Charles H. Lamoureux

Atlas for BIOECOLOGY STUDIES IN HAWAII VOLCANOES NATIONAL PARK

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and

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BOTANY DEPARTMENT
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IN REPLY REFER TO:
N22
(WR)CPS

July 7, 1970

Mr. Wallace C. Mitchell
Acting Associate Director
College of Tropical Agriculture
Gilmore Hall
University of Hawaii
Honolulu, Hawaii 96822

Dear Mr. Mitchell:

We are pleased to authorize the College of Tropical Agriculture to reprint the "Atlas for Bioecology Studies in Hawaii Volcanoes National Park," by M. S. Doty and D. Mueller-Dombois. This publication has served as a valuable reference and the demand has exceeded the initial printing.

We suggest that prior to reprinting, the authors be contacted to provide any revisions necessary to make the publication current. Also, a credit line should be given the National Park Service, and the Hawaii Natural History Association who donated the funds for the original project.

We appreciate the opportunity to participate in a broader distribution of the Atlas. When prints are available, we hope you will forward copies to Hawaii Volcanoes National Park for their use in the area.

Sincerely yours,

Daniel J. Tobin, Jr.
Acting Director
Western Region

A T L A S   F O R   B I O E C O L O G Y

studies in

HAWAI'I VOLCANOES NATIONAL PARK

By Maxwell S. Doty and Dieter Mueller-Dombois

Botany Department, University of Hawaii

HAWAII BOTANICAL SCIENCE PAPER
NO. 2

Prepared for

Hawaii Volcanoes National Park

in fulfillment of Contract 14-10-0434-1504 between the

Botany Department of the University of Hawaii and the Western Region,

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June, 1966

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Introduction

Hawaii Volcanoes National Park is a youthful area surfaced with quite recent lava flow materials and a unique flora including many incipient species. Aside from its most interesting birds, vertebrate animals were almost absent until the advent of man and his dometic companions, the rat, the pig and the dog. Such a young soil and biota is very sensitive and will change rapidly. It is susceptible to small climate variations and to the influences wrought by man. Thus in managing such an area one must know man's influences, how much of what we see is due to seral or progressive change as the vegetations and soils develop and how much is a current reflection of the present variation in climate.

The Park Service has recognized the need for bio-ecological information in order to intelligently and efficiently administer, protect and interpret Park phenomena for the public. In order to learn what has been done already, assemble or at least index that information and estimate what is needed to be done in order to implement and facilitate bio-ecological study of the Park, an agreement was made between the National Park Service and the Botany Department of the University of Hawaii. This agreement was, essentially, to achieve these ends by preparing the manuscript for an atlas of the presently available information and in doing so point out the principal gaps and some of the less obvious, yet major, problems.

The Park is the stage on which impressively active volcanoes put on their show, and dense tree fern jungles cover the wetter landscape with a luxuriant rain forest while but a mile away a desert exists. The Park was established as Hawaii National Park on August 1, 1916, with various boundary changes being made May 1, 1922, February 12, 1927, April 11, 1928, June 20, 1938, July 16, 1940, and July 1, 1961. The name was changed to Hawaii Volcanoes National Park on September 22, 1961, and with the last boundary change February 21, 1963, the Park has come to include 220,345 acres of land. The problems and reasoning leading to establishment of the Park (House of Representatives, 1916) are with us today and make interesting reading.

Hawaii Volcanoes National Park is the result of an era of volcanism coupled with perhaps 100,000 to 1,000,000 years of bio-ecological development and a very disturbing much shorter period of man's influences. The geological processes must be considered first. Historically they were first on the scene insofar as the Park is concerned. They provide the topography which profoundly influences the climate. The geology and climate in turn have caused primitive soils to be what they are. In turn, the biological elements have colonized and formed the biotic communities of the Park, and the communities so-formed have changed with the maturing of the soils which they influence. Lastly, man's influence.

With the arrival of European civilization in the islands a few hundred years ago, the native and aboriginal biotic elements were disturbed; the soil where best developed in the wettest areas was eroded. These disturbing activities have been minimal in the Park insofar as their being overt is concerned. That is to say, the Park looks about the same today as it probably did when the first man saw it—if one looks only for the overt grandeur of the mountains, the sea, the magnificent displays of volcanism or the fern forest so strange and interesting to the itinerant viewer from any other state in our nation. The purely recreational value has even improved, it seems, but the Park is a scientific and historical resource as well.

Geologically, soil-wise and vegetationally and from the point of view of the evolution of species possibly the Park's primitive nature is of greater long-term value to the world than is its recreational value. Its scientific merit has led to the maintenance of the world-famous Volcano Observatory, now of the U. S. Geological Survey, at Kilauea since 1911. Further physically, the Park displays splendidly the changes in climate one can expect with direction of the prevailing wind and altitude. The Park Service's recognition of biological value has resulted in this present effort. The opportunities to study speciation in the islands of older surfaces among more recent lava flows are unparalleled. Such studies are noted in appropriate places in the text. The value of the historic records preserved by the Park should not be overlooked. Ellis's (1825) travels or accounts of the petroglyphs along the Puna shore at Puuloa, or a view of the footprints of Keoua's army destroyed (Dibble, 1843) about 1790 by an explosive eruption, an event that may have greatly altered Hawaiian history, provide enough information to excite one with the historic value of the Park. Dr. George Ruhle (1959) in a booklet on the Haleakala region has a historic section of broad interest. Castro (1953) presents the history of the Park itself.

The scientific use of such natural areas as national parks has been the subject of several symposia (e.g., Field & Field, 1965), and some of them (e.g., AIBS Meeting of August 1966 at the University of Maryland, convened by Dr. George Sprugel, "Ecological research on the vegetation in the National Parks") have dealt directly with the Hawaii Volcanoes National Park at least in part.

Changes have crept in. Some have been so much more sensible than subtile they have disturbed those resident in the Park area over the years no less than the occasional scientist. The causes for worry brought by man fall largely in the following three categories.

The intentional plant and animal introductions form a first class of disturbance introduced by man. Unintentional introductions such as the weedy animals and plants are a second. The direct removal of vegetation by agrarian practice and fire is the third. It was originally hoped that each of these could be considered in turn as a chapter after a consideration of the biotic elements themselves as they are known to occur in or affect the Park today. Unfortunately, this cannot be done as the studies of these subjects for the Park are not done and the purpose of this present manuscript is merely to assemble the already published studies.

Finally, incorporated throughout are leads to further information along with tables of data and complete coverage of the Park by means of the aerial photographs and their overlays. To show no consideration for adjacent areas would be most unwise for what happens there influences the Park and vice versa; so this work has not been restricted just to the Park's boundaries. Its purpose is to provide a guide to what is known already so that on-going detailed and thorough bio-ecological studies will be facilitated. This Atlas is merely a stock-taking or inventory that illuminates the gaps in our knowledge.

Suggestions and information and parts of the text of this Atlas have been combed from a large number of people interested directly in the Park or interested in the particular subject matter. Among the principal people who have provided advice abstracted for inclusion in this report are such staff members of the University of Hawaii Botany Department as Drs. Gladys E. Baker, George W. Gillett and Charles H. Lamoureux. Dr. Andrew Berger of the Zoology

Department has provided textual materials and the check list of birds.

A number of people not connected with the University have assisted. Most conspicuous have been Dr. F. R. Fosberg and Mr. Garrett A. Smathers. Dr. Fosberg, then of the U. S. Geological Survey, has given a great deal of assistance with the floristic and vegetation work and prepared the floristic list. Mr. Smathers, formerly Supervisory Park Naturalist, initiated a number of studies that the above people have continued with the assistance of other Park personnel. He is also to be credited for graciously writing various early editions of most of the bird sections of this Atlas and also assisted the project in many other ways. Dr. R. Malcolm Brown, Jr., University of Texas, provided the list of algae from the Aloi hot spot as part of a special study of this place undertaken by several of the above. Climatological records were made available by the Records and Research Division of the U. S. Weather Bureau, by Mr. Toshiichi Hayashi of the Hawaiian Sugar Planters' Association and by Mr. Eugene Horner. Others are credited for their contributions at appropriate places in the text.

The project once begun was ably carried and expanded by the energy of Dr. Mueller-Dombois who is continuing the study beyond this Atlas stage. He has written the chapters on climate, soils and vegetations in addition to his other major contributions as coauthor. It is to him that credit must go particularly for the excellence of the vegetations mapping as at least two months or more of his time was spent field-checking and improving the vegetation overlays and profiles as well as the classification scheme. The chapters and their parts not otherwise credited were compiled, written or exist editorially as they are by the efforts of the undersigned.

It would seem hopeless to express the coauthors' appreciation individually to the many Park Service people who have made this work

possible. I have similar feelings about such constant supporters as Dr. Chester K. and Juliette Wentworth, Dr. James G. Moore, Mr. Howard A. Powers and Dr. Gordon Macdonald who have often given us assistance and contributed various portions of their unpublished information.

Finally, acknowledgment of the support of the Hawaii Natural History Association should be given for without its participation financing this project would have been unlikely.

Maxwell S. Doty

February, 1966.

Part One: The Physical Environment

Chapter I- Geography-Maps and Aerial Photography

Hawaii Volcanoes National Park represents (Fig. 1) the youngest part of the youngest of the United States of America. To the north and arching away over 1500 miles westward lies the rest of Hawaii and the Hawaiian Islands. The island of Hawaii of 4030 square miles is two-thirds of the total land area of the state. Three hundred and forty-four square miles of the youngest part of the island, 220,345 acres near 19° 20' North Latitude and 155° 20' West Longitude, is the Park. It is spread from the shore up over the low dome-shaped tops of two active volcanoes, Mauna Loa (elevation: 13,680 feet) and Kilauea (elevation: 4090 feet). No newcomer to the Park should overlook the account by Macdonald & Hubbard (1965) of the Park's volcanoes and their history.

In this chapter are described the maps and aerial photographs found to have been of the most use to those who have compiled this Atlas of information. These and their sources are described below. The principal maps are those of the U. S. Geological Survey, the U. S. Coast and Geodetic Survey and the different federal and state soil and water agencies. The aerial photographs are largely those of the U. S. Geological Survey and the Agriculture and Soil Stabilization Conservation Service.

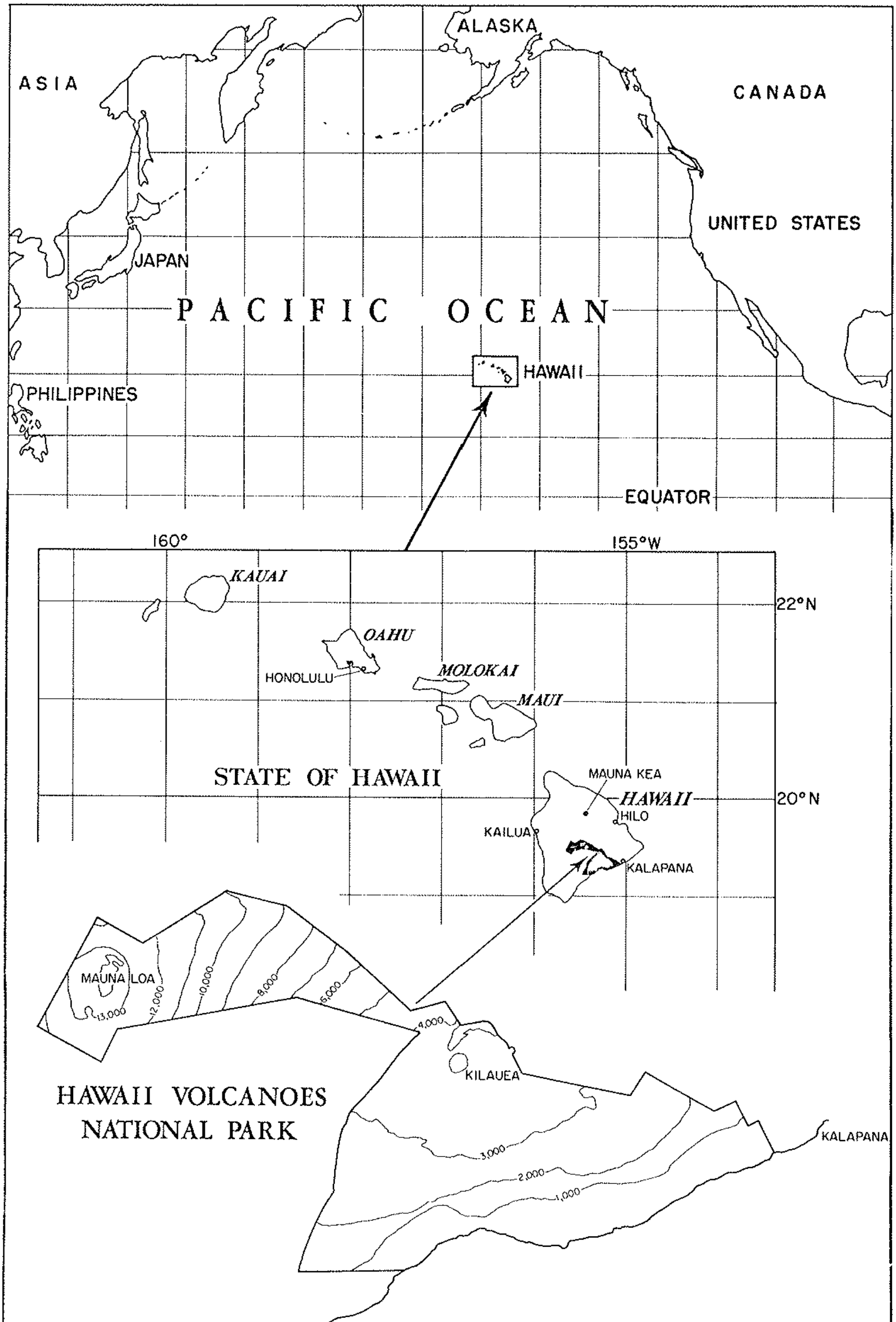


Fig. 1. The location of Hawaii Volcanoes National Park in reference to the State of Hawaii and the Pacific Basin. One degree of longitude or latitude near Hawaii is about sixty miles and the northeast-southwest trending straight boundary of the Park just west of Mauna Loa is 7 miles long. The Kilauea caldera, shown as a rude circle, is about 3 miles in diameter.

A- THE MAPS

The U. S. Geological Survey, a) 345 Middlefield Road, Menlo Park, California, b) 1031 Bartlett Building, 215 West Seventh Street, Los Angeles, California, or c) the Geological Survey, 1028 GSA Building, 19th and F Streets, NW, Washington, D. C., are the sources of most of the maps. Most useful for individual studies are (Fig. 2) the topographic maps. A small scale map is perhaps best put together from the two 1 to 250,000 scale maps NE 5.1 (Hawaii north) and NE 5.5 (Hawaii south); neither has all the Park on it, but NE 5.5 shows all but that on the northern slopes of Mauna Loa. These are obtainable from the above Geological Survey offices or in Honolulu from Trans-Pacific Instrument Company, 1414 Colburn Street, the Honolulu Paper Company, 604 Ala Moana, and in Hilo from the Honolulu Paper Company for $.50 each. The maps can be seen in the library of the University of Hawaii either in Hilo or Honolulu and, of course, at Park Headquarters.

The maps (charts) of the U. S. Coast and Geodetic Survey are indexed in "Catalog of Nautical Charts and Publications, Region 0, Hydrographic Office publication no. 1-N" which, itself, may be purchased for twenty-five cents either from the U. S. Navy Hydrographic Office or from Trans-Pacific Instrument Company, 1414 Colburn Street, Honolulu. Not to be overlooked in working out long distance relationships are the 20-cent plotting sheets such as "H. O. Misc. 9790" showing the whole Pacific north of 50 degrees South Latitude in outline with a 1-degree grid over the oceanic area.
The National Geographic Society, Washington, D. C., published a map of the "Pacific Ocean" drawn in 1952 which is desirable in giving the general location of the State of Hawaii and the Hawaii Volcanoes National Park in the Pacific.

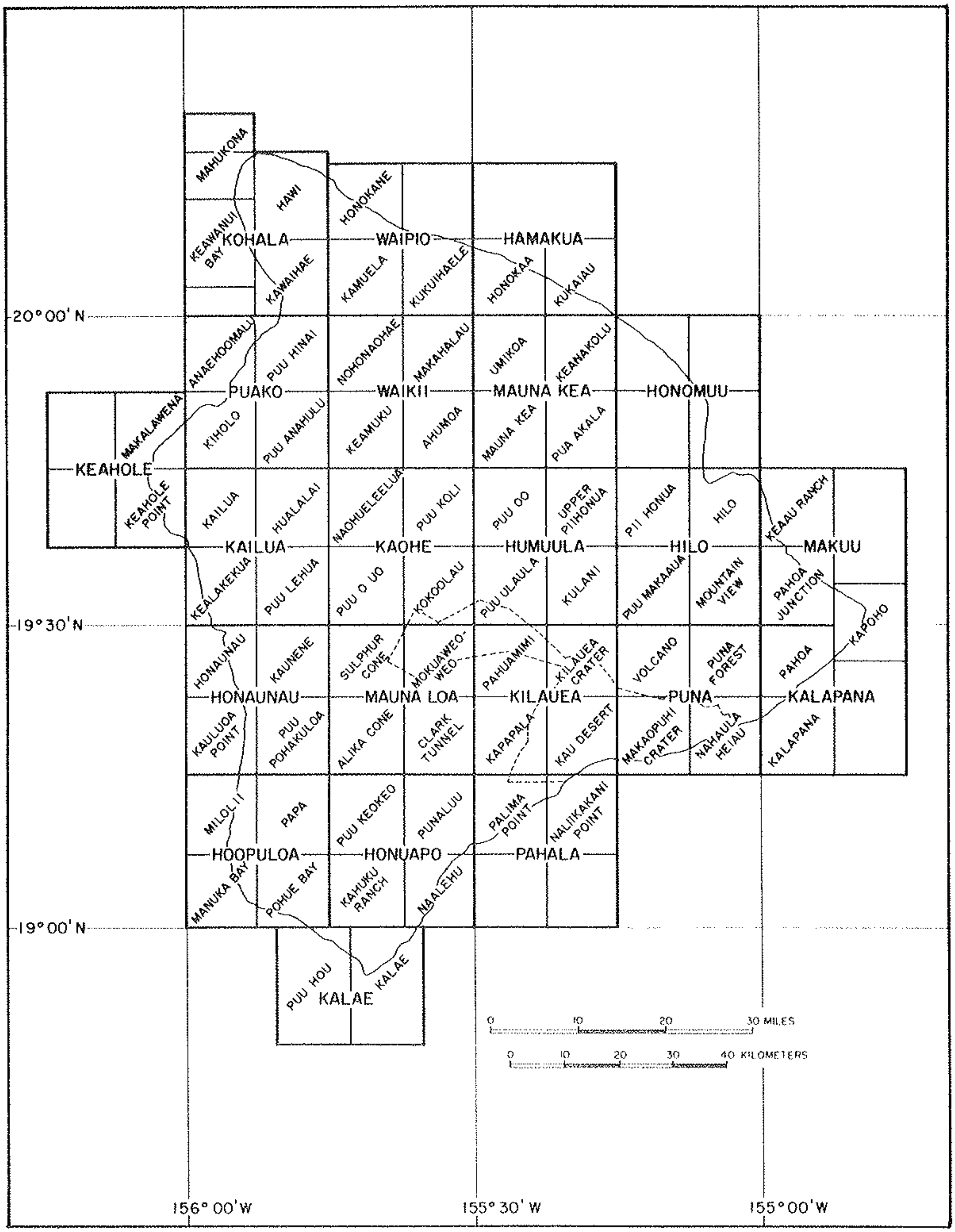


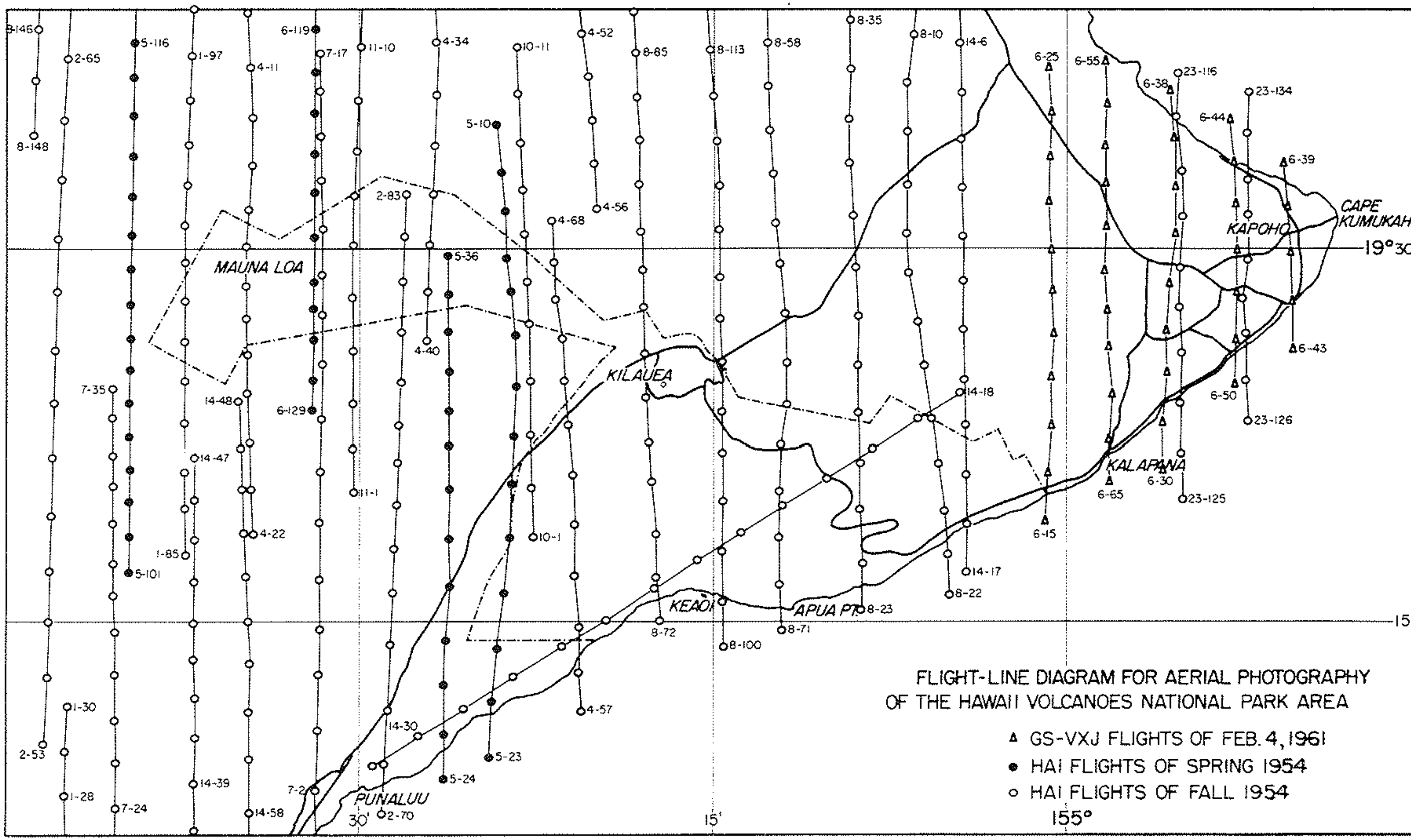
Fig. 2. Index map to the quadrangle topographic sheets.

The large scale topographic sheets are being produced in a new series covering the 7.5-minute quadrangular areas at a scale of 1:24,000 (1 inch = 2000 feet). Some are also available in a shaded relief edition. At present some of the Park area is only available in the older 15-minute quadrangles (scale 1:62,500; 1 inch = 1 mile) but the supply of certain of these is exhausted. The new 7.5-minute maps available at the time of writing to be available soon are indicated on Figure 2 with the name printed diagonally across the area they cover. Inquiries to the above-mentioned sources or to the Map Information Office of the Geological Survey in Washington, D. C., must be made to determine the current availability of either the new 7.5 or the older 15-minute maps, and from these sources the new 7.5-minute quadrangle maps can be purchased for $.30 each.

B- THE AERIAL PHOTOGRAPHS

The aerial photographs from among which a series was selected for the accompanying plates were made during a number of photo reconnaisance flights over the Hawaii Volcanoes National Park area and the island of Hawaii. These are largely indexed in Figures 3 & 4. The selection for this Atlas was made before 1965 when the Agricultural Stabilization and Conservation Service aerial reconnaisance (Fig. 4) was flown. This is an excellent series of photographs and is recommended with the one reservation that the overlays provided for the selection accompanying this Atlas cannot be used with them except with appropriate adjustment for scale and coverage. Directions are given (Table I) for obtaining these.

Fig. 3. Flight line diagram for the aerial photography from the results of which selections were made for this Atlas. Directions for ordering any of these photographs from the U. S. Geological Survey are given in the text.



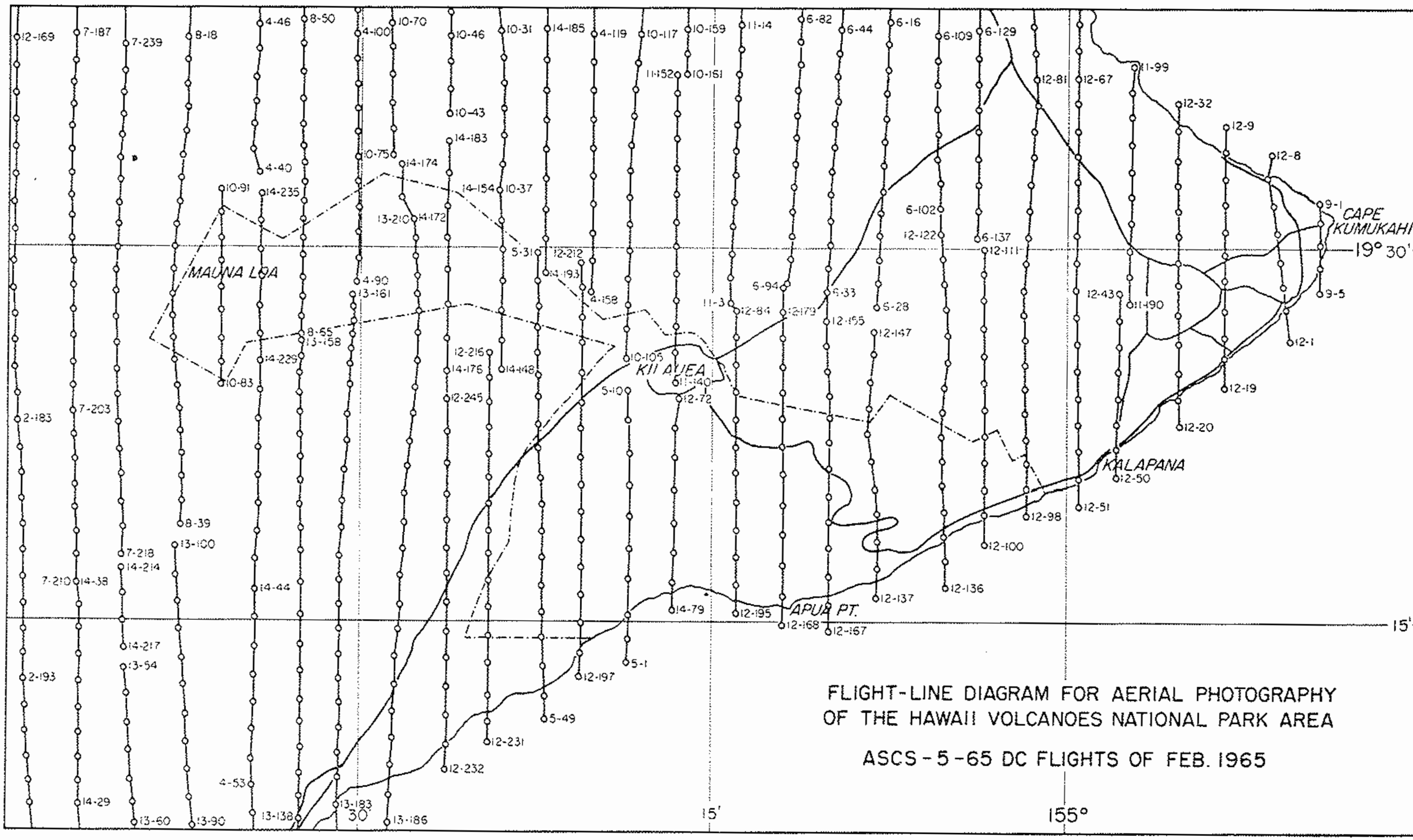


Fig. 4. Flight line diagram of the February 1965 aerial photography done for the Aerial Photography Division of the Agricultural Stabilization and Conservation Service, 2505 Parley's Way, Salt Lake City, Utah. These photographs are currently priced as in Table I.

