia No. of species	15 (1)	8 (3)	62 (8)	113(13)	25 (4)	5 (2)
Cloud No. of species	9(—)	7 (2)	47 (4)	76 (4)	16(—)	4(—)

Considering only the indigenous species, there is a small number of species in the larger leaf-size classes and a large number in the smaller leaf-size classes in the Maritime, Haole Koa, and Guava Zones. In the Koa Zone there is about an equal number of species in the smaller and the larger leaf-size classes, but in the Ohia and Cloud Zones, there is a greater number of species in the larger leaf-size classes than the smaller leaf-size classes.

The above data indicate that with an increase in mesophytism there is an increase in the representatives of the large leaf-size classes. In Kipapa Gulch, the Ohia Zone has the largest number of 3, 4, 5, and 6 leaf-size classes.

Life Forms

The life forms of all the naturalized and indigenous vascular plants growing in Kipapa Gulch were recorded to determine the biological characteristics of the various vegetational zones. The life form of the species is given in the Taxonomy section of this paper in reference to the system of Raunkiaer (43) as follows:

(E) epiphytes

(MM) mega- and meso-phanerophytes, with dormant parts more than 8 meters above the ground.

(M) microphanerophytes, with dormant parts 2 to 8 meters above the ground.

(N) nanophanerophytes, with dormant parts 0.5 to 2 meters above the ground.

(Ch) chamaephytes, with dormant parts not over 25 to 30 cm. above the surface of the ground.

(H) hemicryptophytes, with dormant parts in the soil surface.

(G) geophytes, with dormant parts below the ground.

(HH) helophytes, with dormant parts in water-saturated ground.

(HH) hydrophytes, with dormant parts at the bottom of bodies of water.

(Th) therophytes (annuals).

In Hawaii the temperature conditions are favorable continuously throughout the year with moisture conditions locally and seasonally unfavorable. Hence most of the plants lack well insulated buds or other resting organs that are found on plants in colder regions. Actually most of the plants grow throughout the year, or with but brief interruptions. The position of the growing points has been used in the attempt to apply the Raunkiaer system to the flora. The life form spectra of the plants found in the different zones of Kipapa Gulch are given in table 6. In the table are given the total number of the species of higher flora recorded for the zones and the number of species in each life form.

Table 6. Life forms of indigenous species of Pteridophytes and Spermatophytes found in the different vegetational zones of Kipapa Gulch; data for introduced species in parentheses.

Zones	Life Form Classes								
	MM	M	N	Ch	H	G	HH	Th	E
Maritime No. of species	–(2)	–(–)	2(9)	4(1)	1(10)	–(1)	–(6)	–(5)	–(–)
Haole Koa No. of species	–(3)	2(5)	7(29)	–(4)	6(11)	–(–)	–(–)	2(16)	–(–)
Guava No. of species	–(6)	5(5)	8(26)	1(5)	9(16)	–(1)	–(1)	1(19)	1(–)
Koa No. of species	12(5)	14(5)	13(6)	2(2)	8(5)	–(3)	–(1)	–(4)	2(–)
Ohia No. of species	28(5)	68(5)	47(3)	6(2)	40(9)	–(3)	–(1)	–(2)	23(–)
Cloud No. of species	15(–)	50(2)	30(2)	5(1)	27(3)	–(–)	–(–)	–(2)	17(–)

The ground surface and the moss-covered tree trunks serve as habitats for several species. The following plants with two life forms are not considered in table 6.

Trichomanes Baldwinii
Trichomanes cyrtotheca
Trichomanes davallioides
Asplenium obtusatum
Asplenium monanthes
Elaphoglossum gorgoneum
Lindsaya Macraena
Polypodium tamariscinum
Lycopodium nutans
Lycopodium phyllanthum
Lycopodium serratum
Lycopodium serratum var. dentatum
Psilotum complanatum
Psilotum nudum
Selaginella Menziesii
Astelia veratroides
Anoectochilus sandwicensis
Peperomia elliptibacca
Peperomia latifolia
Peperomia oahuensis
Peperomia reflexa

The spectrum of the maritime flora shows that small herbs, shrubs, and hydrophytes are the common plants of the region with nanophanerophytes comprising about half the species. In the Haole Koa Zone, the shrubs are the important plants, constituting over half the species. The Guava Zone shows a similar spectrum. The Koa Zone shows that larger trees are becoming common, but the shrubs are still the most abundant plants. In the Ohia Zone the tall trees constitute quite a large percentage of the species. Table 6 shows a large number of mega- and mesophanerophytes and micro-phanerophytes in the Cloud Zone but there the species are stunted to about half their normal size.

Table 7. Life form in percent of indigenous species of flowering plants found in Kipapa Gulch compared with the normal spectrum of Raunkiaer (42) and the spectrum of St. Thomas and St. John, Virgin Islands (41).

	Life Form Classes								
	No. of species	MM	M	N	Ch	H	G	HH	T
St. Thomas and St. John	904	5	25	30	12	9	3	1	14
Kipapa Gulch	206	15	39	28	6	12	—	—	1
Normal spectrum	1,000	8	18	15	9	26	4	2	13

The spectrum of the flowering plants of Kipapa Gulch (table 7) shows that microphanerophytes have the largest percentage with nanophanerophytes a close second and mesophanerophytes third. The tall trees, though not many with respect to percentage, constitute a dominant part of the vegetation, especially in the Ohia Zone.

The spectrum of Kipapa Gulch is very similar to that of St. Thomas and St. John of the Virgin Islands. Both are typical of tropical regions in possessing a relatively high percentage of phanerophytes as compared to Raunkiaer's normal spectrum.

Transect Studies

To determine the zonation, stratification, and the composition of the vegetation in Kipapa Gulch, transect lines were surveyed at the Haole Koa, Guava, Koa, Ohia, and Cloud Zones. In every case the survey was made across the gulch from the south to the north ridge (fig. 1). In recording the species, any plant that touched, crossed over or below the tape was recorded. Transect I in the Haole Koa Zone recorded 17 species, none endemic, 3 indigenous, and 14 introduced; transect II in the Guava Zone registered 37 species, 5 endemic, 7 indigenous, and 25 introduced; transect III in the Koa Zone recorded 43 species, 17 endemic, 12 indigenous, and 14 introduced; transect IV in the Ohia Zone recorded 102 species, 69 endemic, 16 indigenous, and 17 introduced; transect V in the Cloud Zone registered 57 species, 43 endemic, 8 indigenous, and 6 introduced.

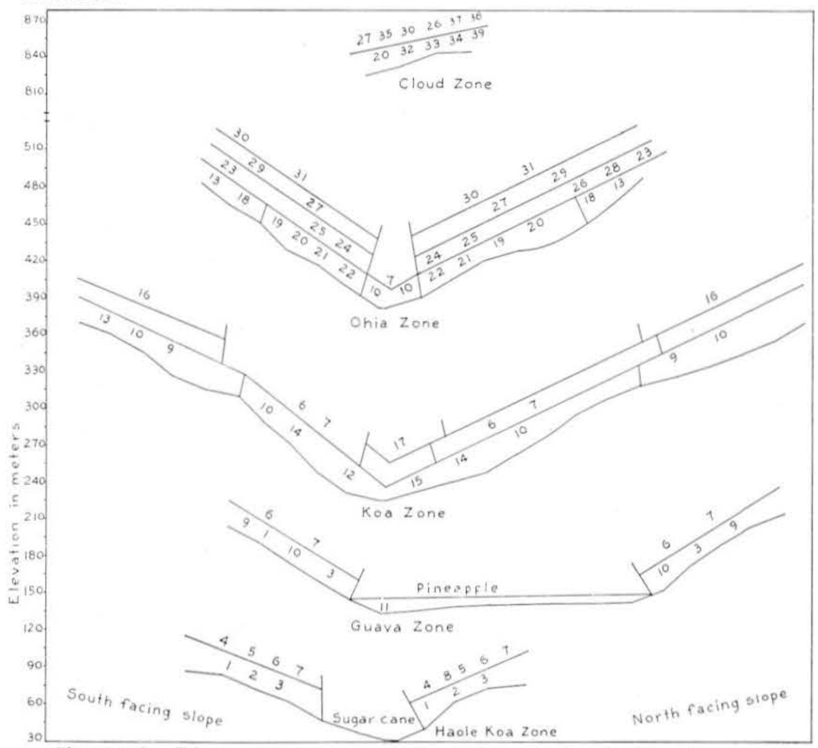

FIGURE 8.—Diagrammatic cross section of vegetation in the plant zones: vertical scale, 6 mm.=15 m.; horizontal scale, 12 mm.=30 m. 1, *H. contortus*; 2, *T. repens*; 3, *C. aciculatus*; 4, *O. megacantha*; 5, *A. Farnesiana*; 6, *L. Camara*; 7, *P. Guayava*; 8, *L. glauca*; 9, *S. chinensis*; 10, *P. orbiculare*; 11, *P. purpurascens*; 12, *C. diffusa*; 13. *G. linearis*; 14, *N. exaltata*; 15, *O. hirtellus*; 16, *A. Koa*; 17, *A. moluccana*; 18, *P. grandiflora*; 19, *Trichomanes*; 20, *mosses*; 21, *Polypodium*; 22, *Elaphoglossum*; 23, *F. arborea*; 24, *Cyrtandra*; 25, *Gouldia*; 26, *Labordia*; 27, *B. elatior*; 28, *P. sandwicensis*; 29, *Straussia*; 30, *Metrosideros*; 31, *E. sandwicensis*; 32, *P. conjugatum*; 33, *P. koolauense*; 34, *P. pachyphylla*; 35, *Pelea*; 36, *Labordia*; 37, *Dubautia*; 38, *E. Martii*; 39, *M. angustifolius*.