Table I. The photographs indexed by Figure 4 may be ordered from the Western Laboratory, Aerial Photography Division, Agricultural Stabilization and Conservation Service, U. S. Department of Agriculture, 2505 Parley's Way, Salt Lake City, Utah, according to the following price schedule. A check made out to the Agriculture Stabilization and Conservation Service, U. S. D. A., for the full amount should be forwarded with the order, and for every photograph provide the following information in tabular form: paper size and scale; quantity; symbol; roll number; and exposure number. A complete set of photo indices for the island of Hawaii as 10 rough photo mosaics can be ordered for $13.00.

	Contact Prints		Enlargements				Photo-indexes
Approximate scale →	1 in.=1667 ft.		1 in.=1320 ft.	1 in.=1000 ft.	1 in.=660 ft.	1 in.=440 ft	Usually 1 in.=1 mi.
Print size → in inches	10"x10"		14"x14"	18"x18"	26"x26"	40"x40"	20"x24"
Quantity ↓	Price per print						Price $1.30 per sheet
1-5	1/ $1.00	2/ $1.50	$2.00	$2.20	$2.60	$5.60	(10 required for whole island).
6-100	.85	1.30	1.70	1.90	2.30	4.70	
Over 100	.65	1.15	1.50	1.70	2.10	4.00	(Unless specified, indexes printed on single weight semi-matte stock).
County coverage	.60	-	1.25	1.45	1.85	3.40	

1/ Double weight semi-matte

2/ Polyester base

Since the major flights were different years, 1954, 1961 and 1965, one is provided with some opportunities to study the changes wrought by time and the recent periods of volcanic activity. Especially interesting is the opportunity provided by infra-red photography (Fischer, et al., 1964) and the fact that about one month after the completion of the 1965 aerial photo series (Fig. 4) the March, 1965, eruption (Fig. 5) took place.

The aerial photographs indexed by Figure 3 provided the selection reproduced with this manuscript. This selection is indexed in Figure 6 and listed in some detail in Table II to facilitate their being ordered from the U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California. Table III provides a resume of the prices for such aerial photographs ordered from the offices of the Geological Survey. A check or money order for the full amount made out to the U. S. Geological Survey should accompany any order. For each photo ordered, indicate the roll number and the photo number. For example, for that shown in the index as "1-0090" the roll number is "1" and the photo number is "90" or "0090". Also the flight must be named, e.g., as HAI Spring 1954, HAI Fall 1954, or GS-VXJ 1961.

These aerial photographs enumerated in Table II are not suitable for making a good photo-mosaic for they are not flown from a geometric plane parallel to the surface photographed. For this same reason in the selection reproduced here the margins, even of the polygonal areas selected, do no quite match as a rule. A reasonable photo-mosaic can be prepared for small areas if every photo in the series is used. In the present work, for reasons of economy, only alternate photos were selected.

The dots, circles and diamonds on the flight line diagrams (Figs. 3 & 4) indicate the centers of every photograph. Since each photograph is

Fig. 5. Map of the 1965 lava extruded onto the surface within and just to the east of the Park as adapted from a preliminary sketch prepared by Dr. James Moore of the U. S. Geological Survey. Aerial photographs covering this area (Fig. 6) are indicated on this figure, but others for the area may be selected from inspection of Figures 3 and 4.

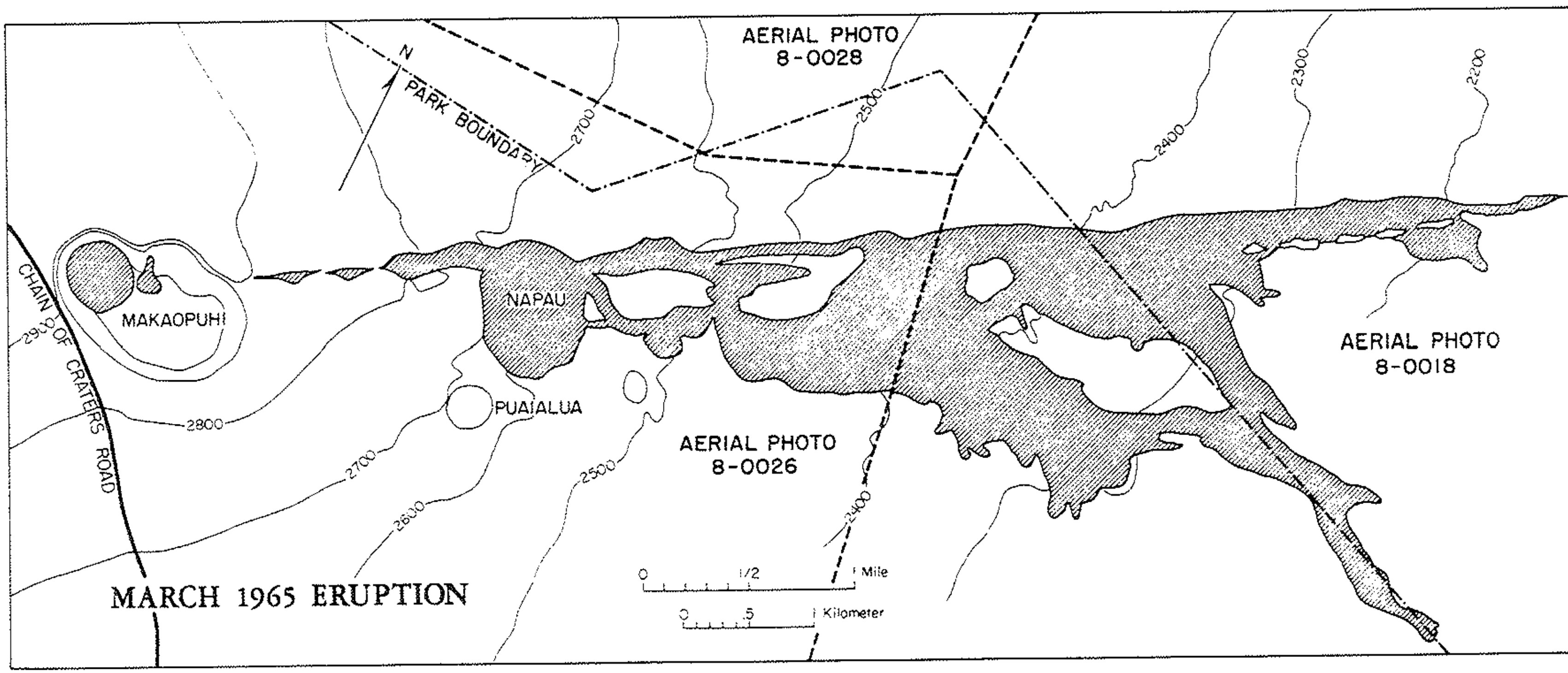


Table II. List of aerial photographs selected for production of this Atlas and for which vegetation and topographic overlays were prepared. Directions for obtaining these are given in the text.

GS-VXJ 1961-	6-16	HAI-Spring '54	5-0012	HAI-Fall '54	8-0062
HAI-Fall '54	1-0090		5-0014		8-0064
	1-0092		5-0016		8-0066
	1-0094		5-0018		8-0068
	2-0081		5-0020		8-0070
	4-0015		5-0022		8-0073
			5-0027		8-0075
	4-0017		5-0035		8-0077
	4-0019		6-0124		8-0079
	4-0036		6-0126		8-0081
	4-0038		6-0128		8-0102
	4-0058	HAI-Fall '54	7-0014		8-0104
	4-0060		8-0018		8-0106
	4-0062		8-0020		8-0108
	4-0064		8-0024		8-0110
	4-0066		8-0026		11-0005
	4-0068		8-0028		11-0007
			8-0030		14-0014
					14-0016

Table III. Resume of types of aerial photography and the prices for photographic reproductions obtainable from the U. S. Geological Survey. Photo indices are available from some areas, but inquiry should be made of the survey before ordering them.

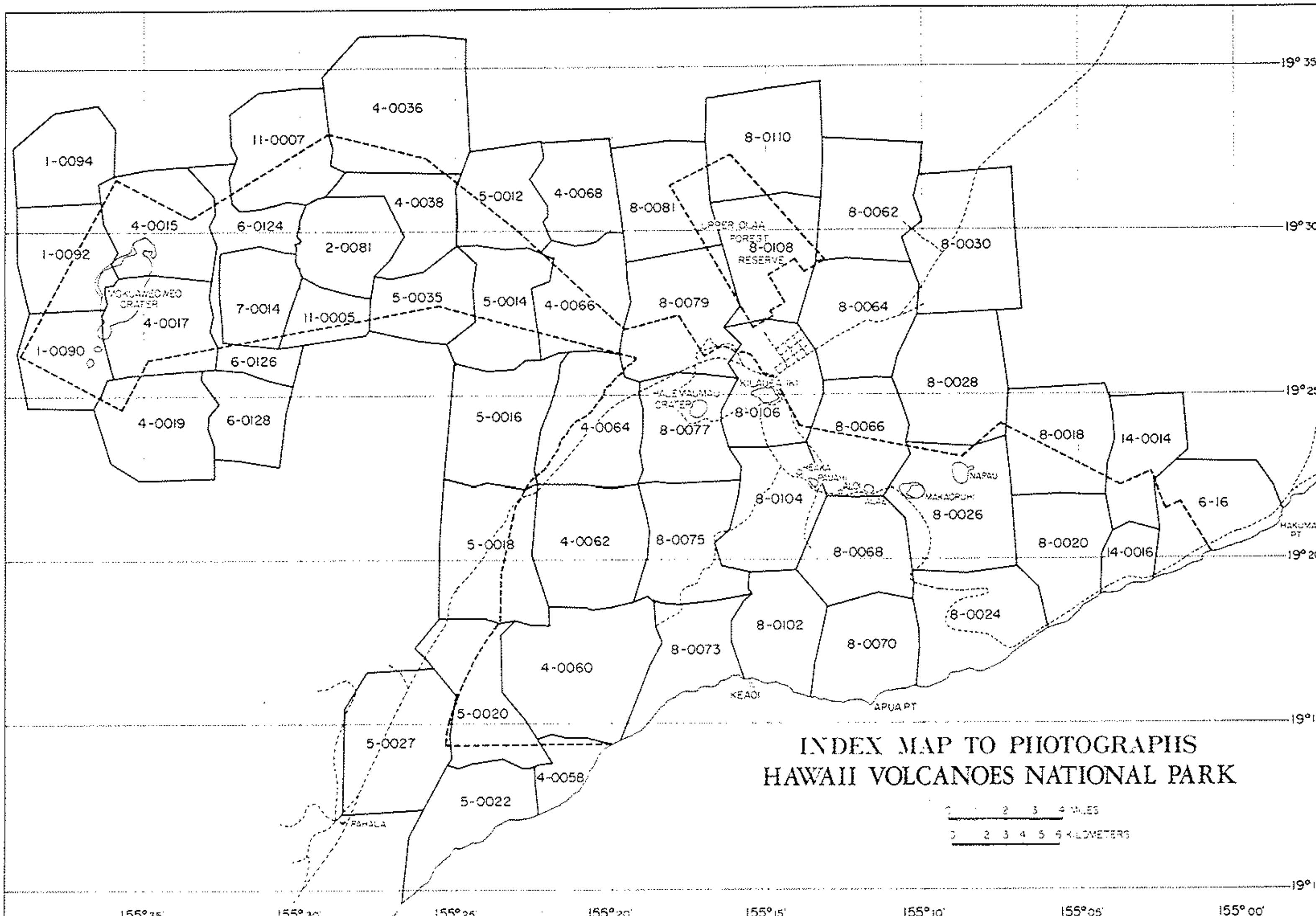
	1 to 5 each	6 to 100 each	101 to 1000 each	Over 1000 each
Contact prints (9 x 9 in.)	$1.00	$0.85	$0.65	$0.60
Enlargements				
Magnification:				
1.5X (14 x 14 in.)	2.00	1.70	1.50	1.50
2X (18 x 18 in.)	2.20	1.90	1.70	1.70
3X (27 x 27 in.)	2.60	2.30	2.10	2.10
4X (36 x 36 in.)	5.60	4.70	4.00	4.00
Transformed prints from either convergent or transverse low-oblique photographs	2.50	2.00	1.75	1.75
Film positives contact printed from aerial negatives	2.50	2.50	2.00	2.00
Multiplex diapositives—reductions on glass, 64 x 64 mm	3.00	3.00	2.50	2.50
Kelsh plates—contact prints on glass. Specify thickness (0.25 or 0.06 inch) and method of printing (emulsion to emulsion or through film base)	5.50	5.00	4.50	4.50
ER-55 plates—reductions on glass, 11 x 11 cm	4.00	3.50	3.25	3.25

square, this allows one to judge the coverage of a given photograph for it will cover almost all the flight line between the centers of the previous and following photographs. A person interested in a particular area should try to obtain a photograph with that area in its center. For example, the photograph from the Fall HAI-flight, roll 8, number 78, is much better in this way for Kipuka Puaulu, the Bird Park, than are those used for this Atlas.

The photographs irregularly numbered in Table II have each had a topographic overlay and a vegetational overlay prepared for them. Figure 6 is a mosaic of the contiguous polygonal areas selected on the individual photographs to provide aerial photocoverage of the Park for the purposes of this Atlas. The chapter on vegetations, below, discusses what is to be found on the vegetation overlays. The topographic overlays were prepared by projection methods, largely by Mr. Edward J. Zubal, as was the original selection of polygonal areas from the aerial photographs.

The rough draft preparation of the vegetation overlays was done by Dr. F. R. Fosberg and insofar as possible these were field-checked by Dr. Dieter Mueller-Dombois during the summer of 1965. From information obtained during the field-checking process, Dr. Mueller-Dombois modified the original vegetational overlays as appropriate and prepared the chapter on Vegetation Mapping, below. Table I, Chapter VIII, below, presents an alphabetical list of the mapping symbols used. The contour lines on the topographic overlays are at 100-foot intervals. On each overlay there is marked not only indicators for the principal corners of the polygons but also the center of the area. The linear scales provided are thought to be most accurate for the centers of each respective area, but where there is considerable topographic relief the scale may be somewhat inappropriate

Fig. 6. Index map to contiguou olygonal areas on the aerial photographs included in this Atlas. With each aerial photography, recognized by the number composed of the roll and exposure numbers, is a vegetation and a topographic overlay. The flight line diagram indicating the centers for all photographs from which these were selected appears as Figure 3.



for a great deal of the particular polygon.

Inquiries should be directed to the Superintendent, Hawaii Volcanoes National Park, Hawaii, for information relative to obtaining copies of the vegetational or topographic overlays.

Chapter II- Geology

Mauna Loa, extending from about 20,000 feet below sea level to 13,680 feet above, is one of the world's greatest mountains. To study the impressive geology of this area, through the efforts of T. A. Jagger, the Hawaii Volcano Observatory began functioning with the completion of the first laboratory building in 1912. The present building was constructed in 1942. However, since 1909 under the auspices of the Massachusetts Institute of Technology detailed observations had been made and records kept by Jagger.

The third number of volume 19 of the periodical "Pacific Science" published by the University of Hawaii Press is a special issue concerning the geophysics of the Hawaiian Islands and adjacent areas. This contains a large amount of information on such subjects as the theoretical structure of the islands, Kilauea caldera, the rift zones, and geochemical studies of the rocks.

The island of Hawaii is actually a coalescence of five separate mountains that were perhaps first constructed during a flush of volcanic activity in the Tertiary period. In the general area of the Park this period was closed by the Ninole volcanic series toward the end of the Pliocene, and this was followed by a long period of erosion. None of the Park surface is (Stearns & Macdonald, 1946: 101) Pliocene, that is, of the older Ninole material.

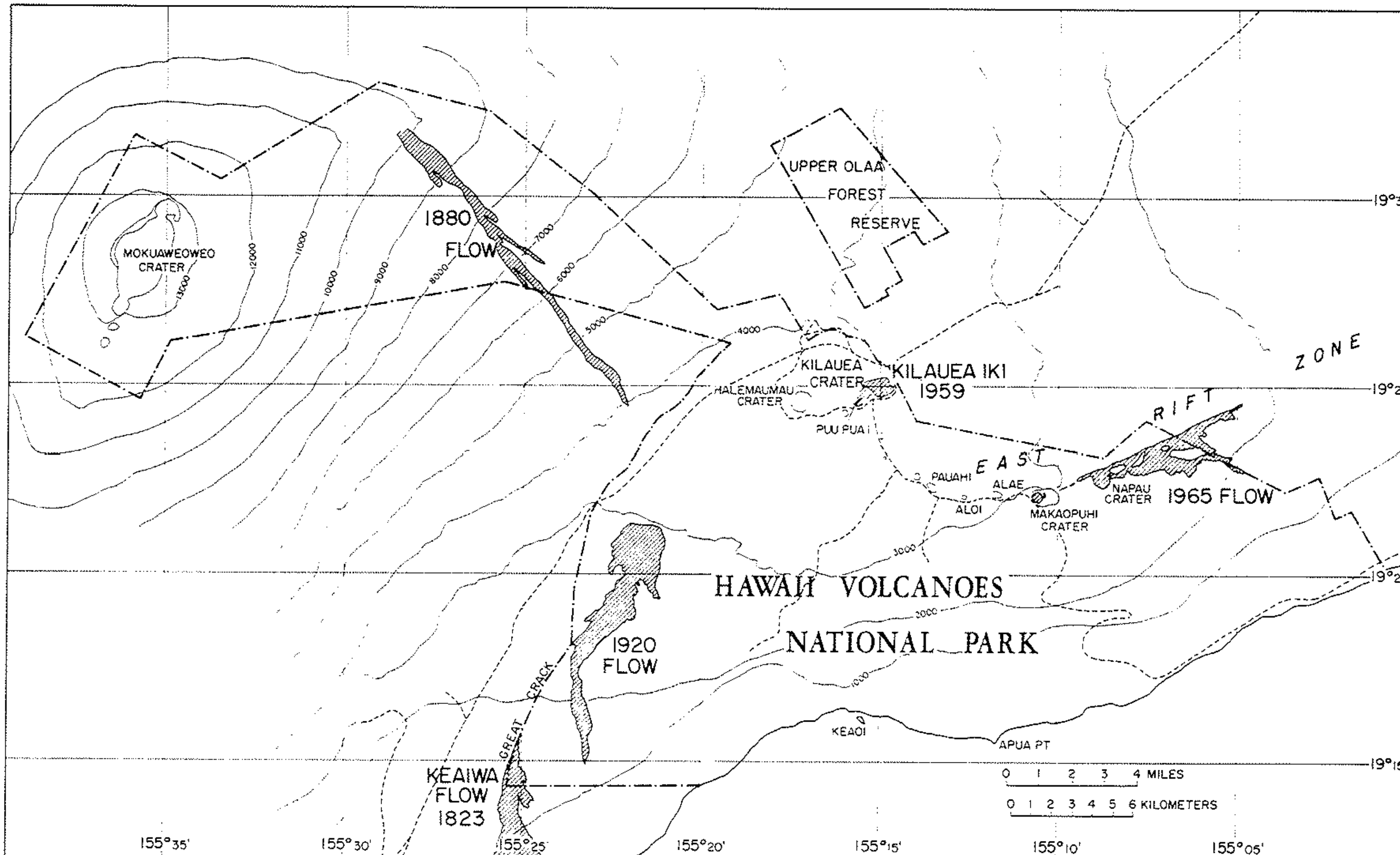
Kilauea probably was not in existence or was but a minor feature in the Pliocene. The likelihood that the Ninole lavas exposed at about the 3000 foot level near Pahala, southwest of the Park, are (Stearns & Macdonald, 1964: 102) the remnants of ridges between deeply eroded and large valleys terminating in sea-cut cliffs argues for this. Had Kilauea been of some size this area would have been in its rain shadow and Kilauea's southerly flows would have prevented the sea from cutting cliffs in the Ninole formation.

The topography and surfaces of principal concern to the biologist and other visitors to the Park are the results of renewed volcanic activity in the Quaternary, the very latest Pliocene or early Pleistocene. The principal features of the Park (Fig. 7) were formed as layer after layer of the earth's magma was extruded from the volcanic vents and solidified as it flowed toward the sea. Kilauea perhaps arose as a lateral rift from Mauna Loa intersecting the main eastward rift of the Hawaiian Islands on which Kohala and Mauna Kea are constructed. On the other hand, the trend of the shore northeast from South Point to Punaluu and the continuing fault series (Honuapo and Kaoiki systems) directed toward the saddle between Kilauea and Mauna Loa and represented in part by the southwest Kilauea rift zone may indicate a major faulting that disrupted this same major rift. Of course, both may have been involved.

In this early Pleistocene period Mauna Loa and Kilauea both grew by successive outpourings of the pyroclastics and lavas of, respectively, the Kahuku and Hilina series. These basalt flows are of the same age. In the Park the Hilina series is seen (Stearns & Macdonald, 1946: Plate 1) only in the great Hilina and Kapukapu fault series near the shore south of Kilauea caldera. There are large exposures of the Kahuka flows both east (the land between Glenwood and Mountain View) and west of the Park, but in the Park they are exposed only as islands (kipukas) in the still younger flows near the 4250 to 4750 foot elevations northwest of the caldera of Kilauea. There are a numberof minor exposures of this series along the highway to Kona southwest of the Park.

Pahala ash overlays the Hilina and Kahuku flow series in series of layers up to about 40 feet thick. It is usually yellowish and glassy in nature and is thought to have been derived from a good many sources during

Fig. 7. Hawaii Volcanoes National Park drawn to show the prominent geological features and the locations of the principal access roads. These latter show as broken lines. Puu Pua'i is the southwestern protrusion extending from the lines indicating Kilauea Iki Crater. Cross-hatching indicates the location of the historically recorded lavas on the surface with the exception of those within the caldera of Kilauea, itself, and at the top of Mauna Loa.

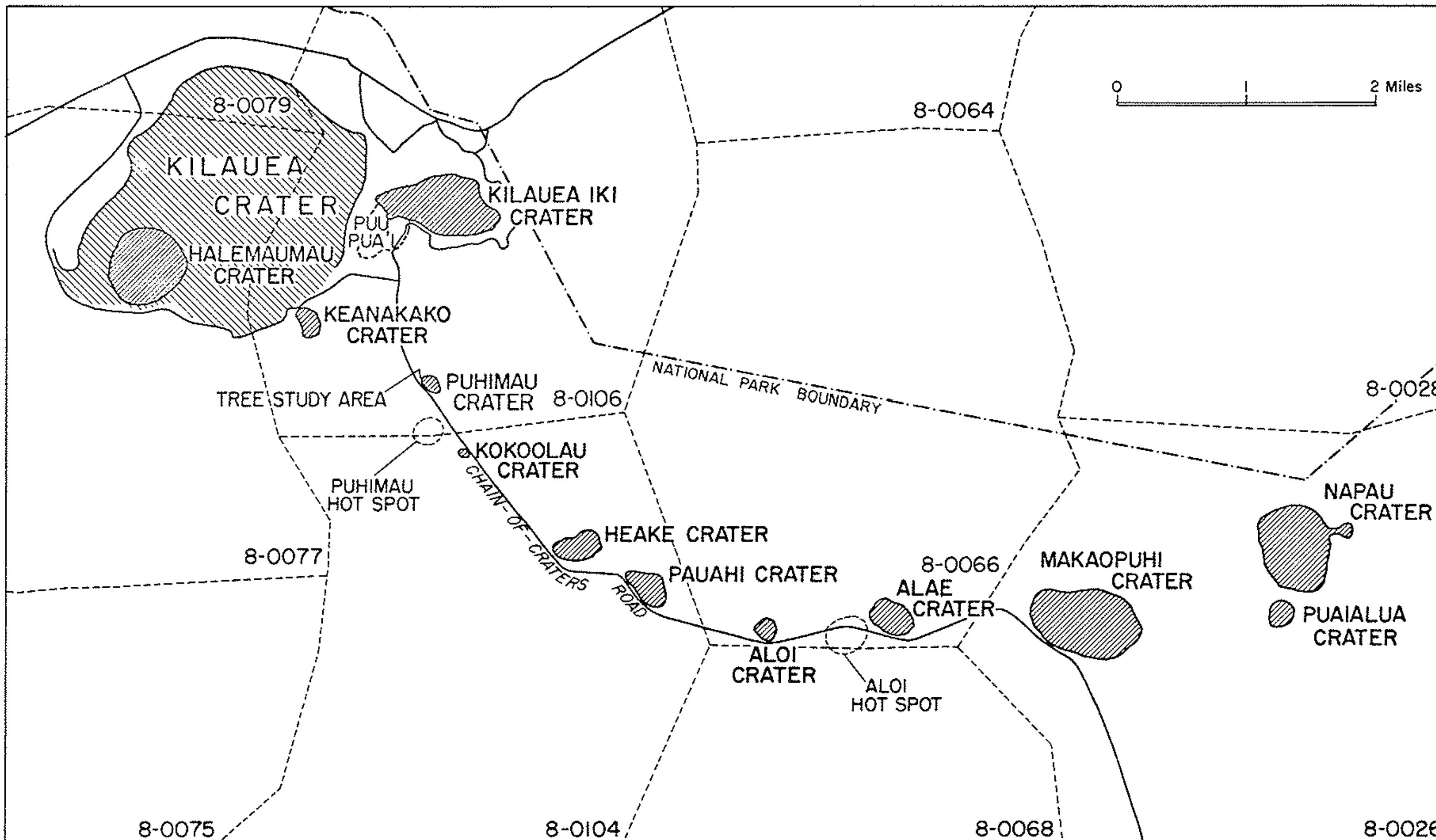


late mid- or early-late Pleistocene. In the Park the most noteable source was (Stearns & Macdonald, 1946: 72) Kilauea as indicated by its layers being much thicker downwind from the main vents. While originally largely yellowish glassy sand or dust, it is altered in differing degrees depending largely on the amount of moisture. In dry areas the color is often greyish. In wetter areas it is yellowish to reddish or even blackened with humus, and it may be a fine-grained palagonite clay and almost non-granular. As such it is a frequent contributor to kipuka soils probably where it formerly capped mounds of one sort or another of Hilina material so that the more recent flows passed along its sides.

The stony present day surfaces of the Park are the prehistoric and historic lavas of the Kau and Puna volcanic series distinguished in respect to their sources, respectively, Mauna Loa or Kilauea and overlaying the Pahala ash. The prehistoric or late Pleistocene lavas are mostly brownish olivinaceous or picritic basalts. The historic flows are usually of black basalt rock. The historic lavas of significant extent in the Park are from rift zones, except quite near the top of Mauna Loa. Macdonald & Hubbard (1965) describe them nicely in a booklet obtainable from Park Headquarters for $1.00. Indeed, lava flows have appeared in the craters (Fig. 8) recently, but out on the surface of the mountain they are actually small in area and have added little other than admirable sights for Park visitors and sites for scientific work.

It seems that Kilauea has moved into a mature phase of activity with the development of a caldera around its major vent. To a lesser extent this may be happening to Mauna Loa too. Thus, the tip of Kilauea is surmounted not truly by a crater but in its place there is a round collapsed area, a caldera, 4 to 5 kilometers across within which is

Fig. 8. The craters of the Chain-of-Craters area. The aerial photographs for this area are indicated by the dashed lines and the numbers in the lower right corner of each polygonal area. Much of the area near Napau Crater has been covered by the March, 1965, lava flow (See Fig. 5).



Halemaumau, an active pit crater or shaft leading to the magma below. The caldera floor is about 400 feet below the general dome level on the northwest side. It is but scarcely depressed to the southeast.

While molten lava fills Halemaumau and even overflows into the principal area of the caldera, there is no historic record of lava spilling over the edge of the Kilauea caldera. However, lava fountains from the caldera walls of Halemaumau and explosive eruptions have strewn the prehistoric surfaces around the caldera for a distance of one or two kilometers with a rather complete cover of ash and rocks of various sizes. Near the volcano observatory 6 humus-rich layers separated by ash have been found (Stearns & Clarke, 1930), at least some of them containing (Stone, 1926) plant fossils.

Previous to 1965 there were (Fig. 7) but three major historic flows within the Park. Like all the rest of the surface of the Park these too are basaltic. Two, those of 1823 near the shore and 1920 nearer the caldera, are along the great crack region of the Kau Desert. The 1823 flow, south of the "footprints area" and along "the great crack" is erroneously labeled 1868 (fide Stone, 1926) on older maps and is largely outside the Park. Ellis (1825) discusses this 1823, Keaiwa flow. The third is the 1880 flow from the northeast rift zone of Mauna Loa. Prof. Gordon Macdonald (personal communication) believes this flow was over, insofar as the Kau branch was concerned, in November, 1880. This flow descends (Fig. 7) southwesterly as a stream across the Park from the 10,000 to the 6000 foot levels and on out of the Park to about the 4000 foot elevation.

Several minor periods of volcanic activity have been recorded, but aside from the 1840 flow to the east of the Park, they seem to have been insignificant in the production of solid materials outside the craters. The explosive eruptions of 1790 and 1924 have been much discussed and produced a great deal of the unconsolidated material in the Kau Desert and around the caldera of Kilauea. Wentworth (1957) describes some of the surface features caused by the ejecta from these two eruptions. The top of Mauna Loa has experienced various eruptive influences in historical times, but they are above the limit of conspicuous biological activity and are bypassed here. Figure 9, extended from the similar figure of Stearns & Macdonald (1946) and Macdonald (1949), records many of these events.

It is accepted as common knowledge that the flank flows, the flows of great biological interest, are usually related to an immediately previous summit eruption. Since most of the flank flows have been outside the Park, little attention is given to them here. However, it is hoped that they will not be overlooked for in many cases the results of their study provide the body of information that must be used at present in interpreting ecological phenomena within the less-biologically studied Park itself. Some, like the 1886 report of an eruption 500 miles southeast of Hawaii, may mean new separate islands will appear in the Hawaiian chain in the future.

After 18 years of inactivity Kilauea erupted on June 27, 1952, and remained active for 136 days. All the activity was confined (Macdonald, 1955) to the crater, Halemaumau. No flank eruption is known to have accompanied this flow.

On May 31, 1954, there was a 4-day period of activity in Halemaumau (Macdonald & Eaton, 1957), but none of this particular eruption affected the area outside the crater. It was, however, but the prelude to the flank activity which followed.

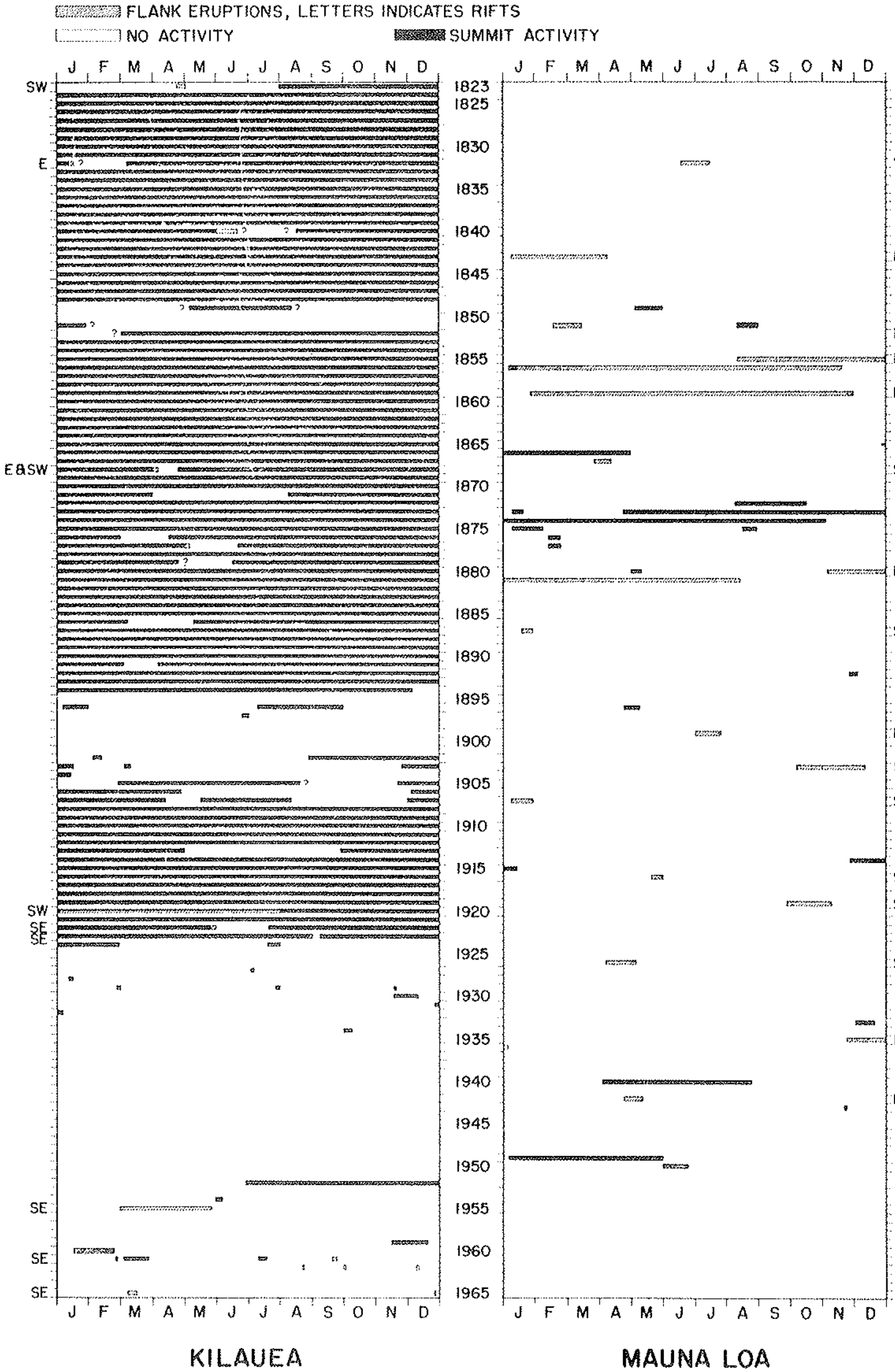


Fig. 9. The volcanic activity of Mauna Loa and Kilauea. The initials along the left and right margins indicate the general directions toward which the rifts extend from the main craters of these two volcanoes. This figure is an independent extension of one produced by Dr. Gordon Macdonald and published variously (*e.g.*, *in* Stearns & Macdonald, 1946).

Entirely outside the Park the east rift (Fig. 7) erupted in 1955 and the lavas covered extensive areas of rock, forest and farm land. Macdonald & Eaton (1955) have published a description of this flow and there are various other studies of this flow in manuscript and in the literature. See the chapter on vegetation, below, for a description of the more biological aspects.

The most exciting outburst in the Park was that of November 14, 1959, when a rift in the wall of the ancient pit crater, Kilauea Iki, (Fig. 10) spewed lava into the crater from a lava fountain which at one time reached a height of 1900 feet. This lava fountain was probably the highest recorded by man. The outburst received considerable attention in the public press which ran many striking photographs of the activity (e.g., Zahl, 1959). Confined to the crater of Kilauea Iki little remains to be seen outside this crater in the Park now. A lot of red hot ash fell, covering (Fig. 10) an area about four-fifths of a mile wide and two and one-half miles long to a depth of one inch or more. This red hot ash fall resulted in the devastation of a sizeable vegetated area as well as in the production of a new ash cone. This latter has been named Puu Pua'i. The biological effects of this eruption are discussed with the chapter on vegetation.

Richter & Eaton (1960) describe in some detail both phases of this eruption that poured 11 x 10^6 cubic yards into the pit, Kilauea Iki, forming a lake at one time 414 feet deep. Actually, the principal activity of this eruption was later and outside the Park at the eastern tip of the island where about 156 x 10^6 cubic yards of lava covered about 2500 acres. Of this, perhaps 500 acres was area newly added to the southeast end of the island above sea level. This latter phase, entirely outside the Park, began

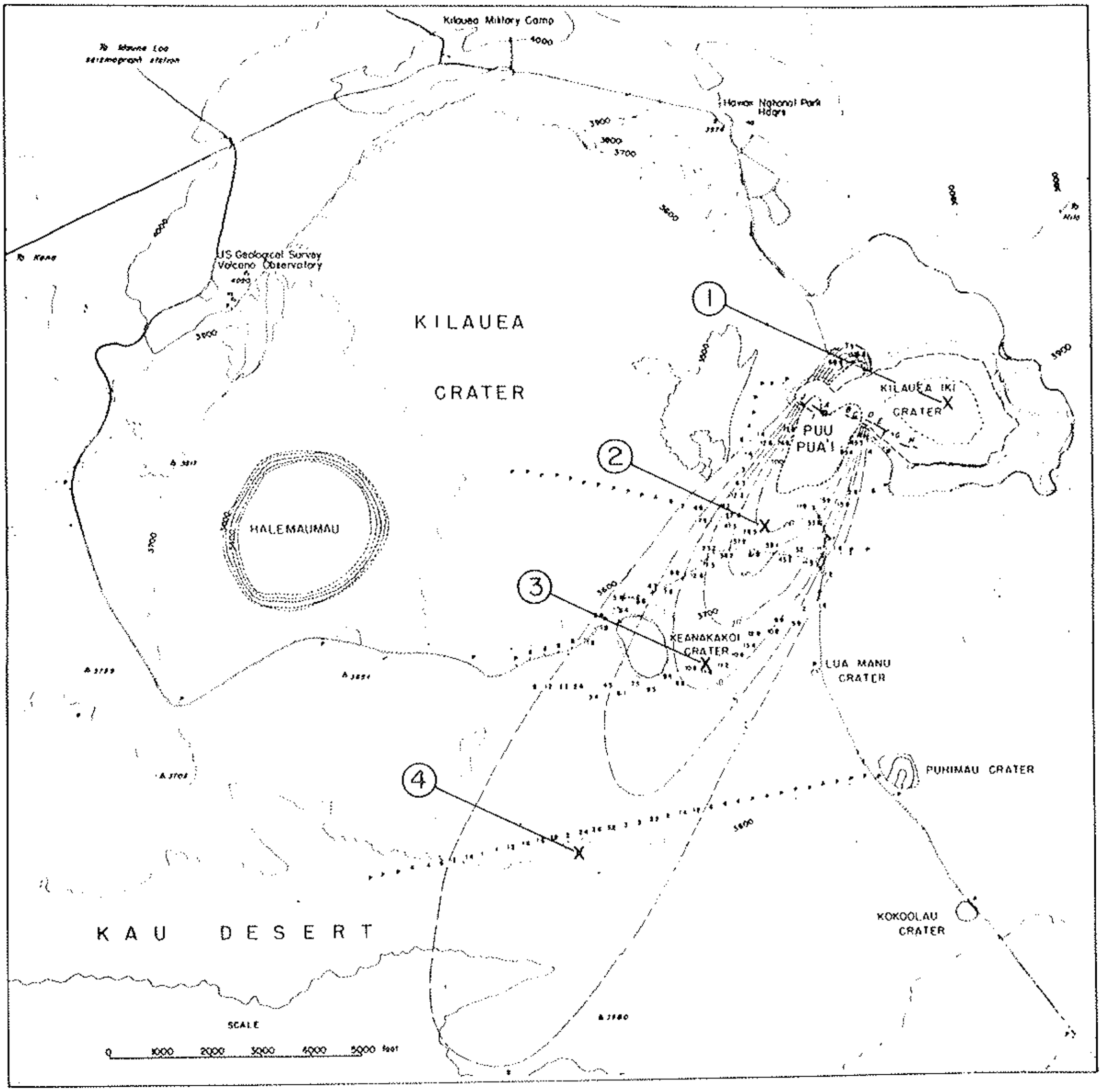


Fig. 10. The Kilauea caldera area showing in particular the ash-fall extending southwestward from the cinder cone formed in 1959 along with the cinder cone, Puu Pua'i. The places indicated by encircled numbers at the ends of arrows are the locations of weather stations specially maintained to assist in interpreting the biological recovery and the succession following this event. The numbers in straight lines are the depths of the ash in feet.

December 21, 1959, and lasted until February 20, 1960. The flow from this phase which destroyed the village of Kapoho began January 14, 1960.

In February, March and July of 1961 Kilauea again erupted with lava being extruded into Halemaumau Crater. However, a considerable amount of ash was thrown out and this generally drifted down onto the area within two miles southwest of the caldera. This ash fall (Richter, et al., 1964) is as much as two feet thick near the crater. In September of 1961 a series of flank eruptions took place with several small lava flows being formed. Table I gives the chemical composition of two samples from this eruption, but they are not biologically of concern for they were covered by the 1965 flow described below. Richter, et al., (1964) describe in considerable detail other geological events as well as the petrography and chemistry of this eruptive series, with maps, photos and a few comments on bio-ecological effects.

In February, 1965, an outbreak of lava appeared from the east rift (Fig. 5 & 8) filling Makaopuhi Crater to a depth of over 900 feet. Further down the east rift the lava covered the floor of Napau Crater. This flow completely covered the minor flow of lava that appeared in the summer of 1961. Actually, this 1965 flow appeared during the terminal phases of preparation of this Atlas and, though studies on it were initiated a day or two after activity ceased, while magma was actively draining back into the main vent of Makaopuhi Crater, none of the results is reported here.

As noted above all the flows affecting the Park are basaltic. Their petrography is (Macdonald, 1949; Richter, et al., 1964, etc.) rather well known. In general the lava series from Kilauea are more uniformly olivine basalt (Table I) than those from the other volcanoes nearby, and thus they are thought to represent more closely the parent magma from deep within

Table I. Chemical analyses of volcanic rock from Mauna Loa and Kilauea. After Macdonald, 1946.

Chemical constituents	Mauna Loa			Kilauea					
	Prehistoric		Historic	Prehistoric		Historic			
	Ninole	Kau	Kau	Puna	Puna	1923	1923	1961	1961
	1 a/	2 a/	3 a/	4 a/	5 a/	6 a/	7 a/	8 b/	9 b/
SiO_2	48.60	50.41	52.30	50.03	51.35	49.33	49.42	50.26	50.22
Al_2O_3	10.75	12.37	11.84	12.10	13.36	11.57	11.83	13.87	13.28
Fe_2O_3	3.92	1.94	2.06	2.10	1.32	2.31	3.83	2.94	1.69
FeO	9.38	9.56	9.03	9.97	9.85	9.48	8.08	8.62	9.70
MgO	9.80	7.68	7.15	9.57	7.62	12.41	12.04	6.75	8.44
CaO	10.38	12.56	10.60	10.58	10.74	9.14	9.28	10.88	10.28
Na_2O	2.54	1.68	2.47	2.01	1.93	2.20	2.35	2.45	2.39
K_2O	0.34	0.40	0.49	0.44	0.50	0.44	0.59	0.59	0.59
H_2O+	0.22	0.22	0.15	0.32	0.29	0.11	0.16	0.02	0.06
H_2O-	0.06	none	0.03	0.16	none	0.01	0.02	0.02	0.01
TiO_2	3.37	2.26	3.98	2.57	2.50	2.85	2.42	3.04	2.92
P_2O_5	0.18	0.57	0.28	0.21	0.28	0.37	0.39	0.30	0.26
MnO	0.05	0.06	0.10	0.16	0.07	0.14	0.14	0.18	0.18
CO_2	none	n.d.	n.d.					0.05	0.02
Cr_2O_3	n.d.	0.05	n.d.	n.d.	0.03	0.08	0.13		
NiO	n.d.	0.004	n.d.	n.d.	0.025				
S				n.d.	n.d.	0.03	0.01		
BaO				n.d.	n.d.	0.02	0.04		
SrO				n.d.	n.d.				
ZrO_2				n.d.	n.d.				
Cl				n.d.	n.d.	0.03	0.02	0.02	0.01
F								0.04	0.04

a/ From Stearns & Macdonald, 1926
b/ From Richter, *et al*., 1964

Table I (continued)

1. Olivine basalt, Kaumaikeohu Spring, Kau District. R.K. Bailey, analyst. Washington, H.S., Petrology of the Hawaiian Islands; II. Hualalai and Mauna Loa: Am. Jour. Sci., 5th ser., vol. 6, p. 122, 1923.

2. Olivine basalt, on Volcano highway at southern boundary of Waiakea Forest Reserve, 1.65 miles northwest of the mill at Olaa, J. J. Fahey, analyst. Powers, H. A., Chemical analyses of Kilauea lavas: Volcano Letter no. 362, p. 2, Dec. 3, 1931.

3. Olivine basalt, lava flow of 1919. H. S. Washington, analyst. Washington, H. S., Petrology of the Hawaiian Islands; II. Hualalai and Mauna Loa: Am. Jour. Sci., 5th ser., vol. 6, p. 113, 1923.

4. Olivine basalt, fragment from wall of conduit ejected during explosions of 1790, collected near Uwekahuna. G. Steiger, analyst. Cross, Whitman, Lavas of Hawaii and their relations: U. S. Geol. Survey Prof. Paper 88, p. 48, 1915.

5. Olivine basalt, National Park quarry on highway 0.75 mile northeast of Volcano Observatory. J. J. Fahey, analyst. Powers, H. A., Chemical analyses of Kilauea lavas: Volcano Letter no. 362, p. 2, Dec. 31, 1931.

6. Olivine basalt, lava of 1923, pahoehoe phase, near Makaopuhi Crater. E. S. Shepherd, analyst. Shepherd, E. S., The gases in rocks and some related problems: Am. Jour. Sci., 5th ser., vol. 35-A, p. 335, 1938.

7. Olivine basalt, lava of 1923, a'a phase, near Makaopuhi Crater. E. S. Shepherd, analyst. Idem. p. 335.

8. Tholeiitic basalt erupted Sept. 22, 1961, Kilauea east rift zone, 9 miles from summit (lava flow one half mile northeast of Napau Crater).

9. Tholeiitic olivine basalt erupted September 23, 1961, Kilauea east rift zone, 19 miles from summit (Jonika lava flow).

the earth. The Ninole series is largely olivine basalt. The Kahuku and Kau flows from Mauna Loa have still more basalt and picrite-basalt or, even, hypersthene-basalt in them and are thus thought to be derived from magma that has stood above the general body long enough for this differentiation to have taken place. This can be interpreted as evidence that Kilauea is both younger than Mauna Loa and is a separate vent extending many, e.g., 35, miles into the earth. It can similarly be said that the differentiation in the Mauna Loa magma has gone on since the Ninole flows were produced.

An interesting idea was brought forth by Macdonald (1944) as a result of his studying the petrography of the 1840 flow that issued from the east rift zone of Kilauea. He observed that the lava from the vents at about 2600 feet elevation had little olivine in them. Those that issued a day later at the 750 to 800 foot levels contained as much as 30 per cent olivine. He interpreted these two flows to have tapped upper and lower parts of the liquid magma and that the difference in composition represented the degree of settling of the olivine crystals in it. That such differentiation takes place has been studied in some detail more recently by others (summarized and extended by Richter, et al., 1964), who have been able to make similar observations consistently on other flows.

Occasional flows with anomalous compositions have been found in the geological columns examined; e.g., in the 446 foot column in the Kilauea caldera wall examined by Macdonald (in Stearns & Macdonald, 1946) a picrite-basalt flow with 35 per cent olivine phenocrysts was found. Possibly the degree of differentiation observed in the anomalous flows represents the time the magmas were held near the surface previous to being extruded onto the surface.

Petrographically Macdonald has analyzed (in Stearns & Macdonald, 1946) the flows in the Kau series in the 410 foot column provided in the crater of Mauna Loa and a 763 foot column in the Hilina series of Kilauea as well as others. Finch & Fagerlund (in Stearns & Macdonald, 1946) studied a 32 foot Pahala ash column and Finch (1942a) as well as Richter, et al., (1964) studied the breccia and other explosive clastic materials near the Kilauea caldera. These latter are largely from the 1790 and 1924 explosive eruptions mentioned above.

Chemical analyses have been made (Stearns & Macdonald, 1946; Macdonald, 1949; Richter, et al., 1964, etc.) of many of the individual flows. While particularly abundant in reference to surface materials, these analyses have included samples from all the principal rock types and volcanic series of which the island of Hawaii is composed. Table I presents a selection of these results for they are so much of the "soil" from which the biotic elements derive the mineral part of their substance.

The influence of water on the lava materials is a large factor in hastening the soil formation sequence, as is temperature. This has been mentioned above in reference to the Pahala ash. It is of interest here to consider some of the changes that are correlated with these factors. The principal changes to be considered are three: a) the natural tropical laterizing chemical process of change; b) experimentally induced changes, and c) the variation seen from changes in the lava as it cools at the surface of a flow during the first few days after extrusion. Macdonald (in Stearns & Macdonald, 1946) considered this point in some detail. Accepting the above it would appear that acids, heat and steam promote, in the sense of accelerating, the laterization process.

A most interesting study would be the response of the biological elements and soil forming process to the residual heat in lava flows or that from magma below. A beginning was made in studies of the 1955 lava flows outside the Park where an influence seems to have been found related to a constant redistilling of the water moving into a warm flow as it tends to provide for some months a moist substratum. A longer term factor would be the warming of the surface by magma coming closer and withdrawing from the surface without actually breaking through. Fischer, et al., (1964) have shown that such influences of relatively short duration may be present. It is also suspected that, e.g., a dike or sill of hot lava beneath the soil could exert a visible influence on the surface, especially in trees the roots of which might penetrate to significantly warm areas that are not felt sensible without instruments on the surface. Such areas, e.g., that shown as the Puhimau Hot Spot (Fig. 8) near Kokolau Crater, are described in the chapter on vegetation. Detailed infrared photography of the Park with this in mind would be very worthwhile.

In looking at the lavas from a given flow two kinds are widely recognized and named from the Polynesian words for them. One is a'a for the rough type. This appellation was possibly bestowed as onomatopoetical by the barefooted Hawaiians who walked on it. The other is pahoehoe, the smooth kind. Pahoehoe is often formed when lava issues forth in a very fluid condition, the dissolved gasses escape and the lava cools quickly while standing stationary. It is often pillowy, ropey, billowy or in solid, often scaley-surfaced stands. A'a is most often found where the lava has cooled in motion. The surface of an a'a flow can be expected to be covered with loose chunks called clinkers. When an a'a surface is solid it is apt to be very rough with an extremely coarse to sandy grain or covered with protrusions as sharp as shattered glass.

Because of the rates of cooling, pahoehoe is apt to be glassy and a'a more crystalline in nature. Either form may be dense or nearly as light as pumice. However, as ground more and more finely the resulting material from light and heavy rocks approaches the same density, so that the differences in density among rocks are seemingly due to the gas bubbles enclosed. An extreme form is found as the light, fine glassy strands called "Pele's hair." These strands may be blown a long way from the lava fountain producing the molten ejecta of which they are spun. Petrographic studies usually support the idea of a'a being more crystalline in nature than pahoehoe and less often glassy.

Frequently the walls of cracks in flows, usually near their sources, are red while the rest of the flow surface is the characteristic black of all historic Hawaiian lavas. Ash productions may sometimes be red beneath the surface. This seems to represent a preponderance of ferric over ferrous oxidation states of the iron in such rocks. Chemically the red and black rocks are hardly distinguishable. Likewise pahoehoe and a'a (see, respectively, nos. 6 and 7 in Table I), or glassy and crystalline lavas, or dense and non-dense (light) lavas may not be significantly different from the chemist's point of view.

Erosion is not a large factor in the Park. There are no regular streams and, in fact, almost no standing water except for a very few very small ponds near the seashore. There seems to be no evidence of significant wind erosion. Erosion, such as it is, is largely that from the constant wearing away of the shoreline by the sea. This is the cause of the marine cliffs at the sea's edge, which are often about 50 feet high. The nearness of the 50-foot contour line to the shoreline is an indication of this.

Stream erosion (Aerial photo 8-0078) is reflected in the vegetation from west and north of the Volcano Laboratory to near the Kilauea Military Camp. Further north, though only a few hundreds of meters away, the rainfall is such that the ash ejecta from Kilauea are sufficiently vegetated or so thinly overlying the lava beneath that such a stream pattern is not visible. Likewise a few hundreds of meters to the south the rainfall is so low that there is little pattern reflected in the vegetation though the dendritic erosion patterns are clear in aerial view.

Chemical changes and soil formation are discussed, below, under edaphic conditions.

Chapter III- Weather

A- GENERAL ACCOUNT

The trade winds and the barrier formed by the island of Hawaii, *i.e.*, topography, are the principal causes of climatic variation within the Park. Figure 11 illustrates this topography. The winds, chiefly the trade winds from the northeast, bring water as rain to the Park. Convectional effects are relatively insignificant in the Park, though major factors elsewhere on the island.

Rainfall and temperature data have been gathered for as long as 77 years at some stations in and near the Hawaii Volcanoes National Park. Figure 11 shows the locations of these stations as numbered dots. Extensive publications (Taliaferro, 1959; Blumenstock, 1961) of these data are available.

Humidity, wind and the consistency, frequency and range of change are likewise very influential ecological factors. Unfortunately, such factors are not as a rule measured. The best that can be done for humidity and wind is to draw on the observations recorded at the Hilo Airport, thirty miles away. Clouds and their effects on insolation and thus on air temperature, humidity and soil temperatures are extremely important. The study by Powers & Wentworth (1941) on wind and clouds in the area between Mauna Loa and Mauna Kea is informational though it does not apply to the Park itself. Chester K. Wentworth (personal communication) has watched the weather at the north rim of Kilauea for years and has observed that when the daily temperature change is over 20 degrees Fahrenheit, the day is sure to be clear. Such data and similar studies are badly needed for more sites within the Park.