The transect studies show that there is quite a definite plant zonation, stratification, and composition in Kipapa Gulch. Figure 8 is a diagrammatic presentation of the vegetation of the gulch in cross-section. Here only the most characteristic species of the respective layers are given.

The most complex vegetation is found in the Ohia Zone. A detailed description of the different zones is given on pp. 201-7.

Frequency and Cover Degree Studies

In order to obtain a definite basis for the subdivision of the vegetation of Kipapa Gulch into zones, quantitative studies were undertaken. This was by the established method of cover degree and frequency readings. Areas were selected at random; then each plot was approximately measured off into quadrats four meters square. After a census, records were made of the number and the amount of vertical ground coverage of each species in the plot, and from these the frequency and cover degree were calculated. The cover degree of each species found growing in the area was recorded according to the system of Braun-Blanquet (6). His cover degree scale is as follows:

I = very scant (covering less than 1/20 of the ground surface)
II = covering 1/20 to 1/4 of the ground surface
III = covering 1/4 to 1/2 of the ground surface
IV = covering 1/2 to 3/4 of the ground surface
V = covering 3/4 to 4/4 of the ground surface

Frequency is expressed on the basis of the five classes of Raunkiaer (43):

Class A = species found in 1-20% of the quadrats
Class B = species found in 21-40% of the quadrats
Class C = species found in 41-60% of the quadrats
Class D = species found in 61-80% of the quadrats
Class E = species found in 81-100% of the quadrats

The readings were made in groups of ten plots, each four meters square. The percentage of frequency of a given species is the percentage ratio which the number of plots on which the species occurs bears to the whole number of plots taken. Raunkiaer points out that, as we proceed to the greater frequencies, the number declines steadily, then, as the highest frequence is reached, increases slightly.

That is, the curve expressing numbers of the different frequencies has two peaks, a high one expressing the least frequence, and another, considerably lower, expressing the greatest frequence. He interprets the law as signifying that, in an association at a state of relative equilibrium, one or several species prosper at the expense of other species growing near by, because the dominant species are better situated to live and develop in the conditions presented to the formations of which they compose part, and by life competition hinder the other species from equaling them. The plant communities in the zones were quite homogeneous (fig. 9).

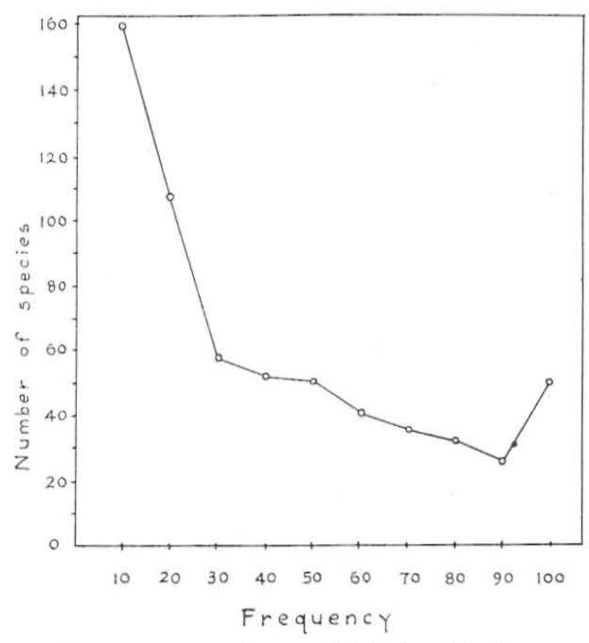

FIGURE 9.—Frequency curve of vegetation in the Ohia Zone.

The cover degree and frequency in percent of the characteristic species in the various vegetational zones are as follows:

In the Maritime Zone, *Batis maritima* had a cover degree of III and a frequency of 70; *Sesuvium Portulacastrum*, III and 75; *Scirpus maritimus*, IV and 53. In the Haole Koa Zone, *Acacia Farnesiana* had a cover degree of III and a frequency of 75; *Heteropogon contortus*, III and 84; *Opuntia megacantha*, III and 65. In the Guava Zone, *Psidium Guayava* had a cover degree of IV and a frequency of 85; *Lantana Camara*, III and 75; *Chrysopogon aciculatus*, III and 50; *Paspalum orbiculare*, III and 60. In the Koa Zone, *Acacia*

Koa had a cover degree of IV and a frequency of 40; *Gleichenia linearis*, IV and 70; *Aleurites moluccana*, III and 30. In the Ohia Zone, *Metrosideros collina* had a cover degree of V and a frequency of 90; *Gleichenia linearis*, III and 60. In the Cloud Zone, *Paspalum conjugatum* had a cover degree of III and a frequency of 40; *Metrosideros collina*, II and 60. The cover degree and frequency of other species found in the different vegetational zones varied from I to II for cover degree and 10 to 70 for frequency.

Maritime Zone

The vegetation of the Maritime Zone, which is poorly represented in the area studied, is influenced mainly by local edaphic conditions that occur adjacent to the beach. The vegetation of this zone is characterized by the *Batis-Scirpus* Community. *Batis maritima* makes a thick stand along the shore of the loch. It is also found growing among patches of *Scirpus maritimus* above the high tide level. *Scirpus maritimus* is conspicuous since it overtops the other species in the area. In drier places *Scirpus laevigatus* is found in patches of 0.5 to 2 meters across and between these is a mat of *Sesuvium Portulacastrum*. On higher places where the soil is dry, *Prosopis chilensis, Panicum purpurascens* and *Pluchea indica* are conspicuous. *Panicum purpurascens* makes a solid growth along the banks of the stream. In the stream where the current is slow, *Potamogeton foliosus* variety *macellus, Lemna minor* and *Spirodela polyrhiza* are found in large numbers.

Haole Koa Zone

The vegetation of this region is predominantly xerophytic. *Opuntia megacantha* forms clumps 1.5 to 3 meters high and from 1 to 5 meters in diameter on the dry rocky hillsides. These are very conspicuous and they give the xerophytic appearance to the landscape (fig. 10). *Acacia Farnesiana, Heteropogon contortus, Lantana Camara, Psidium Guayava, Cassia Leschenaultiana* and *Stachytarpheta jamaicensis* are found filling the spaces between the clumps of *Opuntia megacantha*.

Acacia Farnesiana is a low, much branched shrub 0.5 to 1.5 meters tall, with few leaves at the ends of the branches. *Heteropogon contortus* grows in the open and under bushes, and during the drier months gives a straw-color to the hillsides. *Lantana Camara* and *Psidium Guayava* are low half-dried shrubs 1 to 2 meters tall. In sheltered gullies where there is greater moisture, *Psidium Guayava* becomes slightly taller. At several places in sheltered gullies *Leu-*

caena glauca plants have developed and are quite conspicuous. On eroded places *Waltheria indica* variety *americana* is common and this species seems to prefer such areas. At the upper end of the zone there are a few individual clumps of *Dodonaea viscosa* 1 to 2 meters tall and 1 to 1.5 meters across. The vegetation of this zone is quite uniform, due to the dominance of the four common species; it may be classified as an *Opuntia-Acacia-Heteropogon-Leucaena* Community.

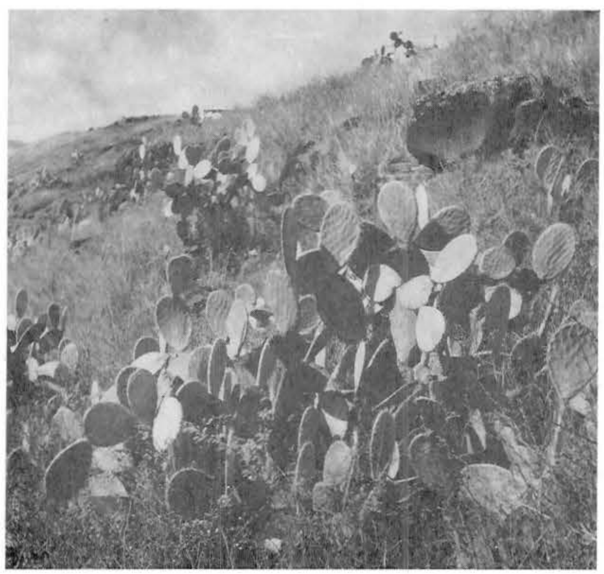

FIGURE 10.—*Opuntia megacantha*, *Acacia Farnesiana*, and *Heteropogon contortus* in the Haole Koa Zone.

GUAVA ZONE

The vegetation of this region is characterized by the uniform cover of *Psidium Guayava* and *Lantana Camara* which are found in mixtures and in pure stands. Those that occupy the steep slopes are scrubby and smaller than those growing along the stream bank and in sheltered bottoms of side gullies. This difference in height is more noticeable with *Psidium Guayava*. The *Psidium* trees growing along the stream bank and in more favorable places attain an average height of 4 to 6 meters. The *Lantana* bushes usually make an entanglement under the *Psidium Guayava* and make it very difficult to pass through such places. Along the stream bank and on areas just back of it, *Commelina diffusa, Paspalum conjugatum,* and *Panicum purpurascens* are found forming the undergrowth in mixtures and in pure stands. On the more open, exposed slopes *Paspalum orbiculare, Chrysopogon aciculatus, Heteropogon contortus* and *Stenoloma chinesis* are common. In the bottoms of some of the side gullies, one to five *Aleurites moluccana* trees 4.5 to 8 meters tall are found. At the upper ends of such gullies large *Acacia Koa* trees 5 to 10 meters in height are found forming solid stands. Probably these stands are the remnants of former large stands. The vegetation of this area can be considered to be a *Psidium-Lantana* Community because of the dominance and distribution of these two species.