Only examples of records are included here as a means of initiating the bio-ecologist into the peculiarities of the local phenomena. At the outset it can be said that random variation is the rule at any given station whether

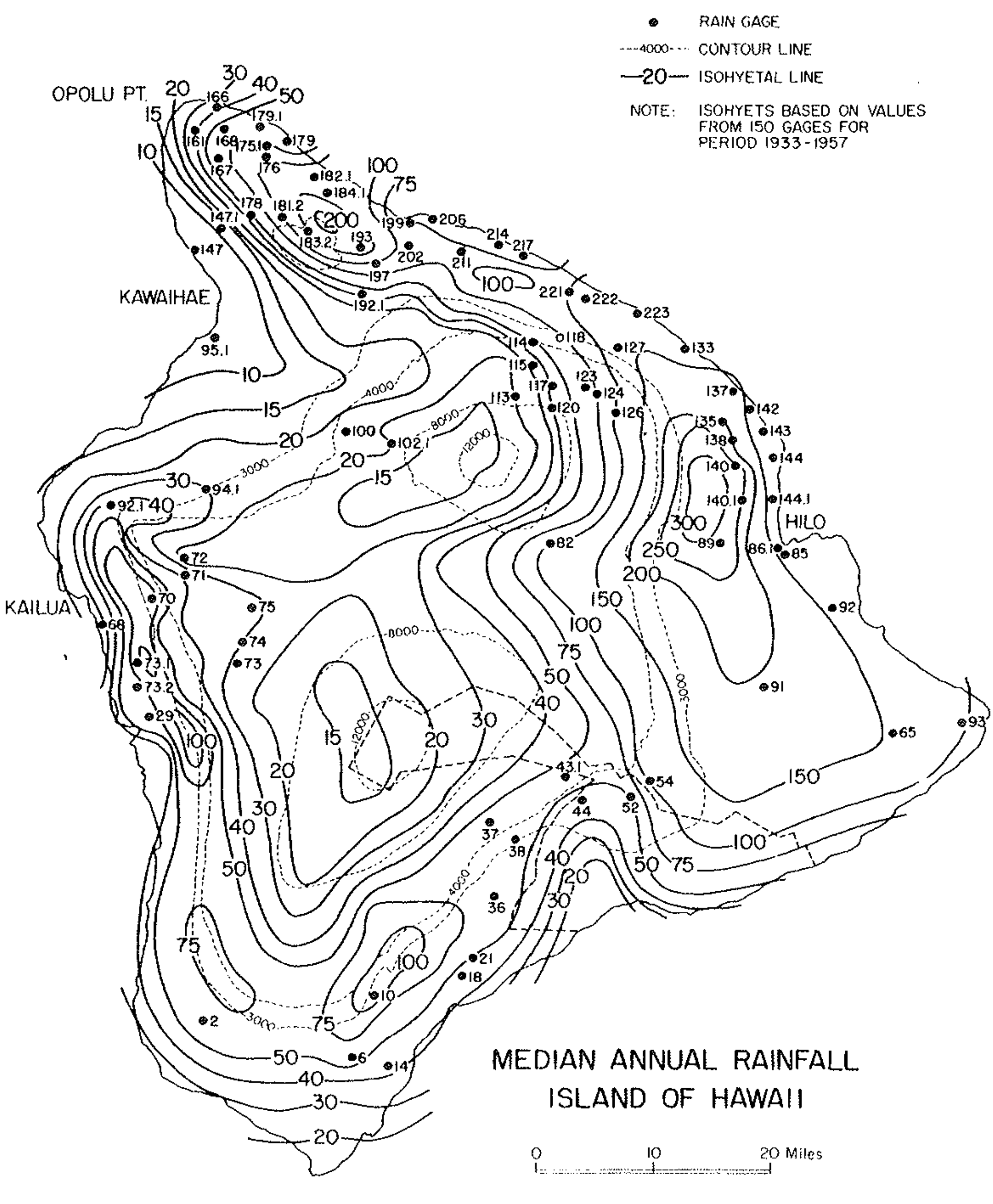


Fig. 11. Median annual rainfall in inches as related to elevation in feet for the island of Hawaii. The Park boundaries show as a dashed line. From U. S. Weather Bureau data as reconstituted by "Hawaii Water Authority" in a bulletin entitled "Water Resources in Hawaii" published in 1959 and available from State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development. The numbered dots are the locations of the weather stations.

one is concerned with the given time of day, day in the month, month in the year or year in the whole record. This is revealed at many places in the enclosed tables of climatic data and in the observations of those who live and work in the Park.

B- WIND

The direction and mean velocities of the wind have been summarized (Table I) as recorded at Hilo Airport, 30 miles away near sea level. There are no significant records of wind from nearer or within the Park. In general the Park is not a windy area, but one is sensible of the trades or lack of them. Occasional strong winds from unusual directions can be expected. It is these that bring most of the heaviest rains to the southeastern part of the Park below the summit of Kilauea. While the trade winds move up the mountains they lose their water and, passing over Kilauea, are then relatively dry winds. As such, along with the very porous soil, these consistent winds from these directions, drying and passing over the shoulder of the island are probably a significant cause of the dry aspects of the Kau Desert region, an area from which there is only a poor record but an indication of a 45-inch rainfall in part. Related to the drying of the air and consequent decrease in cloudiness southwest of Halemaumau Crater (Fig. 7), the Kau region receives more sun and thus more heat than the eastward slopes, and surely this further enhances the effective dryness of this region too.

The well known persistence of the trade winds is interrupted at irregular intervals when the winds may blow from other directions. Especially when these winds are quite contrary to their usual direction, they are referred to as kona winds, and the time the trade winds are absent is a kona period. The average direction of the trade winds has

Table I. Mean hours per month of wind from the different directions during 1953 through 1963 at General Lyman Airport in Hilo. This is the nearest weather station recording such data.

Wind direction													
Azimuth degrees	Compass points	JAN	FEB	MAR*/	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
0	N	42.7	51.6	65.0	43.7	45.8	34.9	51.5	43.3	41.7	37.8	38.1	48.4
23	NNE	31.2	39.7	45.3	37.7	32.2	33.5	41.2	41.0	38.6	33.5	29.1	35.2
45	NE	22.8	32.8	40.2	63.7	46.2	49.5	65.5	59.7	51.3	38.5	33.7	31.8
67	ENE	21.0	24.2	30.6	59.7	52.6	55.4	55.3	59.9	47.0	35.8	30.5	29.3
90	E	27.8	25.0	35.4	42.8	55.1	62.5	50.2	49.6	38.9	37.5	29.5	29.0
113	ESE	39.9	36.3	37.2	39.6	41.2	39.5	32.0	31.3	27.0	40.9	35.6	35.5
135	SE	39.7	27.9	28.3	26.8	19.0	17.2	11.4	16.4	13.8	26.6	25.5	28.5
157	SSE	37.3	21.4	19.3	19.2	10.9	10.3	7.3	10.3	9.2	18.0	20.6	20.5
180	S	51.6	39.4	34.5	29.0	21.8	19.8	17.2	18.1	16.5	27.6	28.1	33.2
203	SSW	85.5	61.6	61.4	50.8	36.6	37.5	31.2	31.7	40.0	59.1	53.6	62.5
225	SW	136.1	101.7	106.2	81.1	88.7	93.4	81.1	72.8	101.5	119.1	108.27	128.4
247	WSW	98.0	86.4	100.0	94.2	119.2	132.7	128.9	131.7	142.1	129.6	131.5	113.0
270	W	34.9	44.5	46.7	50.2	73.7	67.9	82.9	83.8	74.7	58.5	63.4	50.9

Table I. (continued).

Wind direction													
Azimuth degrees	Compass points	JAN	FEB	MAR*/	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
293	WNW	13.2	17.4	19.0	19.5	29.8	17.0	22.7	28.3	22.4	17.2	19.5	20.2
315	NW	13.5	21.3	20.2	17.2	21.6	12.2	31.3	18.4	24.9	14.3	18.8	19.5
337	NNW	21.1	22.7	28.7	22.5	20.0	11.4	18.4	18.7	14.7	15.5	19.1	25.8
Calm	Calm	27.6	20.4	24.0	21.5	29.5	23.5	29.2	27.2	15.7	31.9	36.3	32.2

*/ - March 1961 missing.

shifted from more northerly to more easterly and back to more northerly at least once since 1900. These changes in wind direction are of great importance for both cloud cover and rainfall are greatly affected. Unfortunately, there is little record of such events for any station near the Park.

C- HUMIDITY AND SOIL MOISTURE

Humidity and soil moisture studies are very desirable in connection with any effort to develop an understanding of the "repopulation of devastated areas", i.e., the population of ash falls and lava flows. These have not been consistently recorded for any long period of time nearer than Hilo Airport where humidity records are made. Almost no soil moisture studies have been made, but see the chapter on soils for what information there is. Table II provides the humidity record from the Hilo Airport arranged to show the mean monthly and mean daily variability, such as there was, through a two-year period. It is readily seen that over 50 per cent of the time the humidity was over 80 per cent and about 25 per cent of the time over 90 per cent. Measurements in the higher and in the dryer parts of the Park are generally lower, but often in the 70 to 80 per cent range.

D- FOG DRIP

An additional factor of local importance in determining "wetness" has been described by Ekern (1964) in a paper entitled "Direct Interception of Cloud Water on Lanaihale, Hawaii" in which he describes an increase in rainfall from 149 to 391 inches in going from an open area into an *Araucaria* (Norfolk pine) stand. This influence is discussed as "fog drip" elsewhere and below in the section on vegetation.

Table II. Relative humidity by month recorded at General Lyman Airport, Hilo, Hawaii. The values given are the per cent of the time during the month that the relative humidity was in the range shown in per cent. The data are the means of the daily values for the months from January 1953 through December 1963.

Range of humidity	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
30-49	1.7	2.1	0.7	0.8	0.3	0.6	0.2	0.2	0.2	0.1	0.6	0.5
50-69	26.6	23.8	23.3	23.9	21.5	28.5	25.6	22.7	25.1	23.2	18.7	21.6
70-79	24.2	22.5	20.7	21.6	19.3	20.0	21.0	19.3	19.7	20.7	21.5	22.0
80-89	30.3	27.0	29.7	30.3	28.5	27.4	27.6	28.1	32.2	29.6	29.6	29.6
90-100	17.2	24.6	25.7	23.4	30.5	23.5	25.6	29.6	22.8	26.4	29.7	26.2

E- RAINFALL

Rainfall over the island (Fig. 11) is concentrated on the windward side of the mountains generally between the 2000 and 3000 foot elevations in correspondence with the approach of the northeast trade winds. It is also concentrated between the same levels along the South Kona coast, southwest and outside of the Park, where rain is provided largely by convectional showers.

As the wind passes over the ridge formed by Kilauea and its east rift, especially near and above the 3000 foot level (Fig. 11), the rainfall drops markedly. Thus, while at the Park Headquarters, Station 54, there is an average rainfall of 93 inches, at Halemaumau, Station 52, scarcely a few miles to the southwest over the ridge to the sea and 300 feet lower, the average rainfall is about half that value.

Wide variation from year to year is conspicuous in the rainfall records, some of which are impressive. The longest rainfall record for any gauge station (to 1964) is that of over 77 years maintained by the Kapapala Ranch, Station 36, i.e., beginning in 1887. Figure 12 illustrates the variation in annual rainfall since 1948 for 13 stations. In the Kapapala (Table III) and Park Headquarters (Table IV) records, the minimum and maximum rainfall values are, respectively, 24 (1889) to 126 (1923) and 58 (1899) to 182 (1958) inches. These are five-fold and three-fold ranges, respectively. If one studies the variation between maximum and minimum values for annual rainfall (Fig. 12), especially in the light of the irregularities through the year related below, one gets two impressions without adequate data to really substantiate them. One is that stations with less rainfall are less

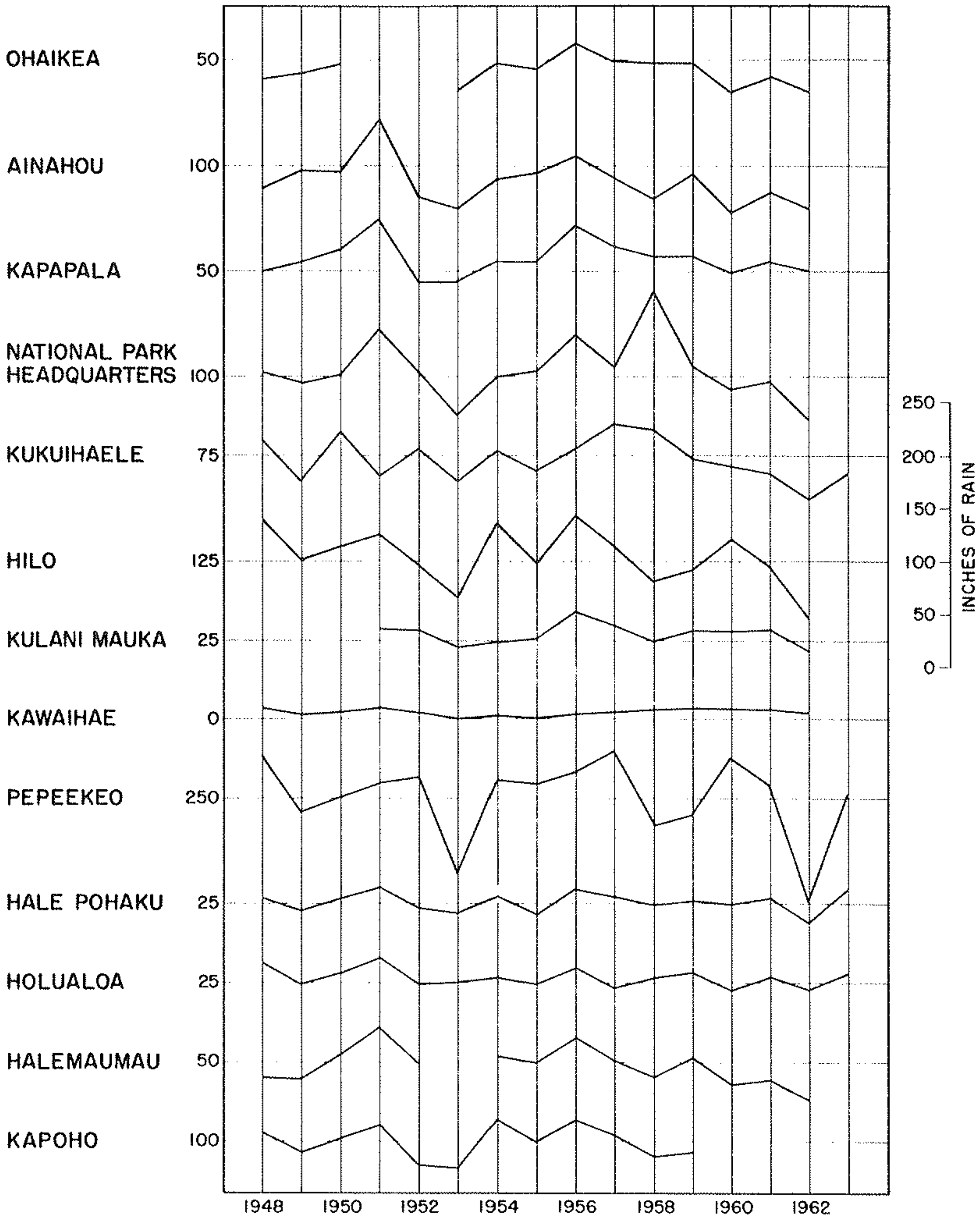


Fig. 12. The annual variations in rainfall at thirteen stations near the Park for a 15 to 16 year period. The numbers along the left margin represent inches of rainfall and are to provide a base for judging variation from year to year by the scale on the right for the respective stations.

Table III. Monthly and annual rainfall values in inches for 76 years at the Kapapala Ranch (Station 36). Elevation 2150 feet.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1887	6.81	13.02	6.46	4.90	2.19	1.25	0.00	2.05	3.58	7.66	8.00	23.02	78.94
1888	4.49	10.52	5.91	4.73	7.41	0.45	4.12	0.00	4.16	8.15	2.50	0.00	52.44
1889	0.95	3.50	0.00	3.30	0.00	1.85	3.15	0.00	6.00	2.50	1.65	1.03	23.93
1890	14.66	7.90	16.10	15.85	5.00	2.50	5.30	4.65	0.00	7.70	1.80	6.10	87.56
1891	4.20	1.00	6.20	1.10	0.00	4.50	0.00	3.02	5.68	13.12	4.15	6.27	49.24
1892	23.00	4.60	2.80	2.77	2.60	0.00	0.64	2.62	3.58	6.89	0.16	2.52	52.18
1893	6.01	13.65	8.30	1.62	1.35	1.27	0.98	3.00	2.60	0.49	13.30	2.65	55.22
1894	12.96	10.95	3.14	3.10	0.60	0.30	4.30	2.05	3.40	1.50	7.68	1.80	51.78
1895	4.70	3.25	1.76	2.06	14.70	0.18	1.40	10.75	4.67	2.90	7.28	7.00	60.65
1896	2.25	3.00	4.34	0.95	1.00	0.00	1.25	9.18	0.78	0.25	6.30	11.55	41.05
1897	3.00	3.20	1.35	0.00	0.00	0.93	0.04	0.76	0.83	2.67	8.39	3.70	24.87
1898	9.80	6.42	27.82	3.14	2.15	1.77	2.73	1.07	3.51	5.15	5.45	3.85	72.86
1899	1.50	1.55	16.90	6.48	2.80	0.20	1.37	0.00	0.60	1.92	0.61	2.30	36.23
1900	0.88	2.80	0.65	3.43	2.92	2.38	2.85	3.57	0.66	7.36	10.69	0.24	38.43

Table III (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1901	3.75	15.92	5.17	2.62	5.72	1.32	3.00	1.23	3.88	8.35	8.25	11.71	70.92
1902	4.04	2.21	13.30	2.75	2.43	4.90	3.30	7.00	4.40	4.65	6.42	3.38	58.78
1903	4.60	4.27	13.10	4.06	2.14	2.15	3.75	0.65	3.10	0.45	5.25	2.45	45.97
1904	3.29	22.93	7.55	5.76	5.08	0.00	1.83	6.65	9.45	1.35	0.00	0.65	64.54
1905	1.76	2.45	3.09	1.71	2.00	2.14	4.24	4.28	2.91	2.43	12.48	1.45	40.94
1906	1.27	3.15	3.81	2.00	4.85	0.00	1.25	8.03	3.30	2.35	18.61	8.80	57.42
1907	13.73	4.25	6.37	2.51	4.11	1.72	1.00	12.70	10.42	9.60	1.90	0.40	68.70
1908	0.79	8.33	10.29	1.89	0.20	0.00	0.00	0.87	1.93	2.72	1.21	1.06	29.29
1909	0.24	4.91	7.52	5.79	2.69	0.50	est. (1.47)	0.00	2.71	2.75	2.56	11.98	43.12
1910	4.99	5.65	0.92	0.98	2.74	1.60	2.53	5.43	4.19	2.17	3.38	3.33	37.91
1911	6.99	7.60	17.21	6.92	4.93	0.00	1.78	2.50	6.80	3.08	1.38	2.81	62.00
1912	0.00	5.37	2.15	2.33	0.58	1.92	3.18	2.33	0.55	5.20	1.40	2.73	27.74
1913	6.97	4.05	1.85	0.60	8.80	5.46	0.42	4.24	1.93	5.81	12.66	1.75	54.54
1914	5.90	2.12	6.33	3.27	6.92	2.53	15.94	10.70	5.95	1.43	3.90	15.70	80.69
1915	0.00	0.98	1.67	5.95	4.52	7.70	5.25	3.32	3.18	7.44	25.37	15.52	80.90
1916	20.10	5.07	18.15	4.60	4.36	1.12	2.35	1.30	2.85	5.30	2.72	21.02	88.94

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1917	9.35	6.26	29.03	5.93	4.67	1.53	0.60	0.55	3.14	3.52	1.45	14.72	80.75
1918	18.07	31.34	11.48	14.95	6.06	2.55	7.08	3.61	5.60	1.68	10.99	1.17	114.58
1919	1.45	0.00	7.15	1.28	5.24	1.76	1.57	5.23	2.54	2.19	4.97	2.02	35.40
1920	10.32	5.06	8.25	3.64	6.53	1.77	0.74	5.75	0.46	6.49	1.48	17.72	68.21
1921	28.54	5.95	3.97	2.32	5.72	0.00	1.51	1.36	1.00	11.41	1.42	3.08	66.28
1922	6.21	8.62	7.92	4.22	1.25	0.89	1.35	1.78	3.54	4.30	7.14	1.69	48.91
1923	29.05	18.69	16.52	25.42	1.99	0.86	0.81	5.92	10.57	2.37	2.37	11.18	125.75
1924	1.00	1.79	17.29	18.06	5.99	3.54	2.08	2.62	1.84	5.62	3.18	3.84	66.85
1925	7.29	1.64	6.12	1.19	2.15	1.72	2.78	1.20	2.79	6.71	1.68	2.26	37.53
1926	2.32	0.68	1.39	3.33	1.70	6.72	2.42	11.16	2.07	5.56	2.08	8.21	47.64
1927	1.89	3.72	9.47	10.99	1.21	1.82	1.04	2.11	11.23	3.42	1.72	41.32	89.94
1928	0.00	2.09	2.64	3.16	4.30	0.50	8.78	0.78	3.50	4.12	3.30	1.84	35.01
1929	6.11	10.25	2.73	1.95	2.48	0.40	4.45	2.81	2.68	4.87	est. (22.12)	10.20	71.05
1930	9.52	3.82	8.59	4.35	0.89	1.46	2.50	11.45	5.60	9.34	5.05	0.30	62.87
1931	0.60	0.07	6.48	4.76	5.92	2.47	4.26	1.05	8.04	11.03	1.35	1.21	47.24
1932	12.36	10.82	2.02	3.21	2.12	2.97	0.44	1.57	6.07	2.14	5.29	5.96	54.97
1933	7.50	5.21	4.20	16.33	4.00	1.16	0.00	1.48	0.22	3.83	7.93	1.53	53.39

Table III (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1934	6.05	4.30	5.05	7.11	12.40	2.35	1.51	3.76	3.85	4.58	5.22	5.44	61.62
1935	7.03	3.18	15.36	5.90	2.73	4.35	2.48	4.48	7.36	11.51	15.27	1.90	81.55
1936	5.03	5.76	5.36	3.38	1.00	2.70	0.84	6.28	5.83	9.35	1.10	3.59	50.22
1937	11.00	14.06	12.30	8.47	5.20	0.30	2.86	11.28	3.10	6.35	2.28	4.32	81.52
1938	16.33	11.55	2.41	7.95	6.00	2.80	3.80	2.47	2.56	5.12	4.98	4.78	70.75
1939	6.12	16.55	22.24	9.25	2.00	2.25	1.81	2.25	7.45	2.79	3.35	0.73	76.79
1940	5.34	4.26	8.69	2.80	1.40	1.78	3.54	10.31	5.50	7.72	7.48	3.20	62.02
1941	2.71	4.37	0.92	2.68	4.75	4.78	1.23	3.15	13.23	8.65	2.46	0.00	48.93
1942	0.86	1.19	5.27	1.95	3.64	2.45	0.50	1.16	5.95	15.43	3.35	3.55	45.30
1943	17.91	4.17	9.27	2.30	8.68	3.62	2.77	3.10	5.59	1.78	0.67	2.95	62.81
1944	1.29	12.29	4.24	1.95	6.05	3.91	1.08	0.76	1.89	3.84	1.31	10.23	48.84
1945	2.53	5.40	3.50	22.34	7.90	2.03	4.87	2.14	1.31	1.98	2.46	7.98	64.44
1946	25.53	7.39	0.57	4.13	3.41	0.51	0.97	1.68	1.03	6.22	7.94	17.47	76.85
1947	3.84	2.61	9.40	1.99	2.36	0.60	2.81	2.98	5.13	1.13	2.36	4.35	39.56
1948	4.64	6.23	6.31	6.61	3.60	3.08	2.52	1.96	3.61	0.57	11.22	1.92	52.27

Table III (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1949	32.33	6.47	1.98	0.49	2.41	2.18	0.61	0.55	0.42	3.80	2.61	4.91	58.76
1950	18.90	8.67	1.11	6.13	1.48	1.17	2.17	6.63	2.60	1.65	19.94	2.41	72.86
1951	11.28	20.88	20.12	3.75	3.32	4.10	0.96	5.11	3.15	11.74	6.76	8.50	99.67
1952	11.10	1.59	5.10	0.82	3.56	0.16	3.81	0.47	2.36	6.59	4.51	0.96	41.03
1953	1.23	10.64	10.15	3.56	1.37	2.79	0.15	1.61	1.50	1.21	2.22	6.06	42.49
1954	4.42	14.08	8.13	1.84	4.91	0.38	0.71	2.86	3.29	1.86	9.35	7.26	59.09
1955	4.56	14.37	8.27	2.68	1.02	0.82	2.15	3.01	3.57	3.54	6.93	7.54	58.46
1956	15.75	12.90	4.88	4.28	3.32	0.17	5.12	7.13	1.18	13.69	22.97	3.42	94.81
1957	14.60	5.00	1.54	6.56	6.12	3.06	0.94	13.75	6.06	6.28	3.97	8.93	76.81
1958	1.15	4.60	16.40	2.44	2.75	1.92	5.32	18.54	0.96	2.56	5.47	4.28	66.39
1959	13.97	6.00	2.67	4.28	3.33	0.38	1.40	7.17	5.05	6.50	13.52	1.68	65.95
1960	4.38	1.32	16.12	3.12	3.54	1.88	2.85	2.73	4.74	4.68	2.56	2.89	50.81
1961	3.33	2.62	1.34	4.62	4.84	1.74	1.37	0.76	2.65	12.15	3.92	21.12	60.46
1962	6.94	4.11	9.32	3.25	7.38	1.19	1.97	1.87	4.73	8.09	0.30	3.35	52.50

Table III (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
Monthly means	7.70	6.81	7.68	4.85	3.78	1.88	2.42	3.99	3.83	5.18	5.86	6.06	60.10
Maximum	32.33	22.93	29.03	18.06	12.40	6.72	15.94	13.75	11.23	13.12	25.37	23.02	125.75
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	23.93

Table IV. Monthly and annual rainfall values in inches for 64 years at the Hawaii Volcanoes National Park Headquarters (Station 54). Elevation 3971 feet.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1899	2.57	3.32	13.73	6.57	10.69	1.97	1.96	3.81	2.37	7.04	3.34	1.04	58.44
1900	0.85	1.90	2.47	3.92	8.05	2.02	3.63	10.10	2.85	12.07	13.77	1.75	63.38
1901	5.83	17.38	15.31	6.78	3.78	1.70	2.80	2.13	4.05	6.66	17.72	10.93	95.07
1902	4.78	2.16	22.21	4.98	4.22	1.75	3.79	14.34	5.06	3.18	12.10	10.79	89.30
1903	4.24	5.57	6.14	9.15	3.11	3.45	11.82	2.47	5.46	3.88	9.85	2.30	67.44
1904	16.19	17.27	4.47	20.29	6.96	2.65	6.68	8.27	4.06	2.86	2.21	2.05	93.96
1905					6.31	6.03	4.31	8.55	9.62	9.15	17.65	4.35	65.97
1906	4.00	2.15	1.88	4.45	6.65	2.49	5.66	12.18	1.94	2.37	10.35	11.25	65.37
1907	8.97	10.90	12.50	5.65	4.10	5.40	7.10	23.70	5.28	6.40	4.86	2.15	96.95
1908	4.50	6.75	4.60	6.70	2.20	1.40	0.90	2.50	4.03	5.42	0.00	8.65	47.65
1909	2.25	8.97	13.85	3.25	6.00	3.60	7.73	2.40	5.60	7.50	3.40	13.09	77.64
1910	12.92	1.66	9.50	7.18	8.34	6.50	3.45	9.40	2.67	3.69	6.17	6.29	77.77
1911	8.50	24.58	10.01	10.44	1.39	4.52	0.00	2.35	8.15	4.71	8.09	9.59	92.33
1912	0.64	11.98	4.95	5.51	0.73	2.92	2.91	2.77	7.20	13.26	8.51	11.99	73.37
1913	17.27	1.92	4.95	8.39	7.47	3.36	3.33	6.60	5.44	2.39	25.15	2.05	88.32

Table IV (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTA
1914	4.84	2.68	6.57	6.51	8.96	10.10	28.38	18.22	16.91	8.13	13.85	10.06	135.2
1915	2.02	1.33	1.97	8.42	2.68	6.90	3.86	2.56	7.39	14.16	34.51	20.12	105.9
1916	12.97	4.11	15.04	13.89	17.06	6.58	6.76	5.66	5.92	9.33	8.11	25.32	130.7
1917	1290	5.04	25.79	11.27	4.16	2.98	2.29	1.96	1.90	2.25	5.45	5.68	81.6
1918	19.02	40.65	12.75	13.82	10.86	4.30	15.51	9.27	3.60	5.44	19.13	17.18	171.5
1919	3.92	3.27	8.52	3.90	2.54	2.99	3.95	5.36	5.72	4.62	3.62	4.14	52.5
1920	8.48	2.11	9.12	3.31	2.66	2.57	3.91	3.66	4.71	7.51	6.74	14.84	69.6
1921	43.96	3.73	2.19	7.63	5.32	1.52	4.25	5.10	5.16	11.37	10.80	6.47	107.5
1922	16.93	15.78	28.13	9.38	3.45	1.28	3.69	4.45	6.14	4.50	6.74	2.34	102.8
1923	26.23	14.26	20.66	27.60	4.33	4.14	3.93	7.19	8.82	7.55	3.14	14.65	142.5
1924	6.78	3.85	10.41	13.27	6.83	1.39	4.74	3.58	2.82	8.22	9.61	4.42	69.9
1925	9.59	0.96	18.40	7.32	2.92	4.88	2.49	9.69	2.55	5.16	5.98	2.41	72.3
1926	1.76	3.50	2.23	2.53	3.02	3.60	2.11	13.46	4.92	4.19	1.67	16.50	59.4
1927	9.00	2.10	7.79	6.70	6.37	3.77	7.01	7.66	15.97	4.49	4.56	43.15	128.7
1928	6.98	2.74	11.72	5.91	5.24	7.33	7.51	3.52	5.14	8.08	7.30	9.98	72.5
1929	5.63	11.32	1.57	5.20	2.92	3.20	7.11	3.71	3.16	2.87	15.34	7.03	75.4
1930	5.92	3.71	4.15	6.35	8.38	6.82	4.14	24.46	9.62	13.83	8.04	4.87	107.8

Table IV (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1931	1.92	6.40	12.81	3.92	3.39	1.88	1.85	4.89	11.55	3.19	8.58	3.21	65.35
1932	24.55	14.34	3.91	8.30	6.64	3.26	3.06	1.52	7.10	1.80	6.98	8.69	90.39
1933	16.29	11.38	12.81	15.16	7.48	1.02	3.92	1.65	3.40	1.67	9.03	1.34	85.15
1934	9.01	4.63	3.91	5.74	7.73	5.67	8.90	2.38	9.41	5.90	6.75	12.52	82.55
1935	10.29	8.56	18.02	9.60	3.13	7.94	3.07	2.59	9.12	9.03	9.64	5.29	96.28
1936	4.85	3.61	9.65	3.69	4.73	6.70	3.52	10.26	7.78	8.74	2.64	18.93	84.90
1937	22.02	20.46	13.40	7.83	8.61	7.89	2.45	24.75	3.47	7.21	10.52	4.83	133.44
1938	21.98	9.72	9.27	9.54	7.02	3.51	4.15	3.96	2.93	7.72	14.44	12.62	106.86
1939	18.01	14.59	29.85	11.28	2.89	4.96	6.65	5.03	2.96	5.27	6.64	1.53	110.66
1940	3.25	1.85	9.22	3.87	3.29	3.05	2.51	20.77	7.99	6.34	10.49	3.08	75.71
1941	1.84	2.22	7.18	2.19	9.19	5.96	10.62	6.57	13.66	15.21	5.47	9.43	89.54
1942	0.70	3.39	17.74	5.45	5.06	3.26	4.38	2.92	5.15	8.34	4.39	6.26	67.04
1943	16.62	10.45	9.63	7.14	7.83	10.34	9.15	5.73	3.36	2.74	2.82	7.27	93.08
1944	3.44	11.58	4.87	11.70	10.09	6.57	4.40	4.74	3.31	7.99	10.82	18.08	97.59
1945	2.58	3.81	18.58	27.91	3.46	2.04	6.74	7.81	5.21	5.96	7.18	10.95	102.23
1946	17.22	16.29	17.26	11.48	2.05	8.29	3.28	2.97	1.62	14.15	6.26	27.83	128.70

Table IV (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1947	4.20	1.43	13.39	6.51	4.91	4.30	3.10	7.70	6.64	4.01	10.71	12.09	78.99
1948	5.37	7.20	18.92	10.26	7.07	5.80	3.31	3.28	3.39	7.14	18.59	18.63	103.96
1949	34.32	8.21	7.92	2.09	1.89	3.92	2.48	3.62	1.57	7.08	5.84	16.60	95.54
1950	13.69	18.30	6.62	14.53	7.46	4.40	5.11	6.17	2.48	3.12	16.25	4.80	102.93
1951	14.11	25.93	28.45	6.09	3.57	4.79	3.59	9.71	2.27	23.73	16.29	6.25	144.78
1952	30.55	4.60	21.67	3.86	6.19	4.74	3.95	2.94	3.82	5.88	11.23	5.84	105.27
1953	1.29	8.65	10.63	1.64	7.72	3.45	1.50	4.44	2.12	2.95	8.80	8.33	63.11
1954	4.53	11.36	7.83	2.38	7.66	6.10	9.82	9.82	5.20	4.17	15.61	20.77	100.77
1955	11.15	21.02	7.64	14.20	9.10	3.04	5.25	4.89	4.69	3.02	10.64	12.30	106.94
1956	15.99	25.96	10.16	8.23	9.46	8.28	2.87	17.17	2.04	14.49	20.56	6.02	141.23
1957	18.60	5.46	3.05	3.41	4.76	2.33	6.28	16.72	5.04	4.58	7.16	22.68	109.93
1958	1.99	2.79	17.91	5.14	5.66	4.51	7.36	14.77	3.30	5.78	11.18	1.94	92.33
1959	19.44	17.05	3.44	6.75	5.75	1.90	4.78	11.56	3.63	2.30	21.73	13.09	111.42
1960	16.83	6.25	8.79	12.07	7.30	4.40	3.17	6.32	5.54	4.35	13.07	2.71	90.88
1961	3.55	14.96	5.31	5.79	4.18	2.95	2.70	4.08	3.70	17.70	12.23	20.27	97.42
1962	3.82	2.96	10.40	3.47	13.90	2.35	3.62	1.80	6.32	3.28	4.47	4.66	61.05

Table IV (continued)

YEAR	JAN	FBE	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
Monthly means	10.45	8.94	9.90	8.06	7.58	4.15	5.33	7.41	5.37	6.83	9.84	9.94	93.39
Maximum	43.96	40.65	29.85	27.60	17.06	10.62	23.38	24.75	16.91	15.21	25.15	27.83	171.53
Minimum	0.64	0.96	1.88	1.64	0.73	1.28	0.90	1.52	1.57	1.67	0.00	1.04	47.65

consistently wet and vary more between maximum and minimum annual amount. The other is that the stations on the windward slopes exposed to the more consistent trade winds have more consistent rainfalls than those on the leeward (Kona) slopes exposed to the more erratic "kona" winds. As an example of extremes that may be experienced, it appears that in 1953 at Kawaihae, Station 148, there was a minimum total annual precipitation for that Station (Fig. 12) of about 0.2 inches. However, there seems to have been no record of any rain at all for the eleven months preceding December of that year.

It is often asked whether there are rainfall cycles, say of eleven years, or it is asked, "Is the annual rainfall increasing or decreasing?" J. B. Cox (1924) believed there were 1, 3.7, 11.1 and 33 year periods. Figure 12 and the data in Tables I-V can be analyzed from this point of view. Certainly if there are cycles, a gradual lessening or increase in annual rainfall, these phenomena might be useful in explaining the changes in the biological populations in the Park. Of course, the actual quantity of rain is important in the rate of development and nature of any vegetation. However, the extremes, especially the minimum values, are apt to be the controlling factors. That is to say, one drought year will be more important than the mean rainfall or that for the wettest years.

The distribution of the rain during the year is strikingly important in regulating the type of vegetation that will appear. Thus, Tables III-X have been included to convey some conception of the regularity or irregularity in rainfall. It is common in these data to find that some particular year a given month may have had over ten times as much precipitation as it had another year. For example, in Table IV the month of January is shown to have had 0.64 inches of rain in 1912 and 16 inches in 1904, but 44 inches in

Table V. Monthly and annual rainfall values in inches for 30 years at the Halemaumau gauge (Station 52). Elevation 3648 feet.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1933	7.97	8.58	10.82	9.52	1.72	0.79	0.05	0.17	0.78	1.14	6.84	0.71	49.09
1934	5.29	2.18	3.05	3.33	4.51	3.64	2.51	0.66	4.86	2.42	1.67	9.21	43.33
1935	7.81	3.92	14.26	4.48	0.85	0.67	2.50	0.71	5.23	8.26	7.88	2.81	59.38
1936	3.60	2.35	7.03	1.64	0.73	0.71	1.44	5.19	3.74	7.06	0.81	8.63	42.93
1937	14.74	16.26	10.57	3.71	3.67	0.61	2.78	14.10	1.09	3.86	3.78	3.36	78.53
1938	14.91	9.13	3.61	5.49	1.54	2.05	0.71	1.33	0.56	5.52	8.20	5.75	58.80
1939	10.81	11.93	23.95	6.50	1.11	1.87	1.04	1.07	0.82	1.93	2.32	0.56	63.91
1940	4.45	1.34	7.74	1.43	0.96	0.45	0.71	12.47	3.85	5.43	9.87	2.34	50.94
1941	1.26	2.24	1.87	0.66	3.93	4.41	1.98	2.60	7.61	8.44	1.63	2.60	39.25
1942	0.59	1.67	6.08	(3.04)	1.57	1.56	1.06	0.49	1.87	4.19	2.94	4.15	29.21
1943	12.12	3.77	(9.22)	4.39	5.54	2.39	4.56	1.44	0.64	0.52	1.03	3.36	48.98
1944	1.01	3.44	3.97	2.32	3.31	0.73	1.21	0.70	0.86	3.37	3.34	15.28	39.54
1945	0.85	2.48	4.78	20.96	2.29	1.06	0.46	2.86	1.36	1.80	3.68	9.70	52.28
1946	15.02	13.19	5.39	2.67	0.52	0.78	2.05	0.72	0.17	9.08	3.98	23.75	77.32
1947	2.24	1.06	3.08	1.84	0.89	0.44	1.46	1.77	3.07	1.28	7.46	5.08	29.67

Table V (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1948	4.05	2.87	4.20	4.50	2.03	0.61	1.07	0.97	0.76	2.69	6.35	4.36	34.40
1949	17.85	3.83	2.87	0.34	0.63	0.50	0.56	0.52	0.10	3.09	2.65	6.08	39.02
1950	5.32	12.43	1.73	7.34	1.76	0.67	1.25	4.69	0.57	1.11	16.90	2.92	56.69
1951	7.81	16.40	18.35	1.90	0.83	1.47	0.76	5.07	0.47	19.78	5.58	4.07	82.49
1952	21.22	3.31	7.85	0.64	1.50	0.41	0.95	0.08	0.79	3.55	6.72	0.49	47.51
1953	0.92	2.45	1.98	0.24	1.25	0.34	0.05	1.03	0.15	0.17	(Gauge (0.34	leaking) Inop.)	8.58
1954	2.01	11.53	4.47	2.35	2.40	0.54	2.00	2.08	1.55	0.86	16.90	10.58	54.79
1955	2.85	14.45	6.16	5.76	0.86	0.17	0.71	1.15	1.50	0.92	6.50	8.58	49.61
1956	12.03	16.80	4.04	2.80	2.58	0.85	0.12	6.50	0.33	8.90	15.49	3.05	73.49
1957	13.42	1.52	0.63	5.65	2.29	T	1.06	7.55	2.90	2.23	3.20	10.50	50.95
1958	0.35	1.39	12.00	1.45	1.05	0.15	1.80	7.75	0.15	2.27	4.70	1.70	34.76
1959	13.75	10.21	0.78	1.73	0.95	0.27	0.74	4.30	1.45	0.97	15.10	3.25	53.50
1960	4.90	1.56	8.23	3.35	2.00	0.15	T	1.11	1.81	2.07	1.90	0.80	27.88
1961	2.17	3.00	0.55	1.29	0.37	0.14	0.15	0.25	1.49	9.81	4.34	9.77	33.33
1962	3.54	0.80	2.01	0.58	3.50	0.87	0.09	0.06	1.29	1.12	0.61	1.09	15.56

Table V (continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
Monthly means	7.16	6.20	6.34	3.73	1.90	0.98	1.19	2.98	4.13	4.13	5.94	5.67	47.52
Maximum	17.85	16.80	23.95	20.96	4.51	4.41	4.56	14.10	7.61	19.78	16.90	23.75	82.49
Minimum	0.35	0.80	0.55	0.24	0.37	T	T	0.06	0.10	0.52	0.61	0.49	8.58

Table VI. Precipitation records for the "devastation area," *i.e.*, the 1959 Kilauea ash-fall rain gauges. The location of these gauges is given in Figure 10. The values given are in inches.

DATE	#1	#2	#3	#4
Dec. 1963				
5	1.62	1.20	1.18	1.28
12	0.33	0.42	0.54	0.60
19	0.47	0.37	0.32	0.23
26	0.09	0.09	0.08	0.09
Jan. 1964				
1	0.59	0.35	0.34	0.33
9	7.23	6.57	6.37	6.63
16	1.38	1.02	1.24	1.10
23	2.97	2.58	2.29	2.01
30	1.38	0.83	0.69	0.72
Feb. 1964				
14	5.70	4.27	3.76	2.38
27	14.74	9.40	8.41	8.32
Mar. 1964				
12	13.98	11.61	10.19	8.29
25	10.28	8.70	9.92	8.85
Apr. 1964				
7	2.82	1.75	1.33	0.91
23	3.90	2.37	2.52	2.30
May 1964				
7	6.24	3.93	3.75	2.96
21	6.08	4.02	3.70	3.90
June 1964				
3	8.36	7.37	6.35	6.80
18	0.09	0.55	0.50	0.43
July 1964				
2	2.34	1.75	1.69	1.80
16	1.87	1.90	0.90	0.82
30	1.02	0.45	0.38	0.67
Aug. 1964				
13	2.10	1.26	1.22	1.08
27	0.41	0.22	0.23	0.13

Table VI. (continued)

DATE	#1	#2	#3	#4
Sept. 1964				
10	2.35	2.12	2.09	1.57
24	2.20	2.32	2.40	2.53
Oct. 1964				
8	2.21	1.38	1.37	0.45
Nov. 1964				
1	2.26	1.61	1.36	1.11
5	1.75	1.13	1.04	1.20
19	0.29*/	7.66	7.19	7.54
Dec. 1964				
3	1.54	1.51	1.65	1.65
17	1.46	4.95	4.95	5.09
31	2.07	2.76	2.85	2.71
Jan. 1965				
14	2.05	3.55	3.52	3.49
26	2.01	3.37	4.16	3.70
Feb. 1965				
11	2.06	4.41	5.37	3.61
25	2.07	1.44	1.36	1.90
Mar. 1965				
11	2.00	1.95	1.70	1.23
30	2.18	3.81	4.16	4.88
Apr. 1965				
13	2.58	7.64	7.85	7.47
27	2.07	3.30	3.95	3.66
May 1965				
10	2.28+	12.31	12.21	12.81
June 1965				
1	2.18	1.80	1.75	1.49
9	1.58	--	--	--
16	1.33	1.38	1.50	1.11
July 1965				
6	2.00	1.52	1.33	0.77
23	2.32	1.57	1.55	0.74

*/ Probably not reliable after this reading.
+Rain gauge leak discovered.

Table VI (continued)

DATE	#1	#2	#3	#4
Aug. 1965				
15	0.52	1.42	1.28	1.86
31	0.48	0.34	0.28	0.30
Sept. 1965				
22	5.64	5.30	5.09	3.85
Oct. 1965				
4	1.37	--	--	--
19	3.05	3.46	3.88	4.05
30	1.53	--	--	--
Nov. 1965				
4	--	2.10	2.45	2.48
12	14.83	12.72	13.15	13.78
Jan. 1966				
19	12.30	11.38	11.30	8.70

Table VII. Precipitation record for the Kalapana sites 1 and 2 inside the eastern Park boundary at an elevation of about 40 feet. Gauge #1 was installed 0.8 miles inside the boundary at the future residence area on January 24, 1964. Gauge #2 was installed on November 30, 1964, at the big bend in the Kalapana Chain-of-Craters Road, as it leaves the coastline, turning inland to climb the pali. The values are given in inches.

Date	Gauge #1	Gauge #2	Date	Gauge #1	Gauge #2
January 1964			January 1965		
30	0.65		3	1.59	1.30
			6	1.05	1.18
			15	1.56	1.98
			19	0.43	0.22
			24	4.45	2.73
			26	0.02	0.04
			31	0.18	0.04
February 1964			February 1965		
13	1.20		5	2.50	2.14
18	2.70		22	0.57	
25	3.00				
March 1964			March 1965		
3	2.86		16		0.45
11	2.50		24	4.49	1.54
18	1.22				
21	2.40				
22	1.41				
30	0.87				
31	0.13				
April 1964			April 1965		
3	0.42		6	4.57	5.55
8	1.09		8	0.61	0.31
15	0.78		14	4.06	9.93
20	0.48				
27	0.59				
28	0.27				
May 1964			May 1965		
5	1.70		3	18.06	8.27
7	1.31		10	11.47	12.91
15	1.80		20	1.56	1.50
22	0.84		28	0.69	0.45
25	3.50		29	0.08	0.04
26	1.26				

Table VII (continued)

Date	Gauge #1	Gauge #2	Date	Gauge #1	Gauge #2
June 1964			June 1965		
11	0.72		1	0.07	
19	0.33		16	0.10	1.46
24	0.70		20	0.33	0.11
26	0.98		27	1.25	2.19
			30	0.24	0.13
July 1964			July 1965		
9	0.27		1	0.14	
21	0.50		7	0.11	0.05
			14	0.68	0.69
			15	0.05	0.06
			16	0.10	0.01
			17	0.53	
			18	0.12	0.48
			19	0.00	0.00
			20	0.42	0.20
			21	0.04	
			22	0.04	0.01
			23	0.01	0.00
			24	0.01	0.00
			25	0.01	0.01
			26	0.00	0.00
			27	0.00	0.00
			28	0.00	
			29	0.00	0.00
			30	0.00	0.00
			31	0.09	
August 1964			August 1965		
7	1.31		1	0.01	0.06
11	0.47		2	0.04	0.07
26	0.74		3	0.04	0.00
			4	0.01	0.00
			5	0.13	0.02
			6	0.18	0.01
			7	0.00	0.00
			8	0.00	0.00
			9	0.42	0.05
			10	0.01	0.00
			11	0.00	0.00
			12	0.12	0.00
			13	0.47	0.04
			14	0.17	0.01
			15	0.01	0.00
			16	0.06	0.21
			17	0.12	0.03

Table VII (continued)

Date	Gauge #1	Gauge #2	Date	Gauge #1	Gauge #2
August 1964			August 1965		
			18	0.00	0.03
			19	0.04	0.00
			20	0.04	0.00
			21	0.05	0.00
			22	0.02	0.00
			23	0.09	0.07
			24	0.18	0.05
			25	0.01	0.00
			26	0.01	0.00
			27	0.00	0.00
			28	0.00	0.00
			29	0.00	0.00
			30	0.00	0.00
September 1964			September 1965		
8	0.88		1	0.00	0.00
10	1.51		2	0.00	0.00
17	0.63		3	0.00	0.00
30	1.46		4	0.00	0.00
			5	0.00	0.00
			6	0.00	0.00
			7	0.03	0.02
			8	0.02	0.00
			9	0.00	0.00
			10	0.02	0.00
			11	0.02	0.01
			12	0.82	1.50
			13	1.37	1.90
			14	0.21	0.11
			15	0.04	0.03
			16	0.08	0.02
			17	0.00	0.00
			18	0.00	0.00
			19	0.12	0.11
			20	0.11	0.57
			21	0.00	0.00
			22	1.43	0.18
			23	0.01	0.00
			24	0.03	0.01
			25	0.01	0.00
			26	0.00	0.00
			27	0.00	0.00
			28	0.01	0.02
			29	0.00	0.00
			30	1.10	0.01

Table VII (continued)

Date	Gauge #1	Gauge #2	Date	Gauge #1	Gauge #2
October 1964			October 1965		
13	0.35		1	0.02	0.01
15	0.41		2	0.01	0.00
22	0.85		3	0.06	0.00
			4	0.00	0.00
			5	0.00	0.00
			6	0.00	0.00
			7	0.28	0.11
			8	0.04	0.05
			9	0.11	0.06
			10	0.00	0.00
			11	0.18	0.78
			12	0.01	0.03
			13	0.63	0.85
			14	0.58	0.23
			16	0.59	0.08
			17	0.01	0.02
			18	0.00	0.00
			19	0.45	1.02
			22	0.02	
			25	0.00	0.00
			31	0.00	0.00
November 1964			November 1965		
4	1.00		1	0.00	0.00
12	15.00		2	0.00	0.00
17	0.18		3	0.00	0.00
30	1.75		4	0.03	0.00
			5	0.01	0.53
			6	0.00	0.00
			7	0.03	0.00
			8	0.00	1.65
			9		0.00
			10	1.04	2.61
			11	0.14	0.00
			12	1.38	0.96
			13	1.19	2.20
			14	1.06	2.59
			16	7.50	1.75
			17	0.00	0.02
			19	0.43	0.13
			20	0.12	0.00
			21	0.58	0.06
			22	0.05	0.00
			23	0.03	0.01
			24	0.09	0.02
			25	0.03	
			26	0.02	0.02
			27	0.09	0.05
			28	0.15	0.04
			29	0.12	0.03
			30	0.00	0.00

Table VII (continued)

Date	Gauge #1	Gauge #2	Date	Gauge #1	Gauge #2
December 1964					
1	0.08	0.13			
11	3.89	3.12			
22	9.60				
24		5.73			
30	0.76	0.25			

Table VIII. Annual monthly maximum, minimum and median rainfall values for the island of Hawaii at 14 stations. For locations of stations refer to the station numbers on Figure 11. The values are in inches, and "T" means there was less than .05 inches.

Station No.	Location	Elev. (ft.)	Years		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
36	Kapapala Ranch	2150	71	Max.	32.3	31.3	29.0	25.4	14.7	7.7	15.9	13.8	13.2	15.4	34.4	41.3
				Med.	5.3	5.1	6.1	3.3	2.9	1.7	1.8	2.6	3.2	4.0	3.9	3.4
				Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
44	Ohaikea	3460	33	Max.	20.5	20.5	22.2	12.0	9.0	5.5	3.8	14.4	11.2	17.1	18.0	23.4
				Med.	3.9	3.5	5.1	1.8	1.1	0.4	1.2	1.3	1.8	3.4	3.1	3.2
				Min.	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	T	0.0	0.0
52	Halemaumau	3648	25	Max.	21.2	16.8	24.0	21.0	5.5	4.4	4.6	14.1	7.6	19.8	16.9	23.8
				Med.	5.3	3.8	4.8	3.0	1.6	0.7	1.1	1.3	1.1	2.6	3.7	4.1
				Min.	0.6	1.1	0.6	0.2	0.6	T	0.1	0.1	0.1	0.2	0.8	0.6
54	Hawaii Nat'l Park Hdqters. (Volcano Obs.)	3971	56	Max.	44.0	40.7	29.9	27.9	17.1	10.6	28.4	24.8	16.9	24.2	34.5	43.2
				Med.	8.5	6.0	9.6	6.9	5.8	3.5	4.3	5.1	5.0	6.0	8.6	8.7
				Min.	0.6	1.0	1.6	1.6	0.7	1.3	0.9	1.5	1.6	1.7	1.7	1.0
58	Ainahou	2975	16	Max.	47.2	32.6	30.0	17.5	6.6	4.2	5.1	10.7	6.3	31.5	27.4	25.7
				Med.	8.0	10.7	9.5	3.8	3.0	2.1	2.1	2.2	1.6	3.2	9.5	10.7
				Min.	1.0	1.1	1.8	1.3	1.3	1.2	0.7	1.1	0.7	0.9	1.4	3.5
68	Holualoa Beach	10	38	Max.	9.6	7.3	8.4	6.8	5.8	9.4	6.6	7.1	10.3	4.6	7.7	10.6
				Med.	1.4	1.1	1.7	2.1	2.3	2.4	2.3	2.3	2.1	1.9	1.4	1.4
				Min.	0.0	0.0	0.3	0.1	0.6	0.4	0.1	0.3	0.4	0.3	0.0	0.0
76	Kulani Mauka	8300	6	Max.	6.6	10.5	11.1	3.9	2.4	2.1	3.3	9.8	4.9	4.0	7.0	5.2
				Med.	4.0	6.1	3.1	1.9	1.6	0.7	2.4	4.7	1.1	2.9	2.6	2.4
				Min.	T	1.6	0.6	0.5	0.5	T	T	T	0.1	0.7	T	0.0

Table VIII. (continued)

Station No.	Location	Elev. (ft.)	Years		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
77	Papaloa	5100	24	Max.	6.7	2.7	6.5	5.0	5.0	3.7	4.1	3.9	3.4	4.0	3.7	6.0
				Med.	1.7	1.1	2.0	1.8	2.3	2.2	2.2	1.7	1.5	1.1	1.0	1.0
				Min.	0.0	0.1	0.7	0.8	0.5	0.8	0.6	0.4	0.7	0.1	0.2	0.0
87	Hilo Airport	31	19	Max.	38.4	39.3	46.3	30.3	18.4	13.1	14.6	26.4	18.0	28.5	22.8	50.8
				Med.	8.0	9.0	13.4	11.4	8.9	5.6	9.0	8.7	6.0	9.6	12.6	13.5
				Min.	0.4	0.7	3.8	3.1	1.1	3.4	3.7	4.8	2.4	2.8	3.5	3.0
93	Kapoho	110	66	Max.	28.2	32.5	64.3	37.8	15.5	17.5	12.5	25.3	15.5	20.3	31.5	36.0
				Med.	9.4	6.3	8.8	6.4	5.5	5.1	6.1	6.2	7.0	6.9	8.5	9.2
				Min.	0.8	1.4	1.4	1.8	1.1	1.6	1.7	2.2	1.1	3.3	2.5	2.2
111	Halepohaku	9500	18	Max.	9.8	12.9	14.5	5.7	4.9	4.1	5.3	11.8	7.8	5.4	8.4	13.7
				Med.	1.8	3.3	2.8	1.1	0.5	0.2	0.7	1.8	0.5	1.5	1.4	2.0
				Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140	Pepeekeo	1550	31	Max.	57.4	50.3	94.0	55.2	45.8	35.7	34.2	50.0	32.7	50.0	32.0	75.1
				Med.	16.3	16.1	25.2	24.4	20.2	12.6	21.0	19.3	14.0	17.5	20.6	23.5
				Min.	0.5	2.4	(2.9)	(6.0)	5.5	6.0	4.4	8.4	3.6	2.9	6.8	4.4
148	Kawaihae	50	20	Max.	3.2	3.9	5.1	1.7	1.1	2.3	0.9	1.0	1.0	2.0	3.8	1.3
				Med.	0.9	0.2	0.3	0.2	0.3	0.2	0.2	0.1	0.2	0.1	0.1	0.5
				Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
199	Kukuihaele	950	48	Max.	30.5	28.5	53.0	48.6	24.6	14.7	28.0	35.5	14.9	23.9	35.9	29.8
				Med.	6.0	6.1	8.7	8.4	5.0	2.8	4.5	5.3	3.2	3.9	8.0	6.9
				Min.	T	1.2	2.1	2.4	0.1	0.6	1.0	0.9	0.2	0.2	0.5	1.0

Table IX. The variability in rainfall at the different gauge stations. The rainfall values are in inches for the fourteen stations of Table VIII.