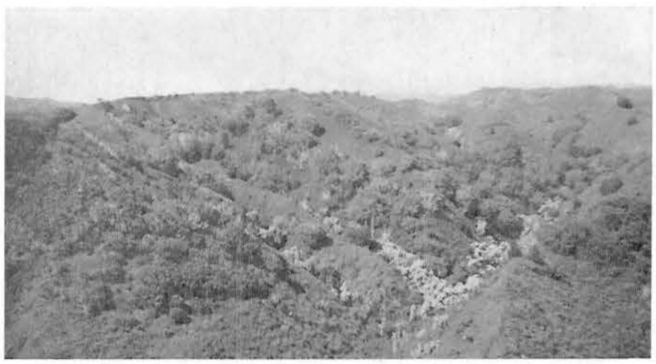

FIGURE 11.—Vegetation of the Koa Zone showing *Acacia Koa* on the upper slope and *Aleurites moluccana* in the gully bottom.

KOA ZONE

The most characteristic features of this zone are the presence of pure stands of *Acacia Koa, Aleurites moluccana* and *Gleichenia linearis.* The *Acacia Koa* and *Gleichenia linearis* occupy the slopes and ridges, while *Aleurites moluccana* occupies the bottom of the gulch and side gullies (fig. 11). The *Acacia Koa* attains a height of about 12 meters and a diameter of 0.5 to 1 meter or more, and is found in groves or solitary. *Aleurites moluccana* grows straight up into trees 15 meters tall and forms patches in the bottoms of the gulch and gullies. The light colored foliage of this species is very conspicuous. *Eugenia malaccensis* is the most common associate of *Aleurites moluccana*. On the open slopes *Gleichenia linearis* makes a dense covering. In areas where the *Gleichenia* fern has not spread, *Cordyline fruticosa* and *Psidium Guayava* are the common species. Under the tall trees, where the ground is moist, *Oplismenus hirtellus*, *Zingiber Zerumbet*, *Marattia Douglasii*, *Dryopteris cyatheoides*, and

FIGURE 12.—Undergrowth vegetation of a side gully in the lower Ohia Zone showing *Nephrolepis exaltata* in the foreground and *Asplenium nidus* growing on the trunks of *Aleurites moluccana*.

Cibotium Chamissoi are common. Under the *Psidium Guayava* shrubs, *Paspalum conjugatum* and *Nephrolepis exaltata* are very common.

OHIA ZONE

The vegetation of this area is predominantly mesophytic with *Metrosideros collina* as the dominant and most characteristic species.

This species is found in large numbers throughout the area but attains its maximum height at 550 meters elevation. Four strata vegetation is found in this zone (figs. 12, 13). Other dominant species are *Bobea elatior* and *Eugenia sandwicensis*; the third layer species include *Elaeocarpus bifidus, Antidesma platyphyllum, Pittosporum glabrum* and *Straussia Mariniana*; the second layer species are

FIGURE 13.—Undergrowth vegetation of the upper Ohia Zone near the ridge showing *Cibotium Menziesii* in left center and *Freycinetia arborea* climbing on tree.

Cyrtandra plaudosa, Phyllostegia grandiflora, Rollandia crispa, Touchardia latifolia and *Cibotium Chamissoi*; the lower layer is composed of mosses, *Trichomanes* spp., *Blechnum occidentalis,* and *Peperomia* spp. The tree trunks are covered with epiphytic plants as *Polypodium pseudo-grammitis, Polypodium lineare, Hymenophyllum recurvum, Astellia veratroides,* and mosses. This vegetation can be called the *Metrosideros collina* Community from the abundance and dominance of this species.

Cloud Zone

Above 600 meters the region is in the cloud area, and an open low scrubby moss-covered vegetation is found. The trees on the slopes and ridges are dwarfed (to about 1 to 2.5 meters in height) and the few tall trees (not more than 6 meters in height) of this zone are found in the gullies (fig. 14). There is no dominant species in the

FIGURE 14.—Vegetation of the lower Cloud Zone showing poor growth of plants due to effect of fog and cloud.

zone and the conspicuous species are quite uniformly distributed. Some of the more conspicuous plants are *Eupritchardia Martii, Cheirodendron platyphyllum, Metrosideros collina, Bobea elatior, Straussia kaduana, Fagara oahuensis, Labordia glabra* and *Labordia fagraeoides* (fig. 15). In this zone four layers of vegetation are found only at the few places where the scattered tall trees are found. A poorly developed three layer spectrum is found throughout the area except at the crest of the summit ridge where the wind blows unceasingly. Here only two layers of vegetation are found. Some of the plants are *Peperomia ellipticibacca, Phyllostegia lantanoides, Panicum* *koolauense, Dubautia laxa, Isachne pallens, Mariscus angustifolius,* and *Paspalum conjugatum.*

North and South Facing Slopes

At elevations above 152 meters in the Guava Zone, there is a difference of vegetation between the north and the south facing slopes. On the north facing slope is found a larger number of native species that are associated with the forest vegetation, such as *Metrosideros collina, Pipturus albidus, Dianella sandwicensis, Scaevola Gaudichaudiana, Wikstroemia oahuensis* and *Santalum Freycinetianum,* while on the south facing slope there are only a few or none of these species.

Data on soil temperature, soil moisture, and evaporation were recorded approximately at 4:00 p.m. on the north and south facing slopes at 220 meters elevation on different days in May, June and October, 1933. Soil temperature at 15, 30, and 60 cm. depths were recorded, and the average of all the depths of the six readings of the north facing slope was 24.0 degrees centigrade and that of the south facing slope 26.0 degrees centigrade, a difference of 2 degrees centigrade. The greatest difference in temperature was found in the 15 cm. depth.

Readings from Livingston white bulb atmometers set up in the open show greater evaporation on the south facing slope, with the average evaporation for the five readings at intervals of seven days on the north facing slope as 217.79 cc., and the south facing slope as 257.00 cc., a difference of 39.21 cc.

The average soil moisture content of the north facing slope was higher than that of the opposite slope with the greatest difference in the first 15 cm. of soil. The average soil moisture of 15 to 60 cm. depths on the north facing slope was 38.21 percent while that of the south facing slope was 30.42 percent, a difference of 7.79 percent. At 15 cm. depth there was 35.94 percent moisture on the north slope and 26.03 percent on the south slope with a difference of 9.91 percent; at 30 cm. depth, 37.86 percent on the north facing slope and 28.69 percent on the south facing slope; at 60 cm. depth, 40.84 percent on the north slope and 36.55 percent on the south slope.

The differences in soil temperature, soil moisture and evaporation show that the north facing slope is more favorable for plant growth than the south facing slope and probably explains the development of forest species. Bates (3) and Cannon (9) found that soil temperature at the soil surface determines the life-and-death struggle of young seedlings and plant distribution. It seems that a difference of 2.2 degrees centigrade in temperature, 39.21 cc. in evaporation and 9,91 percent in soil moisture in the region where seedlings develop, affect the type of vegetation of the slopes.

In the Koa, Ohia and Cloud Zones, it seems that the factors are

FIGURE 15.—Vegetation in the Cloud Zone showing *Eupritchardia Martii, Mariscus angustifolius, Isachne pallens*, and *Paspalum conjugatum*.

not sufficiently different on the two slopes to cause any difference in the vegetation as in the Guava Zone. That is, any difference in the environmental factors lies within the range of the tolerance of this species. In the Haole Koa Zone there is practically no difference in the vegetation of the two slopes.

SUCCESSIONAL RELATIONS

In the Maritime Zone along the shore, *Batis maritima* and *Scirpus maritimus* will probably hold their own against the invasion of other species under the present conditions. On the dry places, *Prosopis chilensis* will undoubtedly become the dominant species with *Panicum purpurascens* as undergrowth if such places are left undisturbed for natural development.

The vegetation of the Haole Koa Zone seems to be changing. *Leucaena glauca* grows into a taller plant than *Psidium Guayava*, *Lantana Camara*, and *Acacia Farnesiana* with which it is associated,

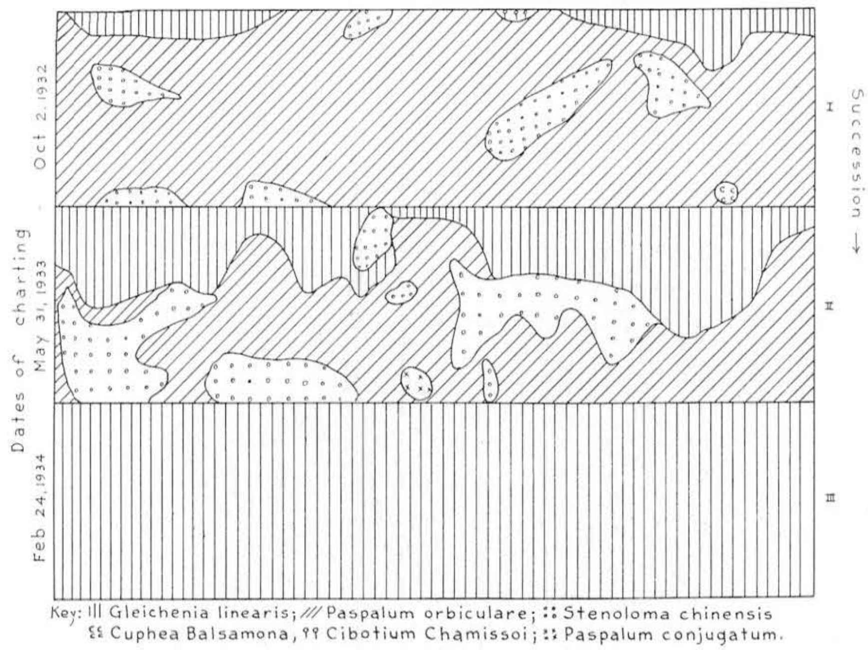

FIGURE 16.—Quadrat 1 x 4 meters at 380 meters elevation showing spread of *Gleichenia linearis*.

and is gradually crowding and shading them out. It also produces a much larger crop of seeds than the associated species.

The vegetation of the Guava Zone can be considered reasonably stable under the present conditions. The quadrat studies point out a well balanced relationship between *Psidium Guayava* and *Lantana Camara* of the upper layer with *Chrysopogon aciculatus* and *Paspalum orbiculare* of the ground layer.

In the Koa Zone, the most active plant succession is taking place. The *Acacia Koa* is coming back into the abandoned pineapple fields at many places. *Acacia* and *Metrosideros* were abundant before the cultivation of pineapple. Abandoned fields at the bottom of the gulch are revegetated principally with *Psidium Guayava, Lantana Camara, Panicum purpurascens* and *Erigeron albidus* during the earlier stages of succession, but gradually *Psidium Guayava* becomes the dominant species. Along the upper margin of the abandoned pineapple fields, close to the native forest, *Gleichenia linearis* is coming in and spreading at an average rate of 90 cm. a year (figs. 16, 17). The present condition indicates a dominance of *Gleichenia* throughout the Koa Zone in the future.

FIGURE 17.—Recording the succession of *Gleichenia linearis* in the Koa Zone.

The vegetation of the Ohia Zone is quite stable. The greatest undergrowth competitor is *Gleichenia linearis* and the ground vegetation of ferns may be crowded out slowly by *Gleichenia*; but the physiognomy of the vegetation will probably not change unless the *Metrosideros* is destroyed by fire or disease. At several open places along the stream bank, *Paspalum conjugatum* is coming in to replace the ferns and other low native plants.

In the Cloud Zone the pigs are destroying the plants and the vegetation is unstable. At several places, whole hillsides have been denuded of vegetation and the destructive work of erosion is taking place. At other places the indigenous ferns and low species are uprooted and *Paspalum conjugatum* is taking possession. At places where bare grounds have been exposed by landslides, *Mariscus meyenii* and *Erechtites hieracifolia* come in first.

TAXONOMY

METHODS

The native, naturalized, and introduced plants in Kipapa Gulch were collected and identified. The specimens have been deposited in the herbarium of Bishop Museum. In working up the taxonomy of the plants found growing in Kipapa Gulch, Hillebrand (23), Rock (44-51), Skottsberg (56-58), Christensen (12), Hitchcock (24), Degener (16), Forbes (19), and works of many others were consulted for the valid names as far as they could be determined.

EXCLUDED PLANTS

In the valley, there are about fifty houses scattered from the Maritime to the Guava Zones and around these houses the people have planted ornamental herbs, shrubs, and trees, such as *Phyllanthus nivosus* (Snow bush), *Codiaeum variegatum* (Croton), *Casuarina equisetifolia* (Ironwood), *Cassia javanica* (Rainbow shower) and *Ficus indica* (Rubber tree). These cultivated species are not included in this study.

There are also the cultivated food plants, as *Carica papaya* (papaya), *Ipomoea batata* (sweet potato), *Brassica sativa* (cabbage) and the leading crops, *Ananas comosus* (pineapple) and *Saccharum officinarum* (sugar cane) that are also not included in this study. At about 120 meters elevation in the gulch, where it is too steep and rocky for cultivation, the Oahu Sugar Company has recently planted fast growing trees and these, too, are excluded.

ANALYSIS OF THE FLORA

The species are divided into three groups in reference to their occurrence in the Hawaiian islands: endemic, species peculiar to the islands; indigenous, species native to the islands; and introduced, those species brought into the islands from other regions. The geographical distribution of these introduced species is given. Many of the endemic and indigenous species found in Kipapa Gulch are widely scattered throughout the Hawaiian islands, but there are several species peculiar to Oahu and a few restricted to the Koolau Range.

The occurrence of each species is given in reference to the number of localities at which the species were observed or collected as: abundant, at more than 34 localities; common, at 16 to 33 localities; occasional, at 7 to 15 localities; rare, at 3 to 6 localities; and very rare, at 1 to 2 localities. Often only a single specimen was observed at a place and at other times 2 to 10 or more plants of the same species were seen at a locality.

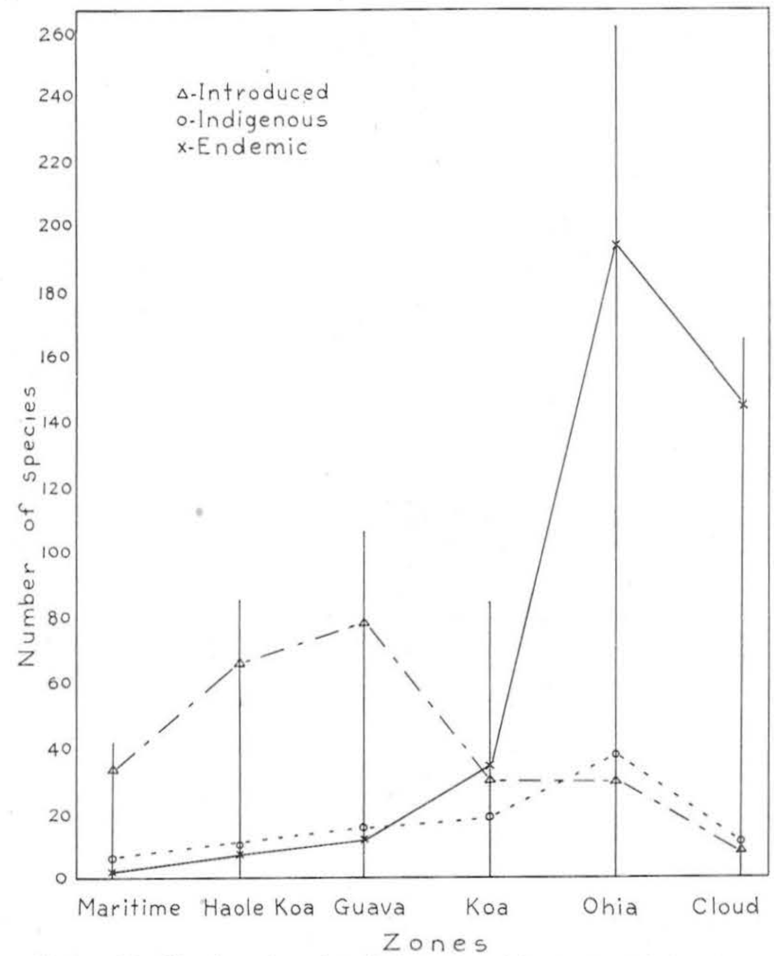

FIGURE 18.—Number of species of plants found in zones studied and number of endemic, indigenous, and introduced species in these zones.

The distribution of the species is recorded with reference to the six vegetational zones of Kipapa Gulch (fig. 18), and table 8.

Figure 18 shows that the largest number of endemic species are found in the Ohia and Cloud Zones; the largest number of indigenous species in the Ohia Zone, and the largest number of introduced species in the Guava and Haole Koa Zones.

Table 8. The floristic composition of Kipapa Gulch.

Plants	No. of Species	Percent
Musci	34	7.6
Pteridophyta	75	16.7
Angiospermae	340	75.7
Total	449	

Table 8 shows that the flowering plants make up 75.7 percent of the flora; ferns and fern allies, 16.7 percent; and the mosses, 7.6 percent. The Musci have not been as intensively collected as the Pteridophytes and Angiosperms.

Table 9. Status of the plants of Kipapa Gulch.

	Mosses	Ferns and Fern Allies	Plants Flowering	Percent
Endemic	22	47	189	57.4
Indigenous	12	23	25	13.4
Introduced	0	5	126	29.2

Table 9 shows that over half of the species of plants considered in the investigation are endemic, less than a fourth indigenous and little over one fourth introduced. One species of moss was not counted because the specific name was not determined. Majority of introduced plants are very suggestive in lower elevations.

Abbreviations

A list of the native or naturalized plants found in Kipapa Gulch arranged by families, genera and species and tabulated according to occurrence, life form, leaf-size, abundance, distribution, and period of flowering are presented in the following pages. When the information of a species is not available, that part is omitted by a dash. In the case of Bryophytes only the occurrence and distribution are given. The symbols used in this section are as follows:

I. Occurrence: E, endemic; I, indigenous; In., introduced.

II. Life form: E, epiphytes; MM, mega- and meso-phanerophytes; M, microphanerophytes; N, nanophanerophytes; Ch, chamaephytes; HH, hydrophytes; H, hemicryptophytes; G, geophytes; Th, therophytes.