	Total median rainfall for 12 months	Average rainfall per month	Standard deviation from the average	Per cent deviation
KAPAPALA RANCH (Station 36)	43	3.6	1.4	38
OHAIKEA (Station 44)	30	2.5	1.4	56
HALEMAUMAU (Station 52)	33	2.8	1.6	58
HAW. NAT'L PARK HDQTRS. (Volcano Obs., Station 54)	78	6.5	2.0	30
AINAHOU (Station 58)	66	5.5	3.8	68
HOLUALOA BEACH (Station 68)	22	1.9	.5	24
KULANI MAUKA (Station 76)	34	2.8	1.5	55
PAPALOA (Station 77)	20	1.6	.5	30
HILO AIRPORT (Station 87)	116	9.6	2.6	27
KAPOHO (Station 93)	85	7.1	1.5	21
HALEPOHAKU (Station 111)	18	1.5	.9	64
PEPEEKEO (Station 140)	231	19.2	3.8	20
KAWAIHAE (Station 148)	3	0.3	0.2	85
KUKUIHAELE (Station 199)	69	5.7	2.0	34

Table X. Daily rainfall at Hawaii Volcanoes National Park Headquarters (Station 54) during 1951. "T" indicates less than .05 inches. Quantities are in inches and the total for the year was 145.28.

Day of Month	January	February	March	April	May	June	July	August	September	October	November	December
1	.15	T	1.29	.35	.02	T	.04	.20	.20	T	.26	.02
2	.04	T	5.20	.04	.01	.02	.01	.03	T	.10	.03	.11
3	T	T	2.92	.03	.31	.13	.06	T	T	.01	.61	.03
4	T	T	.62	.39	.01	.10	.09	T	.01	.06	.14	.08
5	.01	.20	.70	.26	.01	.04	T	.05	T	T	.07	.10
6	T	.59	3.11	.32	.03	.08	.01	.54	.65	T	.10	.31
7	.08	.10	.96	.96	.12	.08	.08	4.41	T	.03	.25	.35
8	.02	T	.18	.19	.14	.13	T	.84	.11	.05	.13	.94
9	.16		T	.17	.02	.21	T	.09	.02	T	.48	.70
10	.05	T	.20	.07	T	.36	T	.05	T	.05	.28	T
11	.41	.01	.06	.28	.04	.65	.01	.06	T	.29	.30	.06
12	1.54	.01	.05	.42	.05	.70	.01	.02	.01	.05	.04	.46
13	1.08	.38	.23	.64	.11	.28	.33	.08	T	.60	.18	.07
14	.60	.83	4.26	.01	.44	.09	.34	T	.07	.06	.55	.24
15	1.03	.38	.27	T	.04	.05	.19		.11	.20	.09	.08
16	1.73	.31	.36	.04	.30	.09	.04	.34	.04	.09	.34	.02
17	.14	.23	3.53	.03	.11	T	.42	.36	T	.02	.02	.08
18	.03	2.40	.43	.09	.05	.02	.11	.01	T	.20		.34
19	T	4.18	.05	.05	.06	.04	.05	.09	T	.02	.45	.11
20	.02	2.82	.66	.03	T	T	.32	.08	T	.20	2.87	.02
21	.20	.86	.44	T	.02	.24	T	.75	T	.43	6.85	T
22	2.05	3.68	.85	.15	.03	.03	.02	T		.11	1.29	.02
23	3.81	3.30	.92	.03	.02	.40	.01	.04		.14	.31	T
24	.42	.15	.09	.18	.01	T	.07	.07		.06	.09	.09
25	.22	1.39	.39	.45	.13	.43	.07	.36	.23	.02	.03	.10
26	.13	1.03	.02	.05	.05	.23	.04	.17	.03	6.00	.18	.04
27	.18	.46		.16	.49	.04	.02	.01	.57	4.43	.16	.02
28	T	2.62	.05	.01	.07	.07	.02	.11	.06	10.00	.02	T
29	.01		.42	.38	.38	.12	T	.64	.12	.57	.09	.02
30	T		.02	.27	.30	.16	.23	.10	.04	.07	.08	.21
31			.17		.20		1.00	.21		.37		1.63
Total	14.11	25.93	28.45	6.05	3.57	4.79	3.59	9.71	2.27	24.23	16.29	6.25
Depart. from Norm.	3.03	18.35	17.03	-2.84	-2.39	.15	-2.37	2.39	-4.25	17.47	7.01	-3.91

1921. With an eye to the importance of extremes, Table VIII has been included in which this range can be seen very readily. Note the large number of zeros as the minimum value given even for those stations where the median rainfall is relatively high. In Table IX a further analysis shows that at wetter stations the rainfall is more predictable and varies less during the year. The wetter stations are for the most part on the trade wind side of Kilauea or its east rift and thus under this steadier influence.

It is not surprising that the daily record of rainfall during the month shows random variation in turn. Table X is presented to show the variation during 1951 on a daily basis at Park Headquarters. Here the rainfall is a little less than 100 inches per year, but this particular year it was 145 inches. Yet note that during the 17th to the 25th of September and earlier in late January and early February there were dry periods. Actually this particular September was a drought month with less than half the usual precipitation, but the particular February was unusually wet. This disparity between dry periods and "departure from the norm" is an indication of the degree of randomness to be expected.

Dry periods are surely more serious for the vegetation in these very porous soils than unusual periods of high daily rainfall such as occurred (Table X) on February 18-23. The rainfall first increases (Fig. 11) as one follows the trade winds from the coast up the slopes to successively wetter areas. There the drought periods are fewer and less extensive, but as one passes the saddle between Kilauea and Mauna Loa or over the ridge, *i.e.*, the rift zone extending to the east from Kilauea, the rainfall drops. As it drops, longer and more severe drought periods appear. At the north rim of Kilauea, an area with an average rainfall of about 100 inches of rain per year, there is rain almost every day, yet (Fig. 13) a month with five inches of rain may leave several days with none.

Figure 13 illustrates daily variation in rainfall graphically. Such variation can be expected to be especially critical for seedlings and the first populants of lava flows and ash falls. A perusal of Table VI of the rainfall in the 1959 Kilauea Iki "devastated area" will indicate the rather certain presence of critically dry several-day periods there where it is not very wet anyway and nearly within the clearer area of the leeward side of the island where the higher insolation and drier air puts a stronger water stress on the populations.

F- TEMPERATURE

Temperature is less important in the more frequently seen parts of the Park than other factors such as rainfall. Very near the shore the temperature of the air a meter or so above the ground is not often greatly different from that of the sea, i.e., 24 to 26 deg. Celsius. In winter at the north rim of Kilauea, days with a minimum of over 70 deg. F. are unusual as are those over 74 deg. F. in summer. As a rule there, 40 deg. F. is a usual minimum for the year but 38 is recorded, but much of the time the daily or even monthly minimum is near 60 deg. F. On the top of Mauna Loa, where during some years there may be snow all the year around, the temperatures vary widely.

There are but few daily records of temperatures from within the Park, however, one set of data (Table XI) for Park Headquarters is given here as an example. It should be noted that frost has not been recorded at the 4000-foot level below which the most dense vegetations and deepest, most mature soils are found. The extreme range is 37 to 85. The mean range of

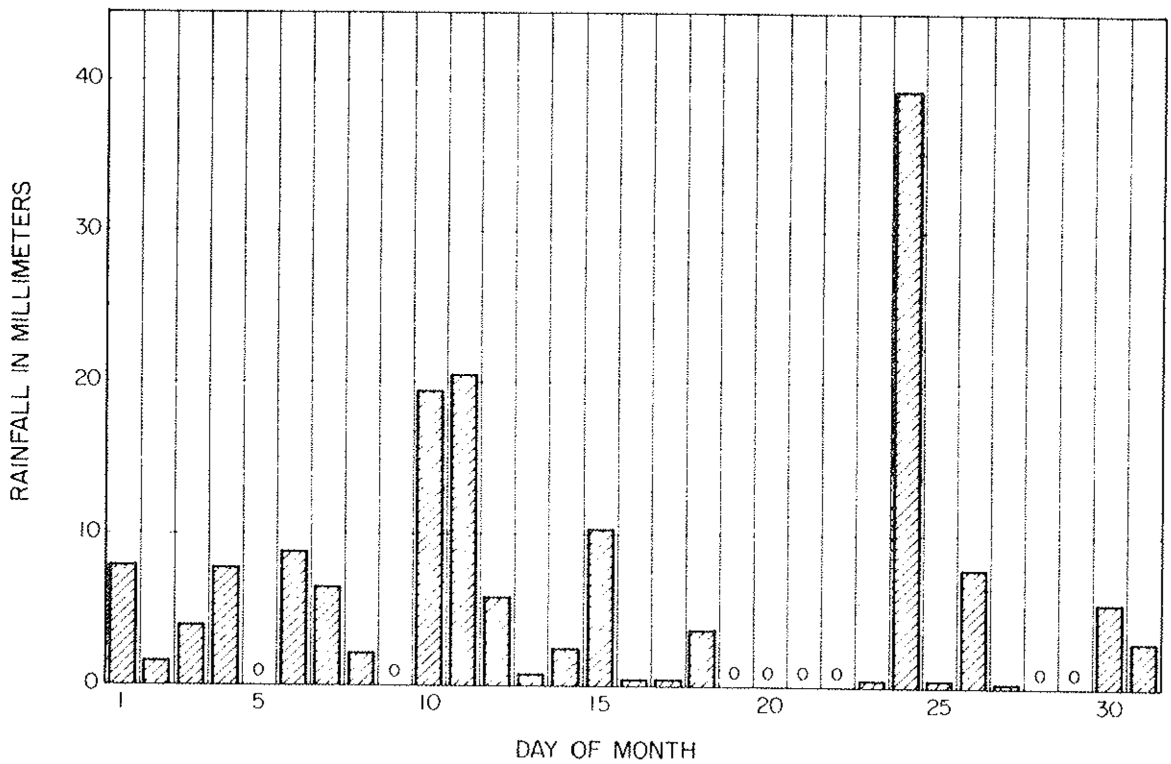


Fig. 13. Histogram of rainfall measured at the residence of Chester Wentworth (= "Kilauea North Rim Station" of various records) during the month of January, 1965.

Table XI. Temperatures recorded at Hawaii Volcanoes National Park Headquarters (Station 54) at 3971 feet elevation from 1948 through 1962. The values are in degrees *Fahrenheit*. Values on the line following the year are maxima for the months concerned, and those to the right and below this line are the minimum values.

Year	January	February	March	April	May	June	July	August	September	October	November	December	An
1948	70 42	72 38	70 42	73 48	82 48	76 47	80 50	78 88	76 50	73 51	75 46	68 44	82
1949	69 40	71 40	70 41	69 44	72 47	74 48	75 50	74 51	75 46	78 49	73 41	73 42	78
1950	74 44	72 44	70 42	71 43	73 48	73 51	75 50	75 50	78 46	75 50	75 49	76 42	78
1951	71 43	74 37	73 48	71 45	47	75 48	76 50	75 50	79 45	74 45	73 49	74 42	79
1952	70 41	72 46	73 47	69 47	72 45	73 50	77 50	76 51	74 49	77 48	73 51	73 45	77
1953	74 42	72 46	70 45	72 47	74 51	72 51	75 50	80 50	76 50	74 49	71 48	73 41	80
1954	72 39	75 44	73 38	76 49	75 48	78 53	76 52	75 53	75 51	76 51	76 45	71 46	78
1955	70 45	70 45	73 42	69 46	70 49	71 48	72 50	73 50	74 49	75 50	76 48	73 41	76
1956	72 45	70 46	69 46	72 43	72 49	75 49	75 49	75 52	76 52	76 51	75 44	72 42	76

Table XI. (Continued)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1957	70 / 46	72 / 42	70 / 41	73 / 47	73 / 47	75 / 50	78 / 52	78 / 50	79 / 49	78 / 49	74 / 47	72 / 47	79 / 4[illegible]
1958	72 / 42	74 / 43	73 / 41	73 / 48	73 / 49	75 / 50	77 / 53	79 / 53	78 / 52	74 / 51	75 / 47	75 / 43	79 / 4[illegible]
1959	75 / 43	72 / 45	76 / 47	73 / 48	74 / 47	75 / 50	79 / 50	79 / 53	78 / 46	80 / 48	79 / 49	70 / 44	80 / 4[illegible]
1960	73 / 43	73 / 42	74 / 45	70 / 48	73 / 48	74 / 49	79 / 50	78 / 52	85 / 50	78 / 49	74 / 47	74 / 45	85 / 4[illegible]
1961	71 / 44	74 / 44	72 / 43	72 / 42	74 / 48	74 / 46	75 / 50	79 / 50	75 / 46	77 / 48	73 / 48	71 / 41	79 / 41
1962	71 / 44	75 / 42	72 / 44	74 / 47	73 / 47	77 / 47	78 / 50	75 / 49	73 / 49	75 / 46	73 / 49	74 / 40	78 / 4[illegible]
Mean Max.	71.6	72.5	71.9	71.8	73.6	74.5	76.5	76.6	76.7	76.0	74.3	72.6	78.9
Mean Min.	42.9	42.9	43.5	46.1	47.9	49.1	50.4	50.8	48.7	49.0	47.2	43.0	40.8

the monthly extremes being 38.1 deg. Fahrenheit (21.2 deg. Celsius).

To provide contrast, a similar record (Table XII) from a lowland area, General Lyman Airport, Hilo, Hawaii, is included. Note that the temperatures are higher and there is less variability, in line with the statement, above, about near-shore areas, than at the higher elevation. The maximum for the 15-year period being 93 and the minimum 54; the mean range of the monthly extremes being 32 deg. Fahrenheit (17.7 deg. Celsius).

G- DATA MOST NEEDED

Climatic data in the categories discussed above are badly needed for more localities within the Park to provide a reliable conception of the extremes and consistency of the different factors. These, to be most economically maintained and useful for bio-ecological studies, should be across the major climatic gradients recognized in the Park. To oversimplify for the moment, these gradients are that to be seen with elevation on a line between Kalapana and Kilauea and on to the top of Mauna Loa and that found in the areas of Park interest on a line that might be drawn from Hilo to Kilauea through the Upper Olaa Forest Reserve and continued thence to the shore at, say, Halape. However, special stations should be established and maintained, e.g., in the Kau Desert and in the devastated areas and other special-study areas. These should be so instrumented and continued that bi-weekly, or at least monthly, temperature and rainfall values are obtained for a ten-year period. Records of light, humidity and wind should be made at a few sites along these transects. Likewise at a few sites variations during the day in the other factors as well as day to day variations should be carried out to determine their nature during typical and especially during extreme periods.

Table XII. Temperatures recorded at General Lyman Airport, Hilo, elevation 31 feet, between 1948 and 1962. The values are in degrees Fahrenheit. Values on the line following the year are maximum values for the months concerned, and those to the right and below this line are the related minimum values.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annua
1948	82 55	85 58	82 58	89 60	84 64	85 65	87 66	85 66	84 66	84 65	82 64	79 66	89 65
1949	83 58	80 60	80 57	80 60	83 64	85 64	83 63	83 66	85 62	86 62	83 58	81 56	86 56
1950	89 60	84 62	84 60	82 60	83 62	84 65	84 63	93 63	85 64	85 60	86 62	82 60	93 60
1951	84 60	81 56	88 60	83 61	84 62	88 63	86 65	85 64	88 64	85 62	84 62	85 60	88 56
1952	81 59	82 60	81 60	81 61	83 62	83 64	87 64	85 64	84 64	88 64	83 64	82 60	88 59
1953	84 58	82 57	81 59	82 60	82 63	83 63	83 65	86 65	84 65	85 63	81 63	82 59	85 57
1954	87 57	83 56	87 61	88 61	85 62	85 65	85 64	85 66	87 66	85 62	85 61	80 58	88 56
1955	82 59	81 58	86 56	81 59	80 62	82 64	84 63	83 63	84 62	84 62	86 62	85 58	86 56
1956	85 60	84 57	81 59	82 59	82 61	83 61	85 63	85 64	85 64	85 63	88 59	85 59	88 57

Table XII. (Continued)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Ann
1957	85 60	81 57	83 57	86 60	84 62	85 64	85 64	85 66	88 65	86 65	85 62	85 61	88
1958	86 57	85 57	82 56	82 62	83 62	84 63	85 65	88 67	85 65	89 63	84 60	85 57	89
1959	89 60	83 59	82 60	84 62	84 64	86 64	88 65	88 65	85 62	86 62	84 63	81 59	89
1960	83 58	87 55	84 59	83 62	84 62	86 64	87 64	88 65	85 64	90 64	83 61	84 58	90
1961	86 55	86 59	84 60	84 61	84 62	86 64	86 64	86 66	86 63	91 64	85 64	83 59	91
1962	84 63	85 55	84 62	86 65	85 66	87 69	89 70	87 71	88 69	87 64	86 63	84 54	89
Mean Max.	84.7	83.2	83.3	83.5	83.3	84.8	85.6	86.1	85.5	86.4	84.3	82.9	88.
Mean Min.	58.6	57.7	58.9	60.9	62.7	64.1	64.5	65.4	64.3	63.0	61.9	58.5	56.

Actually, a very commendable study was begun by Mr. Garrett Smathers in the area devastated by the ash fall from the 1959 Kilauea eruption. The rainfall data are given here for this area (Table VI) though the record is brief and from records read only once a week; Figure 10 shows the location of these gauge stations. The biological events on the Kilauea Iki ash fall are discussed elsewhere, below.

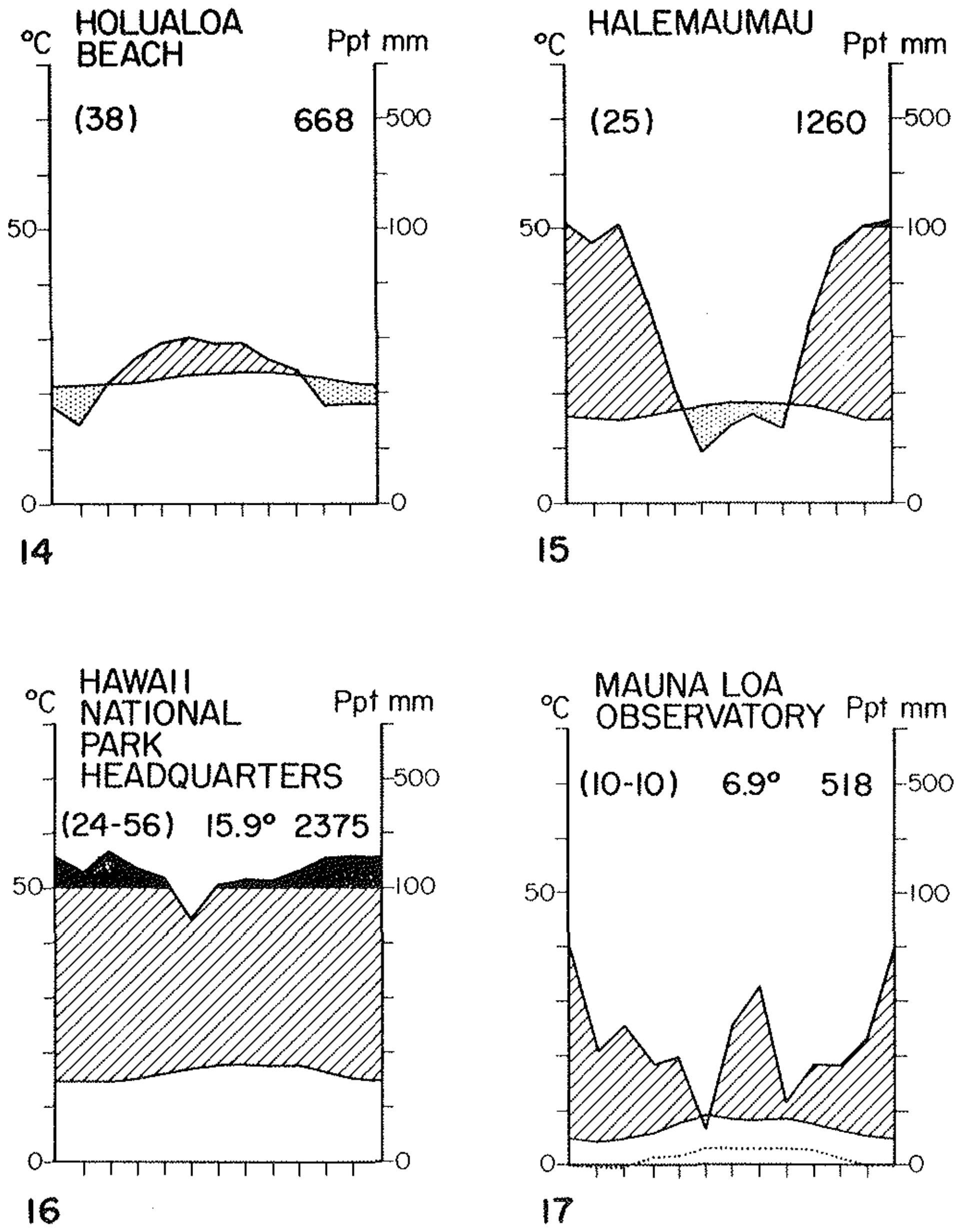
Chapter IV- Climate

by Dieter Mueller-Dombois

The effect of the weather elements described in the above chapter is climate. Climates may be described by such terms as high or low altitude, temperate or tropical, hot, etc. Such terms are interpreted by and convey different subjective meanings to different people and generally convey no one meaning uniformly.

Seeking a way to objectively diagram the climates of the Park, various graphic integrations of weather were considered. Finally, a method (Figs. 14-18) expanded upon at length and used by Walter (1957, 1964) was selected. Searching for the origin of this method of diagramming led us to the story that it was possibly first applied by a meteorologist attached to the German army in North Africa. It is said he devised the method merely as a means of illustrating the principal features of temperature, drought, rainfall and general wetness in briefing sessions. However, *e.g.*, Boergesen earlier (1929) used a similar graphic presentation in discussing the climate of the west coast of India.

The climate diagrams used (*e.g.*, Figs. 14-17) were prepared following Walter's method in which 10 deg. C equals 20 mm of rainfall. Each climate diagram shows on the abscissa the months of the year from January (extreme left) to January (extreme right). Mean monthly temperatures (in deg. C) are plotted in reference to the left ordinate, and monthly precipitation (in mm) is plotted in reference to the right ordinate, resulting in annual temperature



Figs. 14, 15, 16 & 17. Climatic variation in the Park as illustrated by the climate diagrams from, respectively, Holualoa Beach, Halemaumau Crater, Park Headquarters and the Mauna Loa Observatory. The construction and interpretation of these diagrams is given in the text. The location of these and others in respect to the Park is given on Figure 8.

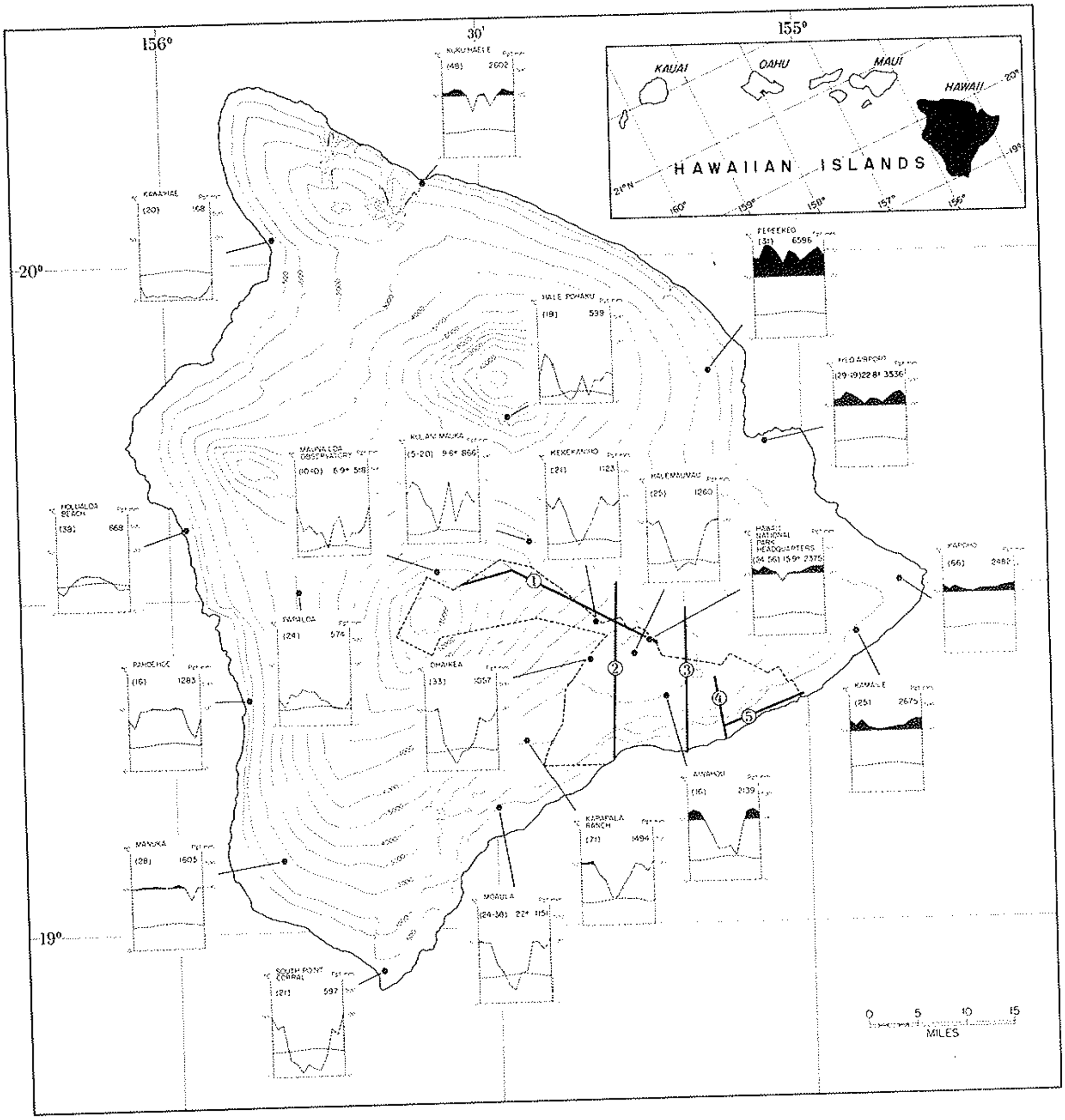


Fig. 18. Orientation map of the island, Hawaii, showing general topography, an outline of Hawaii Volcanoes National Park and illustrating the climates at different weather stations by means of climate diagrams. The five straight lines on the National Park area illustrate the locations of the five vegetation transects numbered 1-5 and discussed in Chapter VIII.

and precipitation curves. Empirical observations have shown that at this scale a pronounced drought period is in evidence whenever the precipitation curve undercuts the temperature curve (dotted fields).