III. Leaf size: 1, 2, 3, 4, 5, 6.

IV. Abundance: a, abundant; c, common; o, occasional; r, rare; vr, very rare.

V. Distribution (Zones): M, Maritime; H, Haole Koa; G, Guava; K, Koa; O, Ohia; C, Cloud.

VI. Phenology (Flowering Period): numbered according to month of year, January=I, etc.

	I	II	III	IV	V	VI
BRYOPHYTA						
Dicranaceae						
Campylopus densifolius Ångström	E				O	
C. umbeliatus (W. Arnott) Bartram	I				C	
Dicranella Hillebrandi (C. Müller) Brotherus	E				C	
D. integrifolia (Brotherus) Bartram	E				G	
Dicranodontium falcatum Brotherus	E				C	
Holomitrium seticalycinum C. Müller	E				O,C	
Leucoloma molle (C. Müller) Mitten	I				C	
L. scaberulum Bartram	E				O	
Leucobryaceae						
Leucobryum gracile Sullivant	E				C	
Funariaceae						
Funaria subintegra Brotherus	E				C	
Bryaceae						
Rhodobryum giganteum (Hooker) Schimper	I				C	
Rhizogoniaceae						
Rhizogonium pungens Sullivant	E				O	
R. spiniforme (Hedwig) Bruch	I				O,C	
Bartramiaceae						
Breutelia arundinifolia (Duby) Fleischer	I				C	
Philonotis sp.	—				O	
Orthotrichaceae						
Macromitrium brevisetum Mitten	E				O	
M. piliferum Schwaegrichen	E				O	
Rhacopilaceae						
Rhacopilum cuspidigerum (Schwaegrichen) Mitten	I				O	
Meteroriaceae						
Barbella trichophora (Montagne) Fleischer	E				O	
Neckeraceae						
Baldwinella kealeensis (Reichardt) Bartram	E				O	
Homaliodendron flabellatum (Dickson, Smith) Fleischer	I				O,C	

	I	II	III	IV	V	VI
Hookeriaceae						
Distichophyllum paradoxum (Montagne) Mitten	E				O	
Hookeria acutifolia Hooker	I				O	
Hookeriopsis purpurea (C. Müller) Brotherus variety ligulacea (C. Müller) Bartram	E				O	
Thuidiaceae						
Thuidium hawaiiense Reichardt	E				O,C	
Brachytheciaceae						
Brachythecium oxyrrhynchium (Dozy and Molkenboer) Jaeger	I				O	
Pleuropus Wilkesianus (Sullivant) Brotherus	E				O,C	
Sematophyllaceae						
Acroporium fusco-flavum (C. Müller) Brotherus	E				O,C	
Trichosteleum hamatum (Dozy and Molkenboer) Jaeger	I				O,C	
Hypnaceae						
Ctenidium decurrens (Sullivant) Brotherus	E				O	
Ectropothecium arcuatum (Sullivant) Mitten	E				O	
Isopterygium albescens (Schwaegrichen) Jaeger	I				O	
Vesicularia graminicolor (Ångström) Brotherus	E				O	
Polytrichaceae						
Pogonatum Baldwini (C. Müller) Paris	E				O	
Orthotrichaceae						
Macromitrium owahiense C. Müller	I				O	
PTERIDOPHYTA						
Hymenophyllaceae						
Hymenophyllum lanceolatum Hooker and Arnott	E	E	3	c	O,C	
H. obtusum Hooker and Arnott	E	E	2	c	O,C	
H. recurvum Gaudichaud	E	E	3	c	O,C	
Trichomanes Baldwinii (Eaton) Copeland	I	H,E	4	o	O,C	
T. cyrtotheca Hillebrand	E	H,E	4	o	O,C	
T. davallioides Gaudichaud	E	H,E	4	o	O,C	
T. parvulum Poiret	I	E	1	r	O	

	I	II	III	IV	V	VI
Cyatheaceae						
Cibotium Chamissoi Kaulfuss	E	N	6	a	K,O,C	
C. Menziesii Hooker	E	N	6	c	O,C	
Polypodiaceae						
Asplenium contiguum Kaulfuss	E	H	4	o	O,C	
A. horridum Kaulfuss	E	H	5	o	O,C	
A. obtusatum Forster	In	H,E	5	o	O	
A. monanthes Linnaeus	I	H,E	3	o	O	
A. nidus Linnaeus	I	E	5	o	O	
A. lobulatum Mettenius variety pseudofalcatum (Hillebrand) C. Christensen	E	H	4	o	O,C	
Athyrium microphyllum (Smith) Alston	E	H	5	c	O,C	
A. proliferum (Kaulfuss) C. Christensen	E	H	5	c	O,C	
Blechnum occidentale Linnaeus	In	H	4	o	O	
Diplazium Arnottii Brackenridge	E	H	5	c	O,C	
D. marginale (Hillebrand) C. Christensen	E	H	5	c	O,C	
Doodia Lyoni Degener	E	H	4	o	O	
D. Kunthiana Gaudichaud	E	H	4	c	O	
Doryopteris decipiens (Hooker) J. Smith	E	H	3	o	G	
Dryopteris crinalis (Hooker and Arnott) C. Christensen	E	H	5	o	O	
D. cyatheoides (Kaulfuss) Kuntze	E	H	5	a	O,C	
D. dentata (Forster) C. Christensen	In	H	4	o	O	
D. globulifera (Brackenridge) Kuntze	E	H	5	o	O	
D. gongylodes (Schkuhr) Kuntze	I	H	4	o	O	
D. hudsonianum (Brackenridge) Roscoe	I	H	5	o	O	
D. latifrons (Brackenridge) Kuntze	E	H	5	o	O,C	
D. paleacea (Swartz) C. Christensen	I	H	5	o	O,C	
D. stegnogrammoides (Baker) C. Christensen	E	H	5	o	O,C	
Elaphoglossum aemulum (Kaulfuss) Brackenridge	E	E	4	o	O.C	
E. gorgoneum (Kaulfuss) Brackenridge	E	H,E	4	c	O,C	
E. micradenium (Fée) Moore	E	E	3	o	O	
E. reticulatum (Kaulfuss) Gaudichaud	E	E	4	a	O,C	
Lindsaya Macraena (Hooker and Arnott) Copeland	I	H,E	4	a	O,C	
Microlepia setosa (Smith) Alston	E	H	5	o	O	
Nephrolepis cordifolia (Linnaeus) Presl	In	H	4	r	O,C	
N. exaltata (Linnaeus) Schott	I	H	4	a	G,K,O.C	
Pityrogramma ochracea (Presl) Domin	In	H	5	o	G	
Polypodium Haalilioanum Brackenridge	E	E	2	r	O,C	
P. Hookeri Brackenridge	I	E	3	r	O,C	
P. hymenophylloides Kaulfuss	E	E	2	o	O,C	
P. lineare Thunberg	I	E	3	a	G,K,O,C	
P. pellucidum Kaulfuss	E	E	4	o	O,C	
P. pumilum W. J. Robinson	E	E	3	r	O,C	
P. pseudo-grammitis Gaudichaud	E	E	2	a	O,C	
P. Saffordii Maxon	E	E	1	o	O,C	

	I	II	III	IV	V	VI
P. sarmentosum Brackenridge	E	E	3	o	O,C	
P. spectrum Kaulfuss	E	H,E	4	o	O	
P. tamariscinum Kaulfuss	E	E	3	o	O,C	
Pteridium aquilinum (Linnaeus) Kuhn	I	H	4	a	H,G,K,O	
Pteris irregularis Kaulfuss	E	H	5	r	O	
Sadleria cyatheoides Kaulfuss	E	N	5	a	G,K,O,C	
S. Hillebrandii W. J. Robinson	E	Ch	5	r	O	
S. polystichoides (Brackenridge) Heller	E	Ch	5	o	O,C	
S. Souleyetiana (Gaudichaud) Moore	E	N	6	r	O,C	
Stenoloma chinensis (Linnaeus) Beddome	I	H	5	a	H,G,K,O,C	
Tectaria Gaudichaudii (Mettenius) Maxon	E	H	5	r	O	
Vittaria rigida Kaulfuss	I	E	3	o	O	
Gleicheniaceae						
Gleichenia emarginata (Brackenridge) Moore	E	H	4	r	C	
G. glauca (Thunberg) Hooker	I	H	5	c	O,C	
G. linearis (Burmann) Clarke	I	H	5	a	G,K,O,C	
Schizaeaceae						
Schizaea robusta Baker	E	H	1	r	O,C	
Marattiaceae						
Marattia Douglasii (Presl) Baker	E	Ch	6	r	K,O	
Ophioglossaceae						
Ophioglossum pendulum Linnaeus	I	E	3	c	O	
Lycopodiaceae						
Lycopodium cernuum Linnaeus	I	N	1	a	K,O,C	
L. nutans Brackenridge	I	H,E	1	r	O	
L. phyllanthum Hooker and Arnott	I	H,E	1	c	O,C	
L. serratum Thunberg	I	H,E	1	r	O,C	
L. serratum Thunberg variety dentatum Hillebrand	E	H,E	1	vr	C	
Psilotum complanatum Swartz	I	H,E	1	r	K,O	
P. nudum (Linnaeus) Grisebach	I	H,E	1	c	G,K,O	
Selaginella Menziesii (Hooker and Greville) Spring	E	H,E	1	c	O,C	
SPERMATOPHYTA						
Pandanaceae						
Freycinetia arborea Gaudichaud	E	M	4	a	K,O,C	
Potamogetonaceae						
Potamogeton foliosus Rafinesque variety Macellus Fernald	In	HH	2	c	M	

	I	II	III	IV	V	VI
Gramineae						
Bambusa vulgaris (Linnaeus) Schrader	In	MM	4	r	K,O	
Cenchrus echinatus Linnaeus	In	Th	3	c	H,G	
C. echinatus Linnaeus variety Hillebrandianus (Hitchcock) F. B. H. Brown	E	Th	3	c	H,G	
Chloris inflata Link	In	Th	2	c	M,H,G	
C. radiata (Linnaeus) Swartz	In	Th	2	o	H,G	
Chrysopogon aciculatus Trinius	I	H	3	a	H,G,K	
Cynodon Dactylon (Linnaeus) Persoon	In	H	1	c	M,H,G	
Digitaria violascens Link	In	Th	2	c	H,G	
D. pruriens (Trinius) Busse	In	H	3	o	H,G	
D. sanguinalis (Linnaeus) Scopoli	In	H	3	o	H,G	
Echinochloa colonum (Linnaeus) Link	In	Th	3	r	M	
E. crus-galli (Linnaeus) Beauvois variety crus-pavonis (H. B. K.) Hitchcock	In	H	3	r	M,O	
E. stagnina (Retzius) Beauvois	In	H	3	r	M	
Eleusine indica (Linnaeus) Gaertner	In	H	2	c	H,G	
Eragrostis amabilis (Linnaeus) Wight and Arnott	In	Th	2	o	H	
E. cilianensis (Allioni) Link	In	Th	2	o	H	
E. deflexa Hitchcock	E	H	2	r	H,G	
E. grandis Hillebrand	E	H	2	r	H,G	
Heteropogon contortus (Linnaeus) Beauvois	I	H	3	a	H,G	
Sorghum halepense (Linnaeus) Persoon	In	H	3	r	M	
Isachne pallens Hillebrand	E	H	2	o	O,C	
Oplismenus hirtellus (Linnaeus) Beauvois	In	H	3	a	G,K,O,C	
Panicum purpurascens Raddi	In	H	3	c	M,H,G,K	
P. koolauense St. John and Hosaka	E	H	1	vr	C	
Paspalum conjugatum Bergius	In	H	2	a	M,H,G,K,O,C	
P. orbiculare Forster	In	H	3	a	H,G,K,O	
Pennisetum setosum (Swartz) L. Richardson	In	H	3	c	G	
Setaria verticillata (Linnaeus) Beauvois	In	Th	3	o	H,G	
Trichachne insularis (Linnaeus) Nees	In	H	3	o	H,G	
Tricholaena repens (Willdenew) Hitchcock	In	H	3	c	H,G	
Cyperaceae						
Carex brunnea Thunberg variety Meyenii (Nees) Kuekenthal	I	H	3	vr	O	
C. sp. (similar to C. sandwicensis)	E	H	3	vr	C	
C. wahuensis C. A. Meyer	E	H	3	o	K,O	
Cyperus alternifolius Linnaeus	In	H	3	r	M	
C. laevigatus Linnaeus	I	H	1	o	M,O	
C. polystachyus Rottboell	I	H	2	o	O	
C. Prescottianus Hooker and Arnott	E	H	4	r	O,C	
Heleocharis obtusa Schuetes variety enotata Hillebrand	E	H	1	vr	O	
Fimbristylis diphylla Vahl	I	H	3	o	O	
Gahnia Beecheyi Mann	E	H	4	o	O,C	
Kyllinga brevifolia Rottboell	In	H	2	o	M,G	
K. cephalotes (Jacquin) Druce	In	H	2	r	O	

	I	II	III	IV	V	VI
Mariscus angustifolius (Gaudichaud) Kuntze	I	H	4	o	O,C	
M. Meyenii Kuntze	I	H	3	o	O	
Rhynchospora glauca Vahl forma lavarum (Gaudichaud) Kuekenthal	E	H	2	o	K,O	
R. sclerioides Hooker and Arnott	E	H	4	c	O,C	
Scirpus lacustris Linnaeus	In	HH	1	o	M,G,K,O	
S. maritimus Linnaeus variety digynus Boeckler	In	H	3	r	M	
Palmaceae						
Cocos nucifera Linnaeus	In	MM	6	o	M,G,O	
Eupritchardia Martii (Wendland) Kuntze	E	M	6	c	O,C	II
Araceae						
Alocasia macrorrhiza (Linnaeus) Schott	In	N	5	vr	K	
Colocasia esculenta (Linnaeus) Schott variety antiquorum (Schott) Hubbard and Rehder	In	G	5	o	M,K,O	
Lemnaceae						
Lemna minor Linnaeus	In	HH	1	c	M	
Spirodela polyrhiza (Linnaeus) Schleiden	In	HH	1	c	M	
Flagellariaceae						
Joinvillea Gaudichaudiana Brogniart and Gris	I	M	4	r	O	VI-VII
Commelinaceae						
Commelina diffusa Burmann	I	N	3	a	M,H,G,K,O	
Pontederiaceae						
Eichornia speciosa Kunth	In	HH	4	r	M	
Liliaceae						
Astelia veratroides Gaudichaud	E	H,E	4	o	O,C	VIII
Cordyline fruticosa (Linnaeus) A. Chevalier	In	M	5	a	G,K,O	XII-I
Dianella sandwicensis Hooker and Arnott	E	H	4	c	K,O,C,	
Dracaena aurea Mann	I	M	4	r	K,O	V
Smilax sandwicensis Kunth	E	M	4	c	O,C	IV
Amaryllidaceae						
Fourcroya gigantea Vent	In	N	6	o	H,G	
Dioscoreaceae						
Dioscorea bulbifera Linnaeus	In	Ch	4	c	O	
D. pentaphylla Linnaeus	In	Ch	4	r	K	
Musaceae						
Musa sapientum Linnaeus	In	M	6	c	K,O	
Zingiberaceae						
Hedychium flavum Roxburg	In	G	4	o	K,O	V-VII
Zingiber Zerumbet (Linnaeus) Roscoe	In	G	4	a	K,O	VII

	I	II	III	IV	V	VI
Orchidaceae						
Anoectochilus sandwicensis Lindley	E	H,E	3	o	O,C	IX
A. sandwicensis Lindley variety B. Hillebrand	E	H,E	3	o	O,C	XI
Liparis hawaiiensis Mann	E	E	3	o	O,C	IX
Spathoglottis plicata Blume	In	H	4	vr	K	
Piperaceae						
Peperomia elliptibacca C. de Candolle	E	Ch,E	3	r	C	
P. latifolia Miquel	E	Ch,E	3	c	K,O,C	
P. leptostachys Hooker and Arnott	I	N	2	o	G,K	
P. lilifolia C. de Candolle	E	Ch	3	o	O,C	
P. membranacea Hooker and Arnott	E	N	3	c	O,C	
P. membranacea Hooker and Arnott variety brevifolia Yuncker	E	N	3	r	O,C	
P. oahuensis C. de Candolle	E	N,E	3	o	O,C	
P. reflexa Dietrich	I	Ch,E	1	o	G,K,O	
P. sandwicensis Miquel	E	N	3	o	K,O	
Piper methysticum Forster	In	M	4	r	O	
Urticaceae						
Artocarpus incisa Linnaeus	In	MM	5	r	G,K,O	VI
Boehmeria grandis (Hooker and Arnott) Heller	E	M	4	vr	O	VI-VIII
Pilea peploides Hooker and Arnott	I	Ch	1	r	C	
Pipturus albidus (Hooker and Arnott) Gray	E	M	4	c	K,O,C	V-IX
P. Skottsbergii Krajina	E	M	4	r	O	
Touchardia latifolia Gaudichaud	E	M	4	c	O,C	V-VIII
Urera sandvicensis Weddell	E	M	4	vr	O	
Loranthaceae						
Korthalsella complanata (Van Tieghem) Engler	E	E	—	o	K,O,C	
K. cylindria (van Tieghem) Engler	E	E	—	vr	O	
K. sp. (similar to K. complanata)	E	E	—	vr	O	
Santalaceae						
Exocarpus sandwicensis Baillon	E	M	3	r	O,C	V
Santalum Freycinetianum Gaudichaud	E	M	3	o	K,G,O	II-X
Chenopodiaceae						
Chenopodium murale Linnaeus	In	N	3	c	M	
Amarantaceae						
Amaranthus hybridus Linnaeus	In	N	3	c	H,G	
A. spinosus Linnaeus	In	N	3	c	H,G	
Charpentiera obovata Gaudichaud	E	MM	3	c	K,O	IV-IX
Nyctaginaceae						
Ceodes umbellata Forster	I	MM	4	o	K,O	VI-XI

	I	II	III	IV	V	VI
Batidaceae						
Batis maritima Linnaeus	In	N	2	a	M	
Phytolaccaceae						
Phytolacca acinosa Roxburg	In	N	3	o	H,G	
Aizoaceae						
Sesuvium Portulacastrum Linnaeus	I	Ch	2	o	M	
Portulacaceae						
Portulaca oleracea Linnaeus	In	Ch	2	a	M,H,G	
Caryophyllaceae						
Drymaria cordata (Linnaeus) Willdenow	In	Ch	2	a	G	
Menispermaceae						
Cocculus Ferrandianus Gaudichaud	E	Ch	3	o	G,K,O	
Lauraceae						
Cryptocarya oahuensis (Degener) Fosberg	E	M	4	vr	O	
Papaveraceae						
Argemone alba Lestiboudois variety glauca Prain	E	N	4	r	H	
Saxifragaceae						
Broussaisia arguta Gaudichaud	E	M	4	a	O,C	III-XI
Pittosporaceae						
Pittosporum acuminatum Mann	E	M	4	o	O,C	
P. Gayanum Rock	E	M	4	r	O	
P. glabrum Hooker and Arnott	E	M	4	o	O,C	IV-VII
P. spathulatum Mann	E	M	4	o	O,C	V-VII
Rosaceae						
Osteomeles anthyllidifolia Lindley	I	N	3	o	H,G	I-VII
Rubus rosaefolius Smith	In	N	4	o	C	
Leguminosae						
Acacia Farnesiana (Linnaeus) Willdenow	In	N	3	c	H	I-XI
A. Koa Gray	E	MM	4	a	K,O,C	I-IV
Cassia bicapsularis Linnaeus	In	N	4	r	H	XI
C. Leschenaultiana de Candolle	In	N	3	c	H,G	
C. occidentalis Linnaeus	In	N	4	o	H,G	
Crotalaria incana Linnaeus	In	N	3	o	H,G	
C. Saltiana Andrews	In	N	3	c	H,G	
Desmodium triflorum (Linnaeus) de Candolle	In	Ch	1	o	H,G	
D. uncinatum (Jacquin) de Candolle	E	N	3	o	H,G	