For practical reasons, the precipitation scale on the climate diagrams (e.g., Fig. 16) has been reduced by a factor of 10 for any monthly rainfall in excess of 100 mm (blackened fields). At the highest altitude station, Mauna Loa Observatory at 11,150 feet, the average monthly minimum temperatures were additionally plotted (Fig. 17, dotted curve) to show the period with daily night-frost as recorded in the standard shelter 1.5 m above ground.

The rainfall records read were obtained from Taliaferro (1959) with the exception of those for the Mauna Loa Observatory, which were obtained directly from the U. S. Weather Bureau, Honolulu. The rainfall data of Kulani Mauka and South Point Corral were extended with 14 years of further records from the U. S. Weather Bureau. The length of the recording period in years is shown on each diagram (Figs. 14-18) in the upper left-hand corner beneath the station name. Where two figures are shown, separated by a dash, the first refers to the recording period for temperature, the second to that for rainfall. The mean annual rainfall (in mm) is shown in the upper right-hand corner on each diagram.

Only 5 stations have temperature records. For these, the mean annual temperature (in deg. C) is shown in the upper central part of the diagrams (Figs. 16 & 17) in front of the mean annual rainfall. The temperatures for Hilo Airport, Hawaii National Park Headquarters and Pahala (Moaula) were obtained from Blumenstock (1961). The temperature records for the Mauna Loa Observatory and Kulani Mauka were obtained from the U. S. Weather Bureau, Honolulu. The temperature curves for the other 16 stations were extrapolated as follows:

1. The Mauna Loa Observatory values were adjusted to obtain values for Hale Pohaku at 9500 feet by correcting for the altitudinal difference as follows:

	Mean temp.	Altitude
Mauna Loa Observatory	6.9° C	11,150 ft.
Kulani Mauka	9.6° C	8,300 ft.
Difference	2.8° C	2.850 ft. (= 1°C/1000 ft.)

2. The Pahala values (Moaula) were, similarly, used for South Point Corral by the following correction:

	Mean temp.	Altitude
Park Headquarters	15.9° C	3,971 ft.
Moaula	22.0° C	550 ft.
Difference	6.1° C	3,421 ft. (= 1.8°C/1000 ft.)

3. The Park Headquarters data were adjusted for all stations in and near the Park (i.e., Halemaumau, Ohaikea, Kekekaniho, Ainahou, Kapapala Ranch) using 1.8°C/1000 feet as an altitudinal correction factor.

4. The Hilo data were used for all remaining stations with the following altitudinal correction:

	Mean temp.	Altitude
Park Headquarters	15.9° C	3,971 ft.
Hilo	22.8° C	31 ft.
Difference	6.9° C	3,940 ft (= 1.9°C/1000 ft.)

The principal differences in the climates distinguished by the climate diagrams (Figs. 14-17) are in respect to the degree and timing of wetness. The several months per year when rainfall exceeds the 100 mm mark (Fig. 16) indicates a humid climate at Park Headquarters. Higher a dry climate (Fig. 17) can be expected and southwest of Park Headquarters a longer summer (Fig. 15) or, if one were in or nearer Kona (Fig. 14), a winter-drought climate. Temperatures are always higher in the summer, but the degree is indicated as "warm" (Fig. 14), moderate (Figs. 15 & 16) and cool (Fig. 17). At this latter station freezing temperatures are experienced every night from mid-November through mid-April as indicated by the dotted line across the bottom of the figure.

Inspection of the 21 climate diagrams (Fig. 18) constructed as described above has led to interpretations that seem to be consistent with the observations one can make on the vegetations, soils and other factors that would appear to be related.

It is to be hoped that in the not too distant future more complete temperature records as well as rainfall and temperature records from a wider range of habitats within the Park will become available. In a broad sense, but on the basis of the present classification, the following three general climatic areas are recognized on the island and within the Park.

(a) The climate near sea level: The climate diagrams show clearly the effect of the northeast trade winds in producing (Fig. 18) a climate on the northeast side of the island that is humid throughout the year. Only the most northern windward station (Kukuihaele) shows rainfall amounts of less than 100 mm in June and September, but rainfall amounts stay well above the temperature curve, showing that there is hardly any danger of dryness or drought. On the leeward side exist approximately the same temperature relations as on the windward side. However, the rainfall pattern is entirely different, as one would expect, and there is without doubt more sunlight. Here, rainfall distribution is not of one type, but of four different types. The most northern leeward station, Kawaihae (Fig. 18), shows a typical desert climate as the rainfall curve remains below the temperature curve throughout the entire year. Holualoa Beach (Figs. 14 & 18) shows a winter-drought climate and Pahoehoe and Manuka a humid climate, comparable to those on the windward side. Finally, South Point shows an extreme summer-drought climate. While perhaps less severe this summer-drought climate extends northeastward along the Park's coastal lowlands.

(b) The climate at mid-altitudes, below 5000 feet: At the Park Headquarters (Figs. 16 & 18) the mean temperature is 7 deg. C cooler than at sea level, but rainfall distribution clearly indicates a humid climate of the same type as that of the windward low-elevation stations. Just three miles to the southwest, at Halemaumau (Fig. 15) there is a distinct summer-drought climate as there is similarly to the west at Ohaikea. The change in climate up-slope from Park Headquarters is not quite as abrupt, but yet distinct, showing a reduction in summer rainfall, which is particularly pronounced in June, e.g., at Kekekaniho. A broad area extending south of Halemaumau shows less extreme reduction of rainfall in summer. There is a similar climate east and south of the Kau Desert. Ainahou, at nearly 3000 feet elevation, shows a similar summer-dry climate as does Kapapala Ranch (outside the Park boundary) near the 2000 foot elevation. Further south below the pali (at Moalua) the typical summer-drought climate extends to South Point Corral.

(c) The climate at higher elevations, above 5000 feet: Hale Pohaku, on the south slope of Mauna Kea towards the saddle at the 9500 foot elevation, shows two summer-drought periods—a well pronounced one in June and a less pronounced one in September. Both these rainfall reduction periods are shown also on the upper windward slope of Mauna Loa (at Kulani Mauka and the Mauna Loa Observatory, Fig. 17), but they are less pronounced here. The higher elevations in the Park, though drier, have this same climate if we interpret correctly from the adjacent stations and topography. It can be seen that the two rainfall reduction periods in June and September are indicated also at the most northern windward station, Kukuihaele, indicating an affinity in rainfall distribution to the northern windward area. Papaloa, on the leeward slope of Mauna Loa, shows two dry periods, one in October through December, and one in February. This rainfall pattern shows an affinity to the second leeward low-elevation station, Holualoa Beach, which has a distinct single winter-drought period.

The reduction in mean air temperature with increasing elevation is only 1 deg. C per 1000 feet at the higher altitudes above 5000 feet, while from sea level to 5000 feet the decrease is nearly twice as great. This temperature amelioration at higher altitudes can be attributed to a temperature inversion pattern that has been observed on the east flank of Mauna Loa above 5000 feet. (Mr. Saul Price, unpublished data, U. S. Weather Bureau, Honolulu.) The average monthly minimum temperature curve at Mauna Loa Observatory indicates (Fig. 17) nocturnal freezing temperatures from the second half of November through the middle of March. However, ground frost can be expected throughout the year. On the assumption that nightly minima at the soil surface are 10-12 deg. C below mean air temperature measured at 1.5 m above ground, the boundary of nocturnal ground frost (*i.e.*, occurring almost every night of the year) has been arbitarily accepted here as at an elevation of 8500 feet.

Chapter V- Soils

by Dieter Mueller-Dombois

A- INTRODUCTION

This chapter attempts to summarize available information on the edaphic factors in the Park. Edaphic factors are those that relate to the soil. Perhaps the first question that could be asked is, whether there are any soils in Hawaii Volcanoes National Park, as the surface area is of such recent volcanic origin. The answer to this question demands a clarification at the start. If soil is understood to be the "weathered crust of the earth's surface" as often interpreted, there is almost no soil in the Park. If, on the other hand, soil is interpreted as the "substrate of ground-rooted plants", nearly the entire Park surface, except for the most recent lava surface, can be considered "soil". A compromise has been made by soil survey workers who have classified as "soil" all surfaces consisting of an accumulation of fine separates over lava rock. On this basis more than 50% of today's Park surface is covered with soil and this soil is considered to be entirely from volcanic ash and none from disintegrated lava (H. H. Sato, personal communication). The rest of the Park surface consists of soil-barren rock material (Cline et al., 1955). However, this soil-barren rock material is not barren of plants and other organisms and thus is of considerable bio-ecological interest. Only the most recent lava flows are barren of plants and the stone desert above 11,000 feet around the summit of Mauna Loa. Even these cannot be entirely ignored when speaking of edaphic factors, as some of the initial stages of weathering and populations are well displayed even on these otherwise soil- and plant-barren surfaces.

Edaphic information relating directly to the Park is very limited, although there are several references that give more general information, some of which include observations in or near the Park area.

B- FROM VOLCANIC ROCK TO SOIL

Lyons (1896) investigated this problem by chemical analyses of selected Hawaiian soils, which he compared to the chemical composition of Hawaiian lavas. Among the selected soils he presents data on a soil from Pahala, Hawaii (outside the S. W. border of the Park). He also presents an analysis (Table I) of Pele's hair from Kilauea in the Park which was exposed to sulfuric vapor from Halemaumau. Pele's hair is of bristly, hair-like lava fragments thrown up at the margins of hot moving pahoehoe flows, where they make contact with the cooled surface material. It is considered to be of the same chemical composition as the solid lava from which it is formed. He sampled several other lava fragments from the islands including partially decomposed old lava from Hilo, which he termed "rotten lava". He stratified the soils of Table I into three classes:

1. New, from lapilli (i.e., glassy volcanic ash). This includes the soil from Pahala, and another from Waimea, Hawaii.
2. New, from partially disintegrated lava. This includes a soil from Hilo, Hawaii.
3. Old, from thoroughly disintegrated lava. This includes a soil from Manoa, Oahu.

The Table I shows that Pele's hair from Kilauea compares rather closely in composition to that of the average of Hawaiian lavas. In the overall analysis Lyons (1896) considered aluminum and iron to have remained rather constant in the formation of soils. Taking these two as a standard for

Table I. Comparison of the chemical compositions of Hawaiian lavas with that of soils in three relative age groups (data from Lyons, 1896). Values in per cent.

Chemical constituent	Average, Hawaiian lavas	Pele's hair Kilauea a/	"Rotten" lava, Hilo	New soil from ash, Pahala		New soil from lava,b/ Hilo	Old soil, Manoa, Oahu
SiO_2	47.9	45.6	24.6	70.4	42.1	31.6	42.5
TiO_2	3.6	3.3	8.1	--	--	--	--
Al_2O_3	15.1	15.1	23.9	13.0	24.0	22.1	26.9
Fe_2O_3	8.6	5.3	37.9	10.9	18.8	44.5	29.7
Ca O	8.6	10.2	trace	3.4	5.7	.4	.3
Mg O	6.1	5.9	1.0	.7	1.4	.6	.7
Na_2O	4.2	3.7	1.4	.7	.2	.2	.2
K_2O	1.1	.9	trace	.2	.4	.4	.2
P_2O_5	.1	2.5	.24	.5	6.5	.5	.3

a/ Exposed to SO_2 vapor.

b/ Partially disintegrated.

unchanged properties, he concluded that in soil formation 50% of the silica is lost, more than 90% of each of the bases, 50% of the phosphate, and very little of the titanium.

Maxwell (1898) studied the problem of soil formation in a somewhat different way. He was intrigued by the sulfuric acid steaming in the Kilauea area. He tested the acidity of the steam with litmus paper and found that it varied from neutral to slightly acid. He determined the steam at Sulfur Bank to contain 5% sulfuric acid in 1896. Then he traced the effect of acid steaming by analyzing pieces of lava under different exposures to steam (Table II). The Table shows a certain reduction in monoxides (bases) upon sulfur steaming.

Next, he analyzed a number of typical lava disintegration products. These included: A, gypsum; B, alum deposits (a mixture of sulfates of the alkalies, iron and aluminum with excess sulfur and sulfuric acid); C, a portion of the so-called "red ochre" found in layers in the lava in great quantities; D, mainly silica released in steam from lava bases, yellow on drying; E, disintegrating lava; F, sound lava, average. The data are shown in Table III.

In addition Maxwell made an experiment to study the action of acid steaming under controlled conditions. He used 52.9 grams of crushed lava (bean-size) of known chemical composition which he placed into a glass tube that was connected to an Erlenmeyer flask containing 5% sulfuric acid (i.e., the same concentration as that of condensed steam at Kilauea Crater, where the decomposition products were sampled). He allowed the acid steam to run over the crushed lava for 120 days. After this, he found 1.221 grams of solid matter in the solution. The composition of this material was: 16% SiO_2, 1.7% Fe_2O_3, 4.6% Al_2O_5, 6.5% CaO, 5% Na_2O, 5.6% K_2O, 60.7% SO_3.

Table II. Chemical composition of lava fragments exposed to differing intensities of sulfur steaming at Kilauea (data from Maxwell, 1898). Values in per cent.

Chemical constituent	Lava froth or scum not affected by steam	Same lava but exposed to sulfur steam (red)	Sample from slightly acid fissure, const. steaming
SiO_2	49.0	55.5	62.5
Al_2O_3	16.1	16.0	9.2
Fe_2O_3	7.3	5.7	5.0
FeO	10.1	6.8	3.0
CaO	10.7	8.0	4.2
Na_2O	4.2	4.4	.3
K_2O	.6	.7	.3
SO_3	.2	.6	--

Table III. Composition of disintegration products from lava at Kilauea (after Maxwell, 1898). Values in per cent.

Chemical constituent	A gypsum	B alum	C red ochre	D yellow silica	E disintegrating lava	F sound lava, av.
SiO_2	4.0	.8	32.5	75.8	67.0	49.9
Fe_2O_3	.7	12.3	44.5	4.9	8.6	14.4
Al_2O_3	--	26.2	18.1	1.5	9.7	14.5
Ca O	43.4	.5	.2	--	4.3	9.9
Mg O	.5	4.6	.5	--	6.7	4.9
Na_2O	--	1.1	2.2	4.6	3.2	2.4
K_2O	--	.5	.1	.2	.3	.8
SO_3	44.7	45.6	1.6	1.3	--	--

From this Maxwell drew his conclusions about the mode of disintegration. His data give an indication of the amount of silica removed by action of sulfuric acid on the bases in the lava. It further shows how "alum" deposits are formed by the separation of alumina and alkalies as sulfates from lava. The deposits of gypsum are simply the results of the removal of lime, while iron is less affected. This suggests that those decomposition products that are very rich in iron (i.e., red ochre) are residual rather than separation products; that is, they show what is left of the original lava after the soluble silica, and the elements which form the alums and gypsum have been removed. He points out also that there are modes of disintegration other than sulfuric acid steaming, some of which result in the removal of iron.

Starting from the Kilauea area Maxwell located abundant evidence for sulfuric acid steaming as an important rock decomposing phenomenon, firstly by pointing out the abundance of old cinder cones down to sea level away from the great centers of volcanic activity; secondly by sampling what appeared to be lava-decomposition products in soil-covered areas on all larger islands. The "earth" samples, as he calls them, were taken from various depths (road cuts, etc.) and classified according to their color-resemblance to the recent lava-decomposition products in the Kilauea area. Partial chemical analyses of a large number of these color-classified samples showed a close chemical similarity to currently forming decomposition products in the Kilauea area.

The effect of steam on Kilauea lava was investigated experimentally also by Ferguson (1919). However, the objective of Ferguson's experiment was quite different from that of Maxwell. It had been suggested that steaming in general (not necessarily acid steaming) was effective in converting ferrous oxides (FeO) to ferric oxides (Fe_2O_3). If this was a universal process, the presence of olivine and other iron-bearing minerals (high in ferric oxides) found in association with glass of Kilauea lava could be taken as an indication of the water content of volcanic exhalations. Preliminary experiments had shown that lava was not appreciably attacked by water vapor at 1000°C. Ferguson used powdered Kilauea lava that was heated to 1000° or 1100°C in a platinum boat, in a porcelain tube through which steam was passed for a period of an hour for each of several tests. There was no formation of ferric oxide in spite of the fact that some ferrous iron was lost. He attributed the reduction of ferrous iron to the deliberation of reducing gases from the lava on account of heating and also, to some extent to absorption of iron by the platinum boat. Thus, the steam appears to have acted as an inert gas, and the tests leave no doubt that ferrous iron, when in silicate combinations, can exist in the presence of water vapor at high temperatures. In lava, ferrous oxide does not exist as a separate phase, but mainly in silicate minerals. Ignition experiments have shown that free oxides are much more easily oxidized. Ferguson's experiments seem to indicate that the red layer in pahoehoe (near the surface, for example) is not the result of steaming, but probably of differential original heating.

McGeorge (1917) investigated the chemical changes involved in the formation of Hawaiian soils from parent rock and ash. Among one parent rock analysis series he included Pele's hair, a sample from the 1910 overflow of Kilauea and various other dated flows of Hawaii. In discussing the change from lava to soil he emphasizes the individual elements in relation to their relative abundance in the different textural classes, sand, silt and clay and elaborates on the properties of the differently sized soil particles. He had assumed that the larger particles (coarse sand) had more nearly the composition of the parent lava, since disintegration had not far progressed in these. However, he found in most cases that leaching was already so complete that there was little difference in composition whether the soil was from lava or ash. The coarse particles consisted in most cases of complex magnesium silicates. His main conclusions are (1) that there is a wide variation in the chemical composition of soil particles of the same size, (2) that this is due primarily to differing intensities of weathering and (3) that iron, titanium and manganese are most prevalent in coarse grains and silica, aluminum and phosphate in fine grains.

Hough et al. (1941) also tried to obtain an idea of the direction or course of weathering by comparing the composition of soils of differing degrees of weathering with that of unweathered parent rock. Similarly as Lyons (1896) they divided the sample-soils into three age groups, but they also related them to rainfall. The three age classes of soils were marked "exceedingly young", "young" and "old". The exceedingly young soil class included a soil near the Park. The source of the sample is described as a semi-virgin roadside location on a gentle sloping spur of Kilauea Volcano in the Kilauea truck-farm region, Hawaii (May 1936). Two other "exceedingly young" soils sampled were from near Hilo and near Olaa, respectively. In the category of "young" soils, they included a soil from Moaula near Pahala, outside the southwest border of the Park. This soil, from Pahala ash, may compare to the soil on Puu Kaone inside the Park in the coastal lowland below Hilina Pali, which is likewise from Pahala ash. The category of "old" soils included samples from the older islands. The following table (Table IV) shows the data on the two soils from near the Park and an "old" soil from Maui. Their constituents are compared to that of Hawaiian lavas. The latter compare rather closely to the data of Lyons (Table I) and Maxwell (Table III).

Table IV. Composition of Hawaiian lava and three soils of different age groups (data from Hough *et al.*, 1941). Values in per cent.

	Hawaiian lava	"Exceedingly young" soil, Kilauea (2500 mm rain)	"Young" soil, Moaula (1250 mm rain)	"Old" soil, Maui (2500 mm rain)
SiO_2	36-62 av. 49	47.5	36-40	8-21
Sum of bases	12-31 av. 21	21-23	4-6	1.5 - 2.5
Al_2O_3	8-19 av. 14	13-14	20-27	30-35
Fe_2O_3	5-22 av. 14	13-14	22-27	40-53
Combined water	---	.5	10-12	10-16

The general trend in compositional change with weathering is quite apparent from Table IV. Hough et al. concluded that alumina are the least soluble constituents in soils that are neither markedly weathered nor in soils exposed to low rainfall, that iron is less soluble than alumina in the more highly weathered soils and that silica and the bases are by far the most soluble constituents in soil and lava. Bases are more rapidly lost than silica, particularly in the early stages of weathering. They considered the silica content to be the best index of the degree of weathering.

The above anlysis was based on whole soils (weathered and unweathered materials). In examining the colloidal fraction they obtained an even clearer picture of weathering. On this basis it was concluded that the exceedingly young soil at Kilauea is made up almost exclusively of unweathered materials. They also found that the kind of colloidal material formed varies with rainfall and to some extent with parent material. The colloidal material formed under high rainfall is lower in silica and higher in iron, alumina and combined water than that formed under low rainfall conditions.

C- SOIL FORMATION THEORY

Maxwell (1898) distinguished between "chemical" and "simple" weathering. Under chemical weathering he understood the decomposing action of sulfuric acid steaming as currently going on in the Kilauea area of the Park. He believed that not only the before-discussed chemical decomposition products are the result of acid steaming, but also the formation of lateritic soils; that is, that acid steaming is the initial process in laterization. This is best expressed by the following quotation from Maxwell (p. 54):

". . . it appears, without doubt, that the laterites of the Hawaiian Islands owe their origin on a grand scale to the action of sulphurous steam in the disintegration of the lavas."

His ideas are well developed with supporting observations and analyses. He points out, among other things, that red laterites are found on the windward and in certain areas of the leeward side of the islands, thereby occurring within a wide range of annual rainfall. He considered particularly the tufas as steam-weathered as they show a reduction of alumina, an exhaustion of lime and an enormous increase of iron. It may be remarked here that Ferguson's (1919) experiments did not lend support to the idea that the ferric iron and magnitude of red-colored lava has resulted from vapor steaming. Instead Ferguson attributed the red color to original thermodynamic changes at the time of lava formation.

Maxwell did not consider chemical weathering to have acted in broad-area decomposition, and points out that vast areas have not been influenced by this mode of disintegration. However, he said that all lava, whether influenced initially by chemical weathering or not, is decomposed by "simple" weathering into soils. Under this he understands the atmospheric influences of heat and moisture.

The course of atmospheric weathering of Hawaiian soils is well indicated in the preceding discussion. The process in which silica is removed in presence of a neutral to basic reaction caused by solution of the bases and the oxidation of iron and aluminum is generally called laterization. Laterization gives rise to reddish iron-aluminum clay soils that are base depauperated and, therefore, show an acid reaction. Hough et al. (1941) considered two stages of weathering as characteristic for Hawaiian soils, both in the category of "simple" weathering, to use Maxwell's interpretation. The first stage of weathering (laterization) gives rise to a "uniform" profile. In these the horizons do not vary by more than 5% in silica, alumina, iron and titanium. He believed that the uniformity was probably obtained when all primary minerals were decomposed. However, in 5 out of 12 old profiles analyzed, he found a marked decrease in titanium and a proportionate increase in alumina downward in the profile. Iron was found to be less abundant than at the top of the profile. Thus, there was a pattern produced by translocation of constituents, whereby alumina had moved down further than iron. This he considered a second stage in weathering resulting in a non-uniform profile, which he described as podzolization of soil material lacking in quartz and high in titanium. He thought that this type of profile develops when all primary minerals are decomposed, which may coincide with advanced leaching of the soil material indicated by a pH of 5. These non-uniform soils are probably the so-called Humic Ferruginous Latosols described by Sherman (1950) and Cline et al. (1955). They are found on all older islands except Hawaii and appear to be best expressed on Kauai, the oldest island of the group. As implied in the above soil name, laterization is still considered the major soil forming or weathering process. The major agent in physical disintegration is believed to be the amount of rainfall as implied in the following statement by Stearns and Macdonald (1946), which refers to an observation at the northern tip of Hawaii near Mohukana:

> "The fertile red-brown soil, 10 to 20 feet deep and covered with crops, thins to 2 feet or less of red soil sparsely covered with desert vegetation. The rocks along the road are the same age; the change in soil depth is due solely to decrease in rock decomposition with increase in aridity."

In the Park itself no such observations have been made. Here soil depth is almost solely a function of the depth of the ash deposits. The soils are extremely recent in origin, and the more weathered ash beds are those composed of Pahala ash, which underlies some of the soils in the east and southwest area of the Park, and which is locally exposed on Puu Kaone. In this deposit the ash and lapilli are now almost entirely altered to a yellow-brown as orange palagonite (Macdonald, 1946). This is a secondary mineral that develops in the early stages of weathering of volcanic glass. It appears to be an amorphous aluminosilicate containing Ca, Mg and K ions (Swindale & Sherman, 1964). Thus, in the Park, soil formation is only incipient.

D- SOIL TERMINOLOGY

The Park area was included in the State-wide soil survey reported by Cline et al. (1955). The soils are classified into several categories that fit into one another like smaller boxes into larger ones. The largest category includes three separations, zonal, intrazonal and azonal soils. Zonal soils are those in which the major soil-forming influences or factors are the zonal climate and the zonal vegetation. Intrazonal soils are those in which edaphic or topographic factors assume a greater influence on soil formation than does zonal climate. Such soils are, for example, those on steep slopes or in poorly drained positions. Azonal soils are those of recent origin, in which soil formation is not yet reflected by well developed soil horizons on account of too short a time for weathering. Most of the Park soils are, therefore, azonal soils.

Another important, smaller soil category is the "Great Soil Group". The criterion for classifying soils into one of several great soil groups is their specific reflection of a major soil forming process in terms of soil horizon development. For example, within the group of zonal soils, two major soil forming processes have been recognized for the Hawaiian Islands, laterization and calcification. The latter process occurs in areas where rainfall is insufficient to leach out the bases, which instead are found to accumulate in horizons below the surface. These soils are found on the leeward sides of the islands. Their over-all soil formation is, however, related also to laterization. Thus within these two soil forming processes, a few soils can be separated as to the relative intensity of each process. For example, there are four types of lateritic soils recognized: Low Humic, Humic, Hydrol Humic and Humic Ferruginous Latosols.

The 1955 Soil Survey Report comes equipped with two kinds of soil maps: generalized and detailed. The generalized maps show the soils for each island at the "Great Soil Group" level. According to this, four great soil group types are found in the Park: a Hydrol Humic Latosol (zonal soil), a Latosolic Brown Forest soil (intrazonal)[1/], a Regosol (azonal, material consisting of relatively unweathered ash) and a Lithosol (azonal, material consisting of relatively unweathered lava rock).

The detail maps cover the islands in several sections at a scale of 1:62,500. They show still smaller and more homogeneous units, which are recognized in the successively smaller group concepts of "Soil Family", "Soil Series", "Soil Type" and "Soil Phase", each larger unit again contains several of the next smaller ones. The concept "Soil Family" takes care, to a certain extent, of the natural continuum, by allowing for separation of typical and atypical profiles in a "Great Soil Group". Up to this point, only soil genetic features have been stressed. Differences in parent material and minor differences in the profile are recognized in the "Soil Series" concept.

1/ Recently also considered as zonal rather than intrazonal soil (Swindale & Sherman, 1964).

On the level of soil series and family, soils are named according to the locality where the soil in question was first described. For example, the name "Kapapala series" refers to the Kapapala Ranch (outside the southwest border of the Park), where this particular soil was first described. The same name is then applied to all soils with similar characteristics regardless of their location. The concept "Soil Type" refers to a subdivision in a series based on textural differences of the surface soil. An example would be Kapapala loam. The ultimate separation is that into "Soil Phases", in which differences in degree of slope, stoniness, erosion and soil depth are recognized.

The intensity of soil survey is classified into 4 categories: compiled maps, reconnaissance survey, semi-detailed survey and detailed survey. These survey intensities are defined and shown on an orientation map that accompanies the 1955 Soil Survey Report. According to this, the Park has been mapped at the Reconnaissance Survey stage, which means that traverses were run at 1 to 10 mile intervals. The soil categories mapped vary from family to phase; i.e., they differ in homogeneity and size in accordance with the before mentioned criteria. More recent, as yet unpublished information, is presently compiled on a more detailed survey basis. Some of this is included here (H. H. Sato, manuscript).