	I	II	III	IV	V	VI
Erythrina sandwicensis Degener	E	M	4	vr	H	II
Indigofera suffruticosa Miller	In	N	4	o	G	
Leucaena glauca Bentham	In	M	4	c	H	
Medicago denticulata Willdenow	In	Ch	2	vr	H	
Mimosa pudica Linnaeus	In	N	3	r	G	
Phaseolus lathyroides Linnaeus	In	N	3	c	H,G	
Prosopis chilensis (Molina) Stuntz	In	MM	4	c	M,H,G	
Oxalidaceae						
Oxalis corniculata Linnaeus	In	H	2	c	H,G	
O. corniculata Linnaeus variety viscidula Wiegand	In	H	2	c	H,G	
O. Martiana Zuccarini	In	G	3	c	G	
Rutaceae						
Pelea clusiaefolia Gray	E	M	4	c	O,C	VII-XI
P. oblongifolia Gray	E	M	3	o	O,C	
P. rotundifolia Gray	E	M	4	o	O,C	XI
P. Mannii Hillebrand	E	M	4	r	C	II
P. sandwicensis (Gaudichaud) Gray	E	MM	4	c	O,C	
P. waianaensis Léveillé	E	M	4	vr	O	XI
P. Wawraeana Rock	E	M	4	c	O,C	
P. cinerea (Gray) Hillebrand variety sulfurea Rock	E	M	4	vr	O	
Platydesma campanulata Mann	E	M	4	o	O,C	VII
P. cornuta Hillebrand	E	N	4	r	O	V-XI
Fagara oahuensis (Hillebrand) Engler	E	M	4	o	O,C	VII-X
Meliaceae						
Melia Azedarach Linnaeus	In	MM	4	r	H,G	V-VI
Euphorbiaceae						
Aleurites moluccana (Linnaeus) Willdenow	In	MM	4	a	G,K,O	X-IV
Antidesma platyphyllum Mann	E	MM	4	a	O,C	VI-VIII
Claoxylon sandwicense Mueller	E	M	4	r	O	V-XI
Euphorbia bifida Hooker and Arnott	In	N	2	a	H,G,K	
E. geniculata Ortega	In	Th	3	c	H,G	
E. hirta Linnaeus	In	Th	2	a	H,G	
E. multiformis Hooker and Arnott	E	N	3	o	O	VI-IX
E. Rockii Forbes	E	M	3	c	O,C	III-X
E. thymifolia Linnaeus	In	H	1	o	H,G	
Ricinus communis Linnaeus	In	M	4	r	H,G	
Aquifoliaceae						
Ilex anomala Hooker and Arnott	E	MM	4	c	O,C	V-XII
Celastraceae						
Perrottetia sandwicensis Gray	E	M	3	a	O,C	IV-X

	I	II	III	IV	V	VI
Sapindaceae						
Alectryon macrococcum Radlkofer	E	MM	5	vr	O	
Sapindus oahuensis Hillebrand	E	MM	4	vr	K	
Dodonaea viscosa (Linnaeus) Jacquin	I	M	3	o	H,G	X-II
Elaeocarpaceae						
Elaeocarpus bifidus Hooker and Arnott	E	MM	4	c	O,C	XI-IV
Malvaceae						
Hibiscus Arnottianus Gray	E	MM	4	r	O	VI-XI
H. tiliaceus Linnaeus	In	MM	4	o	H,G,K	
H. Youngianus Gaudichaud	E	N	3	r	G,K	V
Malva rotundifolia Linnaeus	In	N	3	o	H	
Malvastrum coromandelianum (Linnaeus) Garcke	In	N	2	c	H,G	
Sida fallax Walpers	In	N	3	o	H,G	
S. rhombifolia Linnaeus	In	N	2	c	H,G	
Sterculiaceae						
Waltheria indica (Linnaeus) variety americana (Linnaeus) R. Brown	In	N	3	a	H,G,K	
Theaceae						
Eurya sandwicensis Gray	E	M	3	o	O	VII
Violaceae						
Viola oahuensis Forbes	E	Ch	3	r	C	
Flacourtiaceae						
Xylosma hawaiiense Seemann	E	M	4	o	O,C	X-XI
Passifloraceae						
Passiflora edulis Sims	In	N	3	o	K	V
P. foetida Linnaeus	In	N	3	o	H	
Cactaceae						
Opuntia megacantha Salm-Dyck	In	M	—	c	H	
Thymeleaceae						
Wikstroemia elongata Gray variety recurva Hillebrand	E	N	3	r	O	III-XI
W. oahuensis (Gray) Rock	E	M	3	c	K,O,C	V-IX
Lythraceae						
Cuphea Balsamona Chamisso and Schlechtendal	In	Ch	2	a	G,K,O,C	

	I	II	III	IV	V	VI
Myrtaceae						
Eugenia malaccensis Linnaeus	In	MM	4	o	K,O	IV-VI
E. sandwicensis Gray	E	MM	3	a	O,C	VII-XII
Metrosideros collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety glabrifolia (Heller) Rock	E	MM	3	a	K,O	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety glaberrima (Léveillé) Rock	E	M	3	c	K,O,C	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety glaberrima (Léveillé) Rock forma sericea Rock	E	MM	3	c	O	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety incana (Léveillé) Rock	E	MM	3	a	O	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety Newellii Rock	E	M	3	c	O	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety prostrata Rock	E	Ch	2	o	C	
M. collina (Forster) Gray subsp. polymorpha (Gaudichaud) Rock variety typica Rock	E	MM	3	c	K,O	
M. macropus Hooker and Arnott	E	MM	3	c	O,C	
M. rugosa Gray	E	M	3	r	C	
M. tremuloides (Heller) Rock	E	M	3	o	O	II
Psidium cattleianum Sabine	In	M	3	r	K	
P. Guayava Linneaus	In	M	4	a	H,G,K,O,C	
Onagraceae						
Jussiaea villosa Lamarck	In	N	3	o	O	
Araliaceae						
Cheirodendron Gaudichaudii (de Candolle) Seemann	E	MM	4	o	O,C	V-VIII
C. platyphyllum (Hooker and Arnott) Seemann	E	MM	4	o	C	VIII-X
Pterotropia gymnocarpa Hillebrand	E	MM	5	vr	C	
Tetraplasandra meiandra (Hillebrand) Harms	E	MM	5	o	O,C	VI-X
T. oahuensis (Gray) Harms	E	M	4	o	O,C	VII-VIII
T. oahuensis (Gray) Harms variety B. (Hillebrand) Rock	E	M	4	r	O,C	
Umbelliferae						
Centella asiatica (Linnaeus) Urban	In	H	3	c	G	
Hydrocotyle verticillata Thunberg	In	H	3	r	O	
Sanicula purpurea St. John and Hosaka	E	H	3	vr	C	

	I	II	III	IV	V	VI
Ericaceae						
Vaccinium dentatum Smith	E	N	3	o	O,C	
Epacridaceae						
Styphelia Tameiameiae (Chamisso) Mueller	E	M	1	c	G,K,O	V
Myrsinaceae						
Suttonia Fernseei Mez	E	M	4	r	C	
S. Hillebrandii Mez	E	M	3	vr	K,C	
S. Lessertiana (A. de Candolle)	E	M	4	c	O,C	I-II
S. sandwicensis (A. de Candolle) Mez	E	M	2	r	O,C	I
Sapotaceae						
Planchonella sandwicensis (Hillebrand) Pierre	E	MM	4	c	O	IV-VII
Ebenaceae						
Diospyros Hillebrandii (Seemann) Fosberg	E	MM	4	o	O	VII
D. sandwicensis (A. de Candolle) Fosberg	E	MM	3	c	O,C	IV
Oleaceae						
Osmanthus sandwicensis (Gray) Bentham and Hooker	E	MM	4	c	K,O,C	XI-II
Loganiaceae						
Buddleia asiatica Loureiro	In	N	3	o	O,C	V-X
Labordia fagraeoidea Gaudichaud	E	M	3	c	O,C	VII
L. glabra Hillebrand	E	N	3	r	C	III
L. hedyosmifolia Baillon	E	N	3	r	C	VII
L. Cyrtandrae (Baillon) St. John	E	N	4	r	O,C	VII
Apocynaceae						
Alyxia olivaeformis Gaudichaud	E	M	3	a	K,O,C	I-V
Pteralyxia macrocarpa (Hillebrand) K. Schumann	E	MM	4	vr	O	I
Rauwolfia sandwicensis A. de Candolle	E	MM	4	r	K,O	
Asclepiadaceae						
Gomphocarpus physocarpus E. Meyer	In	N	3	c	G,K	
Convolvulaceae						
Convolvulus arvensis Linnaeus	In	H	2	o	M	
Ipomoea aquatica Forskål	In	HH	3	vr	M	
I. Bona-nox Linnaeus	I	N	4	a	H,G,K,O	VIII
I. indica (Burmann) Merrill	I	N	3	a	H,G,K	
I. obscura (Linnaeus) Ker-Gawl	In	N	3	c	M	
I. pentaphylla (Linnaeus) Jacquin	In	N	3	c	H,G	
I. pes-caprae (Linnaeus) Sweet	I	Ch	4	vr	M	
I. tuberculata Roemer	In	N	3	c	H,G	
Jacquemontia sandwicensis Gray	E	Ch	3	r	M	

	I	II	III	IV	V	VI
Boraginaceae						
Heliotropium curassavicum Linnaeus	I	Ch	2	r	M	
Verbenaceae						
Lantana Camara Linnaeus	In	M	3	a	H,G,K,O,C	I-XII
Stachytarpheta dichotoma (Ruiz and Pavon) Vahl	In	N	3	a	M,H,G	
S. jamaicensis (Linnaeus) Vahl	In	N	3	c	H,G	
Verbena bonariensis Linnaeus	In	N	3	o	H,G	
Labiatae						
Phyllostegia glabra Bentham variety Macraei (Bentham) Sherff	E	N	4	c	O,C	I-XI
P. grandiflora (Gaudichaud) Bentham	E	N	3	c	O,C	I-XII
P. hirsuta Bentham	E	N	4	r	O,C	V
P. lantanoides Sherff	E	N	3	r	C	X
P. parviflora (Gaudichaud) Bentham	E	N	4	vr	C	X
Stachys arvensis Linnaeus	In	Th	2	o	G	
Solanaceae						
Lycopersicum esculentum Miller variety cerasiforme Hortorum	In	N	3	c	M,H,G	
Nothocestrum longifolium Gray	E	M	4	o	O	V-VI
Solanum nodiflorum Jacquin	I	N	3	a	M,H,G,K	
S. sodomeum Linnaeus	In	N	4	r	H,G	
Physalis peruviana Linnaeus	In	N	3	r	K	
Gesneriaceae						
Cyrtandra sp.	E	N	4	vr	O	
C. cordifolia Gaudichaud	E	M	4	a	K,O,C	II-XI
C. Garnotiana Gaudichaud	E	N	4	r	O	IV-XI
C. grandiflora Gaudichaud	E	N	4	o	O	
C. kalichii Wawra	E	N	4	c	O,C	II-XI
C. kalichii Wawra variety tristis (Hillebrand) Rock	E	N	4	r	O,C	XI
C. laxiflora Mann	E	N	4	r	O	V
C. laxiflora Mann variety grandifolia Rock	E	N	4	vr	O	
C. Lessoniana Gaudichaud	E	M	4	c	O	X
C. longifolia Hillebrand variety calpidicarpa Rock	E	N	4	r	O	VI
C. longifolia Hillebrand variety degenerans (Wawra) C. B. Clarke	E	N	4	o	O,C	
C. paludosa Gaudichaud	E	N	3	o	O	V
C. propinqua Forbes	E	N	4	vr	O	II
C. waiolani Wawra	E	N	4	vr	O	
Plantaginaceae						
Plantago major Linnaeus	In	H	4	o	M	
P. pachyphylla Gray	E	H	4	vr	C	VII-XII

	I	II	III	IV	V	VI
Rubiaceae						
Bobea brevipes Gray	E	MM	3	vr	K,O	VI-VIII
B. elatior Gaudichaud	E	MM	4	a	K,O,C	IV-VIII
Canthium odoratum (Forster) Seemann	I	M	3	o	K	
Coprosma longifolia Gray	E	M	3	o	O,C	II
Gardenia Remyi Mann	E	MM	4	c	O,C	V-VII
Gouldia St.-Johnii Fosberg variety typica Fosberg	E	M	3	o	C	VII
G. terminalis (Hooker and Arnott) Hillebrand variety typica Fosberg	E	M	4	c	O,C	VI-VIII
G. terminalis (Hooker and Arnott) Hillebrand variety coriacea (Hooker and Arnott) Fosberg	E	M	4	o	O,C	VI-VIII
G. terminalis (Hooker and Arnott) Hillebrand variety Wawrana Fosberg	E	M	4	o	O,C	VI-VIII
G. terminalis (Hooker and Arnott) Hillebrand variety macrothyrsa Fosberg	E	M	4	o	O	VI-VIII
Kadua acuminata Chamisso and Schlechtendal	E	M	4	r	O	V-VI
K. fluviatilis Forbes	E	N	3	r	O	II-III
K. glomerata Hooker and Arnott	E	N	4	vr	O,C	VIII-IX
Morinda citrifolia Linnaeus	In	M	4	c	G	X
M. trimera Hillebrand	E	MM	4	vr	O	IV-VI
Nertera depressa Banks and Solander	I	Ch	1	c	O,C	
Psychotria sp.	E	M	4	vr	O	V
Richardsonia scabra (Linnaeus) St. Hilaire	In	Ch	3	a	H,G	
Straussia Fauriei Léveillé	E	M	3	r	O,C	VII-IX
Straussia sp.	E	M	4	vr	O	V
S. kaduana (Chamisso and Schlechtendal) Gray	E	M	4	a	K,O,C	IV-VII
S. leptocarpa Hillebrand	E	M	4	r	O,C	VI-VII
S. Mariniana (Chamisso and Schlechtendal) Gray	E	M	4	c	K,O,C	IV
Cucurbitaceae						
Momordica Balsamina Linnaeus	In	N	3	o	M	
Campanulaceae						
Clermontia kakeana Meyen	E	M	4	c	O,C	V-XI
C. oblongifolia Gaudichaud	E	M	4	vr	O,C	II-III
C. persicifolia Gaudichaud	E	M	4	o	O	III-X
Cyanea acuminata (Gaudichaud) Hillebrand	E	N	4	o	O	V-X
C. angustifolia (Chamisso) Hillebrand	E	M	4	c	O	V-XI
C. Grimesiana Gaudichaud	E	N	5	c	O	VI-XI
Lobelia Gaudichaudii A. de Candolle	E	N	4	r	C	IX-X
L. hypoleuca Hillebrand	E	N	4	o	O,C	IX-X
L. oahuensis Rock	E	M	4	r	C	VII-VIII
Rollandia angustifolia (Hillebrand) Rock	E	N	4	o	O,C	VI-VII
R. calycina (Chamisso) G. Don	E	N	4	o	O,C	VII-VIII
R. crispa Gaudichaud	E	N	4	c	K,O	II-V
R. Humboldtiana Gaudichaud	E	N	4	r	O	XI

	I	II	III	IV	V	VI
R. lanceolata Gaudichaud variety kipapaensis Hosaka	E	N	4	r	O	V-VI
R. lanceolata Gaudichaud variety tomentosa Rock	E	N	4	o	K,O	V-VII
R. longiflora Wawra	E	N	4	o	K,O	II-V
R. St.-Johnii Hosaka	E	N	3	r	C	VII-IX
Trematolobelia macrostachys (Hooker and Arnott) Zahlbruckner	E	N	4	r	O,C	X-XII
Goodeniaceae						
Scaevola cerasifolia Skottsberg	E	M	3	r	O,C	V-XI
S. Gaudichaudiana Chamisso	E	M	3	a	G,K,O,C	I-XII
S. Gaudichaudiana Chamisso forma leucocarpa Skottsberg	E	M	3	vr	O	VII-XI
S. glabra Hooker and Arnott	E	M	4	c	O,C	III-XI
S. mollis Hooker and Arnott	E	M	3	c	O,C	III-XI
S. procera Hillebrand	E	M	3	r	O,C	IV-XI
S. Skottsbergii St. John	E	M	3	vr	G	VII-XI
Compositae						
Acanthospermum australe (Loefling) Kuntze	In	Th	2	c	H,G	
Adenostemma Lavenia (Linnaeus) Kuntze	In	N	3	o	O	
Ageratum conyzoides Linnaeus	In	Th	3	a	M,H,G	
Ambrosia artemisiaefolia Linnaeus	In	N	2	a	H,G	
Artemisia vulgaris Linnaeus	In	N	3	c	H,G	
Bidens macrocarpa (Gray) Sherff	E	N	3	o	O,C	IV-XI
B. pilosa Linnaeus	In	Th	3	a	M,H,G,K	
B. pilosa Linnaeus variety minor (Blume) Sherff	In	Th	3	c	G,K	
Crepis japonica (Linnaeus) Bentham	In	Th	4	c	G,K,O,C	
Dubautia laxa Hooker and Arnott variety Bryanii Sherff	E	N	4	r	O,C	IX-XI
D. laxa Hooker and Arnott variety pseudoplantaginea Skottsberg	E	N	3	vr	O,C	VII-X
D. laxa Hooker and Arnott variety obovata forma glabrescens Sherff	E	N	4	r	C	
D. plantaginea Gaudichaud	E	M	4	vr	C	X-XII
Emilia sonchifolia (Linnaeus) de Candolle	In	Th	4	a	H,G	
Erigeron albidus (Willdenow) Gray	In	Th	3	a	H,G	
Erechtites hieracifolia (Linnaeus) Rafinesque	In	Th	4	a	G,K,O,C	
Eupatorium adenophorum Sprengel	In	N	3	vr	C	
Galinsoga parviflora Cavanilles	In	Th	2	c	G	
Gnaphalium sandwicensium Gaudichaud	E	Th	2	o	H	
Hesperomannia arborescens Gray	E	M	4	r	O	V-VII
Lipochaeta lobata de Candolle variety leptophylla Sherff	E	N	3	vr	H	II
Pluchea indica (Linnaeus) Lessing	In	N	3	c	M	IX
Sonchus oleraceus Linnaeus	In	Th	4	a	M,H,G	
Verbesina encelioides (Cavanilles) Bentham and Hooker	In	N	3	o	M	
Vernonia cinerea (Linnaeus) Lessing	In	Th	3	a	H,G	
Xanthium saccharatum Wallroth	In	N	4	o	M,H	

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