E- TYPES OF SOILS AND THEIR DISTRIBUTION

Since this information is intended for bio-ecological purposes, the soils are summarized here (Fig. 19) on the basis of their major physical characteristics. The major criterion used for regrouping is volume of soil material in terms of depth to underlying bedrock and surface coverage within type; i.e., whether occurring in pockets only, or being discontinuous or continuous over the bedrock. This form of summary should facilitate an

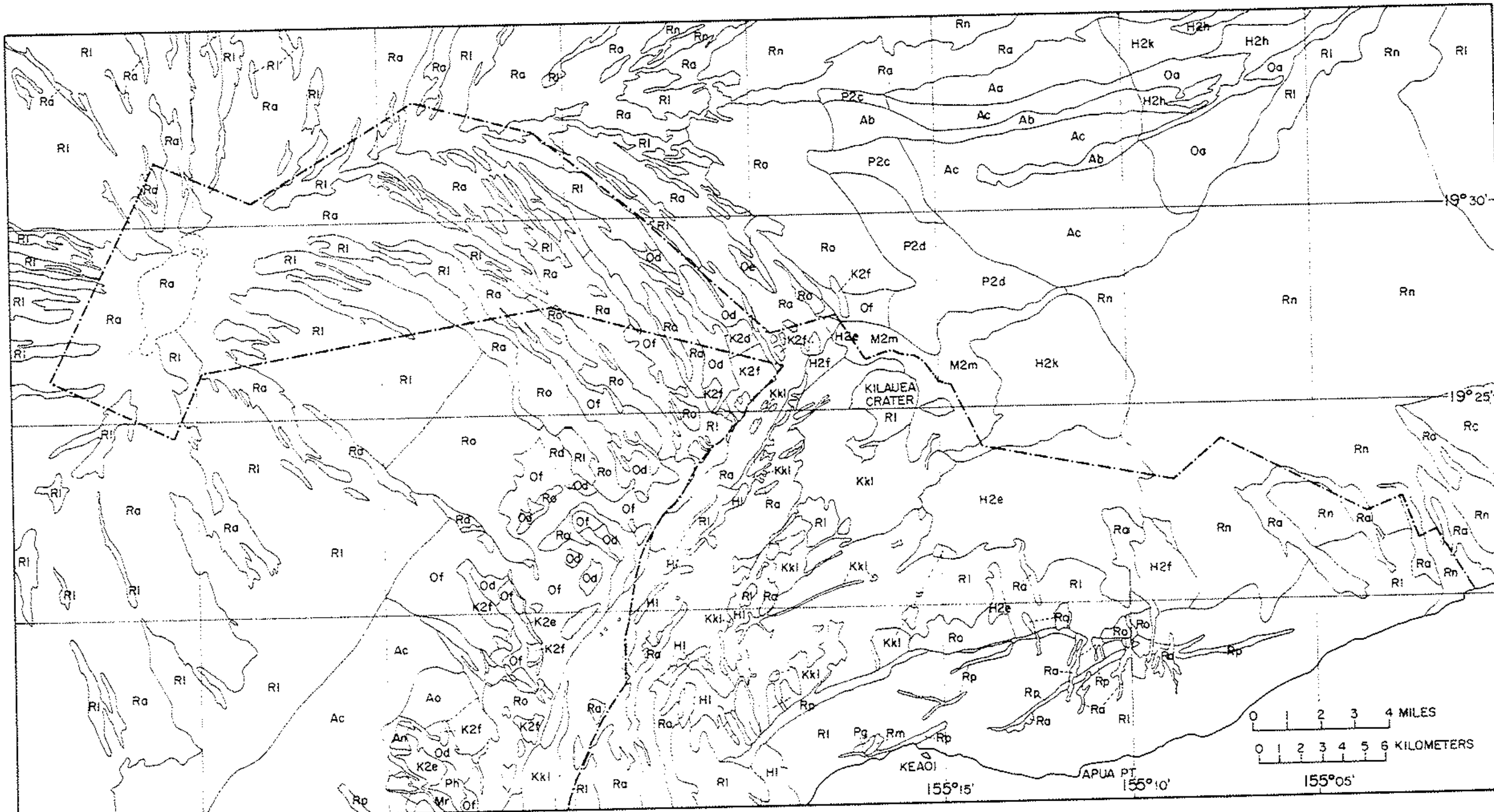


Fig. 19. Soil Map of Hawaii Volcanoes National Park (Cline *et al.*, 1955), Hawaii Sheets No. 7 and 8. The Park soils are described in three geographic areas: Area 1, Mauna Loa east slope, from summit to Kipuka Puaulu (Bird Park); Area 2, from Kilauea Crater south to coastline and southwest along Park border and Kona highway; Area 3, from north around Kilauea to east and southeast (near Kalapana). The symbols which are given outside the Park are explained in Cline *et al.*, 1955.

H2e........Horizontally continuous ash-soil, 30-60 cm deep, in summer-dry climate (Area 3).

H2f........Very shallow, discontinuous ash-soil in summer-dry climate on pahoehoe (Area 3).

H2k........Very shallow, discontinuous ash-soil in humid climate on pahoehoe (Area 3).

Hl.........Ash-pocket soil, weakly developed Al (southern fringe area of Kau Desert) on pahoehoe (Area 2).

K2d........Horizontally continuous ash-soil, moderately deep (15-150 cm, averaging 100 cm) and Ohaikea soil (Area 1).

K2f........Horizontally continuous ash-soil, very deep (2 m+) Kipuka soils (Area 1).

Kkk........Horizontally continuous ash-soil, shifting ash dunes (Area 2).

Kkl........Horizontally continuous ash-soil, stable, raw ash (Area 2).

M2m........Horizontally continuous ash-soil, 32-100 cm+ deep, in humid climate (Area 3).

Od.........Horizontally continuous ash-soil, shallow (10-50 cm deep) (Area 1).

Oe.........Very shallow, discontinuous ash-soil on a'a (Area 1).

Of.........Very shallow, discontinuous ash-soil on pahoehoe (Area 1).

Pg.........Horizontally continuous ash-soil; Pahala ash-soil on Puu Kaone (Area 2).

Ra.........A'a-lithosol (Areas 1, 2 & 3).

Rd.........Ash-pocket soil on a'a (Area 1).

Rl.........Pahoehoe-lithosol (Areas 1, 2 & 3).

Rm.........Ash-pocket soil, well developed Al (coastal lowland) on pahoehoe (Area 2).

Rn.........Ash-pocket soil in humid climate on pahoehoe (Area 3).

Ro.........Ash-pocket soil on pahoehoe (Area 1); in summer-dry climate (Area 3).

Rp.........Pali-lithosol (colluvial a'a mostly) (occurring only in Areas 2 & 3 above coastal lowland).

ecological interpretation in terms of water relations. Soil chemical differences in terms of parent materials play a minor role as all soils are considered to be (Swindale & Sherman, 1964) from phreatic basaltic ash.

The distribution of the kinds of soils in and near the Park (Fig. 19) have been summarized from the detail maps of the Soil Survey. These detail maps for the Park area are Hawaii sheet no. 7 (Mauna Loa and Kilauea with Kau Desert, i.e., the west and southwest part of the Park) and Hawaii sheet no. 8 (Chain-of-Craters Road including Kilauea Iki and Kalapana; i.e., the southeast part of the Park.)

For the detailed discussion of the Park soils which follows, the Park is divided into three geographic areas (a) east slope of Mauna Loa, (b) area south and southwest of Kilauea and (c) area north, east and southeast of Kilauea. The official soil class names and map symbols are added in parentheses to the soil categories used in this report. In addition ten profile descriptions of soils in or near the Park are shown in an Appendix to this chapter.

(1) Soils on the east slope of Mauna Loa

The area includes the summit of Mauna Loa (13,680 feet) and the Park area on its east flank down to Bird Park (Kipuka Puaulu) at about 4000 feet elevation.

The following 6 soil categories have been recognized in this area:

(a) Lithosols (2 types). These are rock-substrates without any significant accumulation of "fines" or soil material. Two major kinds are found in this area: a'a lava, barren of any soil (Rockland, a'a lava; map symbol Ra); pahoehoe lava, barren of any soil (Rockland, pahoehoe lava; map symbol Rl).

A'a lava is (Fig. 20) the broken-up, clinker like lava with numerous deep crevasses and fissures. Pahoehoe is (Fig. 20) the smooth, often ropy, bedrock-type lava, with widely spaced, usually shallow and narrow cracks. Both these major lava types are easily recognizable, but they are by no means uniform; instead they show considerable variations in physical surface shape with age of exposure. With regard to structure and surface roughness Jones (1943) has recognized (Fig. 20) eight different lava types that are well described by the Figure and in Table V.

Another interesting aspect of a'a lava structure has been reported by Macdonald (1945). He observed in many of a'a flows a massive phase, generally thicker than the clinker phase. In measured sections the proportion of clinker to total a'a varied from 15 to 66%. The massive lava core is usually found within a few feet of the surface. This feature can be observed on many road cuts in the Park.

Moreover, with regard to age, one cannot say that these two lava types, a'a and pahoehoe, though relatively barren of soil, are entirely unmodified. The two lavas differ strongly in color, particularly on the upper slopes of Mauna Loa, a'a lava being from almost black to medium brown, pahoehoe being from silvery to purplish-black over steel-gray to light brown or buff. The brown lavas are the most oxidized and weathered types and on these one finds a certain accumulation of small lava fragments particularly on the pahoehoe. Here, they usually occur in form of small cubicles (1-3 cm^3) that are broken apart _in situ_ or blown into the cracks where they form incipient soil pockets.

On the soil map (Fig. 19) the two lithosols are the only substrates that extend in an east and southeast finger-like pattern from the summit at

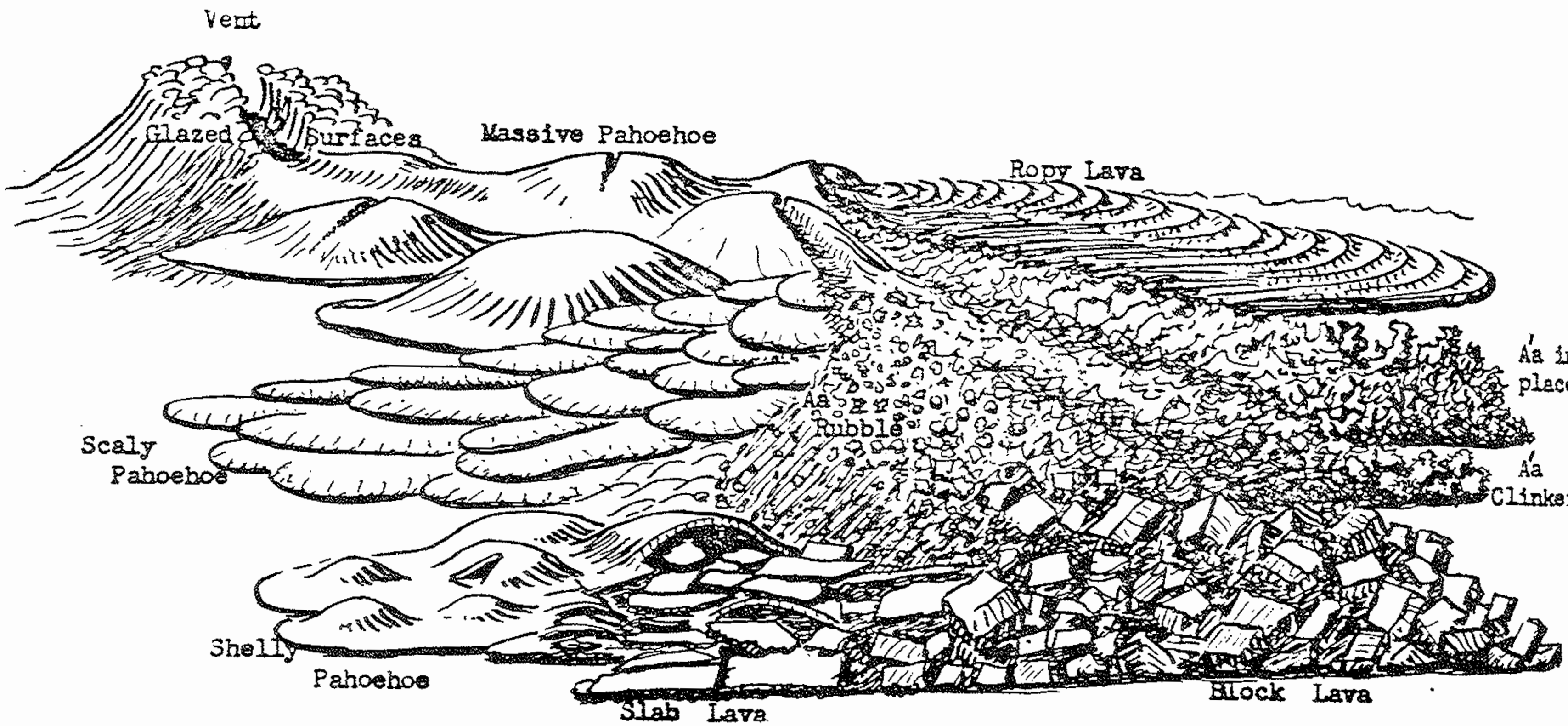


Fig. 20. Idealized drawing, illustrating a classification of lava surfaces (after Jones, 1943).

Table V. Classification of lava flows (Jones, 1943)

		Ordered smooth surfaces	to Rough disordered surfaces
Weak loose structure to solid structure	Glazed surfaces found inside caves, bubbles, and vents along with drip pendants and flow-lines	Massive pahoehoe of very thick cross-section (10+ feet) with hummocks or tumulii, and with cracks at infrequent intervals	Ropy lava (on surfaces, slabs and blocks) fine smooth ropes to coarse rough ropes (1 to 6 inches) formed by folding of viscous surfaces due to the drag of underlying mobile lava (grades to furrowed a'a)
		Scaly pahoehoe thin (one-quarter to one foot) small flow-units overlapping like scales, but solid, may show pillows and toes	A'a-lava in place Fine-a'a: 0.1 to 1 cm, < 1/2 in. Medium a'a: 1 to 10 cm, 1/2 to 4 in. Gross-a'a: 10 to 100 cm, 4 to 40 in.
		Shelly pahoehoe thin bubbles of weak structure (one-half foot) that break into slabs and plates of loose structure = slab-lava	A'a-rubble of fragmental scoriatious character, few fractured surfaces (grades from rubble to a'a-clinker)
			Block-lava usually four to five fractured sides (grades in size from one-half foot to 10+feet)

13,680 feet down to about 7000 feet. The first soils appear at this latter level, but the more recent lava flows cut as lithosols still further down through the lower limit of this geographic area at 4000 feet, here mostly as a'a lava (around Kipuka Puaulu and Kipuka Ki). It may be mentioned, however, that pumice-strewn and cinder-covered areas are also found above 7000 feet. These substrates, that have resulted from explosive volcanic activity, are physically very different. They are "Regosols" in the proper sense; i.e., substrates composed of an accumulation of relatively unweathered "fines". However, these substrates are of more local distribution and, for this reason, did not find recognition on the soil map.

(b) Ash-pocket soils (2 types). There are two kinds in this category: an ash-pocket soil on pahoehoe (Rockland, pahoehoe lava with Puu Oo, Maile or Olinda soil material; map symbol Ro) and an ash-pocket soil on a'a (Rockland, a'a with the same soil materials; map symbol Rd).

The ash-pocket soil on pahoehoe is the more dominant of the two. It extends from about 7000 feet to 4000 feet on the east slope of Mauna Loa. However, it is of restricted distribution in the Park. Two areas occur west of Ohaikea and one north of Kipuka Puaulu (Bird Park). At the high altitudinal limit, this soil forms the continuation on some of the older (buff-colored) pahoehoe flows, which are barren above 7000 feet and covered with ash-soil pockets below this elevation. Here, the soil material occurs only in pockets of 10-15 cm depth, and more than 50% of the surface consists still of barren pahoehoe bedrock. These shallow soil pockets are comprised of only one soil horizon, a dark brown to black A1. The dark coloration is caused by incorporation of organic matter, which is rather high, because of the slow rate of decomposition at these altitudes with relatively low temperatures (mean air temperature from 10^{o} at 7000 feet to 15^{o} at 4000 feet).

The soil is therefore a combination of mineral and organic particles. The mineral particles are considered to be primarily from ash rather than weathered pahoehoe particles. The soil is of loamy texture, has a crumb structure and a pH from 5.5 to 6.5.

The ash-pocket soil on a'a lava on the map is represented in Kipuka Maunaiu, but it is present also up-slope from the Mauna Loa rest house at 6600 feet to about 7500 feet along the Mauna Loa Trail. The difference from the lithosols described above is that on a'a lava the soil pockets take the form of partially to fully filled crevices. Thus, they may be much deeper than 15 cm, they are much smaller in diameter and more uniformly and densely distributed across the surface. However, in common with the ash-pocket soil on pahoehoe, more than 50% of the surface is barren rock. The a'a substrates may contain a greater volume of fine soil—as mentioned in the soil survey report—which here appears to be due to a greater contribution of weathered fine lava particles. In the above defined area, the writer noticed that many a'a rocks protruding at the surface can be broken apart by tapping with the foot.

(c) <u>Very shallow, discontinuous ash-soils (2 types)</u>. Two soils in this category are described as very shallow phases of the Olinda soil family. These are: a very shallow, discontinuous ash-soil on pahoehoe lava (Olinda family, very shallow phase—pahoehoe lava complex; map symbol <u>Of</u>), and a very shallow, discontinuous ash-soil on a'a lava (Olinda family, very shallow phases—a'a lava complex; map symbol <u>Oe</u>).

According to soil survey estimates, 20-40% of the lava surfaces is occupied by soil material in these types. Both soils are geographically rather restricted, the <u>Of</u> soil on pahoehoe forms the dominant substrate of Kipuka Maunaiu, which extends from about 7000 to 4000 feet across the southern border of the Park on the east slope of Mauna Loa, and the Oe soil on a'a forming the substrate of Kipuka Kekake at the northern Park border, from about 6000 to 4500 feet.

The very shallow, discontinuous ash-soil on pahoehoe (Of) is less than 30 cm deep and averages between 15-20 cm depth to bedrock. Similarly as in the previous ash-pocket soil on pahoehoe (Ro), the soil consists only of an A1 horizon of dark brown to almost black color. Thus except for the greater soil volume with regard to surface cover and depth, which is reflected in greater water holding capacity, there is no other important difference.

The very shallow, discontinuous ash-soil on a'a (Oe) represents likewise merely an increase in soil volume over the previously described ash-pocket soil on a'a (Rd). In the Oe soil, soil depths have been described as reaching 45 cm or deeper. In those deeper crevice-soils the A1 horizon (about 20 cm deep) is underlain by a transition zone (AC horizon) that grades into relatively unmodified sandy ash and cinder (C horizon). Average soil depths are between 20-25 cm, but the clinker-like a'a rocks crop out at the surface, of which they occupy 20-40%.

(d) Shallow, continuous ash-soil (1 type). There is only one soil in this category (Olinda, very shallow phase; map symbol Od). This is the dominant soil that extends from the Mauna Loa rest house at 6600 feet to about 4500 feet, where it is covered by a parkland forest and shrub savannah.

The difference from the previous category is that this soil is more or less continuous. Rock outcrops occur only occasionally. It also may overlie either pahoehoe or a'a. The range in depth is from 10-50 cm and it averages between 20-25 cm. Two ash materials have been found in this soil, an older, light-brown, silty textured, more weathered ash (Pahala ash) next to the lava, and a more recent, grayish, sandy textured, less weathered ash (of Kilauea or Halemaumau origin). The A1 horizon is similar to the previously described soil, but it is here underlain by a thin transitional B horizon that grades into slightly weathered, sandy volcanic ash (C). Because of the presence of a B horizon the soil can be considered relatively well developed. Therefore, it has been classified as Latosolic Brown Forest soil. The pH increases somewhat in the C horizon to 6.0-7.0, from 5.5-6.5 in the A1 and B horizons (Appendix, Olinda Series).

(c) Moderately deep ash-soils (1 or 2 types). (Kapapala fine sandy loam, sloping phase; map symbol K2d; and Ohaikea series, not on the 1955 map, *i.e.*, Fig. 19). The Kapapala fine sandy loam (K2d) occupies a relatively large area west, up-slope of Kipuka Ki under the more open savannah vegetation south of the Mauna Loa Road, from where it extends south across the Park border to the Ohaikea Ranch. The soil is described as derived from recent volcanic sands and gravel of Halemaumau origin and from discontinuous layers of older Pahala ash, which form part of the B horizon. The depth of the fine soil to bedrock, which is mostly pahoehoe, ranges from 15-80 cm.

This area has recently been resurveyed and much of this soil and also some of the deeper soils shown on the 1955 map (Fig. 19) as Od have been newly described as Ohaikea series (H. H. Sato, manuscript). Therefore, the revised map, which is currently in preparation will show new soil type boundaries.

The soil description for the new Ohaikea soil was made from a soil pit dug on the Keauhou Ranch property, approximately 2.1 miles northwest of Kipuka Puaulu and about 0.1 mile northeast of the fence bounding the National Park. (This would place it into or near Kipuka Kekake, which in the 1955 report by Cline et al. was described as underlain by a very shallow, discontinuous ash-soil on a'a; Oe. This discrepancy will probably be cleared up on the forthcoming revised soil map.) In addition, the Ohaikea soil description probably applies to the tree savannah outside and next to Kipuka Puaulu in the Park and the grazed tree savannah on the neighbouring property of the Keauhou Ranch (north and northeast of Kipuka Puaulu). As in the previous soil, the underlying lava has been described as either a'a or pahoehoe and range in soil depth to lava is given as between 90-150 cm. The soil has an almost black A1 horizon from 10-15 cm depth, which is underlain by a narrow (about 3-5 cm), reddish brown C horizon, which is believed to have resulted from intense burning. This layer was found to contain bits of charcoal. Beneath this is another dark horizon of about 10 cm depth, which appears to be a former buried A1 horizon. Below this occurs a zone (5 cm) of gravelly ash and cinder and next to this layer a deep B horizon of dark brown color from about 32 cm on down to bedrock. This deep B horizon is believed to be from older ash. The overall texture is clay-loam, which however feels like silt-loam due to aggregation and porosity of the soil.

Both the above soils are classified as Latosolic Brown Forest soil.

The profile description of the Ohaikea soil is shown in the Appendix (Ohaikea series). Here it is followed by the new type-soil description of the Kalapana soil series. This soil was described from a soil pit dug near halfway house on Kapapala Ranch. This location is 9 miles southeast of Kipuka Puaulu, thus a considerable distance away from this area of the Park. Therefore, extrapolation from this soil to the savannah soils or soils stocked with open forest in or near the ash-kipukas (Ki and Puaulu), mapped as K2f, must be viewed with some caution.

(f) Deep ash-soil (2 types) (Kapapala loam, sloping and moderately steep phases; map symbol K2f). These are the soils of Kipuka Puaulu and Kipuka Ki, which were recently studied in some detail (see Chapter VII, B-Kipukas and Soil Relations). According to the 1955 soil map (Fig. 19) the Kapapala loam (K2f) is found in seven other, similarly small (10-100 acre) kipukas between 5000 and 4000 feet on the lower Mauna Loa slope in the Park. However, in the 1955 report no profile is described specifically for these kipuka soils. Only the modal profile for the Kapapala series (a more encompassing unit than the phase) is given, which here refers to a moderately deep soil of 50 cm, the type locality of which is not stated. It is therefore more appropriate to use the soil descriptions made by the writer for the soils in Kipukas Ki and Puaulu. Rock (undated manuscript, probably written around 1917) observed that the depth of fine soil in Kipuka Puaulu is in places at least 5.5 m. In two soil pits dug in this kipuka and in another one dug in Kipuka Ki, the writer found soft soil to continue at least below 2 m. However, it is quite possible that shallow soil depths occur at the margins of the kipukas in places, since they are believed (by the present writer) to have originated from ash dunes that were later surrounded by more recent lava, as are nanatuks by glaciers.

The three profile descriptions are shown in the Appendix (P1, P2, Ki). All were dug in a level position beneath a dominating *Acacia koa* tree. One (P2) was dug in the open tree savannah occurring in Kipuka Puaulu and the other two (P1 and Ki) were dug beneath closed forest.

The common characteristic of these deep soils is that they are of an overall dark brown color and thus thought to be very rich in organic matter, that they are of a very friable consistency, of a crumb to blocky structure and an overall loamy texture, except where gravelly ash strata are well preserved (P2). The soils would be classified as Latosolic Brown Forest soils, as were the previous soils discussed. The two profiles beneath closed forest (Ki and P1), even though from different kipukas about 1 mile apart, show greater similarity with one another than to the two profiles from same kipuka (P1 forest and P2 savannah) which were about 70 m apart. The difference is not in depth of fine soil (all were deeper than 2m), but in a different stratification of the organic matter. Below the black A1 horizon (about 15 cm deep) and above the buried A horizon at about 60-70 cm depth, common to all three soil profiles, organic matter is concentrated in narrow bands in the savannah soil, while it is more uniformly distributed in the two forest soils. This appears to be related to the different manner of rooting of grasses and trees. The grasses root intensively and form shallow (10-20 cm deep) sods, the trees root extensively, throughout a greater soil volume, and their roots are not as crowded. Also, the somewhat more acid organic matter from trees (see Appendix) may have contributed to a greater weathering of the ash strata. In contrast, they are much better preserved beneath the savannah. The charcoal found at 70 cm in Kipuka Ki was dated by the carbon-14 method, showing that a fire occurred here 200 years B.C. This evidence gives support to the contention of the writer that the kipuka savannah is already very old, and originated from a fire and not from cattle grazing, as was believed by Rock (1913).

(2) Soils south and southwest of Kilauea

This geographic area includes the Park section from about the Volcano Observatory and thence straight south from Halemaumau, the Kau Desert, Hilina Pali and the coastal lowland with Puu Kaone. To the west it is bounded by the Kona Highway and the Park boundary.

(a) Lithosols (3 types). About 70% of the surface in this geographic area is mapped as lithosols, and of this, about 80% as pahoehoe-lithosol, 15% as a'a-lithosol and about 5% as pali-lithosol (Rockland, very steep; map symbol Rp). The first two types have already been discussed in the description of the Mauna Loa slope area, but the pali-lithosol represents a new type. This essentially soil-less substrate in the Park is formed not by steep to vertical, smooth, solid rock-faces, as in the older parts of the islands, but by a steeply sloping (40-80%) a'a lava. Much of this is colluvial material. The pali-lithosol represents a pronounced physiographic separation between the upland part of the Park south of Kau Desert and the coastal lowland. It drops as Hilina Pali from about 2200 feet to 700 feet over a distance of less than half a mile. This pali area extends from the southern part of this geographic section in a northeast to east direction roughly parallel with the coastline on into the southeast area of the Park. It continues on as Poliokeawe Pali up beyond the Naulu Forest at the new Kalapana highway, encompassing a longitudinal distance of 17 miles. A few "splinter" palis, also mapped as pali-lithosols, occur below this major pali area partway in the coastal lowland (Fig. 19).

The pahoehoe-lithosol occurs in the Kilauea caldera, in much of the Kau Desert and the coastal lowland, there forming most of the coastline. A large area of a'a-lithosol occurs as a continuation of the Mauna Loa slope-a'a, where it surrounds Kipuka Puaulu and Kipuka Ki, along the Kona highway to the half-way house (Kapapala Ranch). Here it is known as the late prehistoric Keamoku flow. Other larger a'a lithosol areas occur south of the Kamakaia and Kealaalea hills.

(b) Raw ash soils (2 types). These are unmodified deposits of ash. One type represents an ash substratum that has not been translocated by wind and has settled where it arrived after explosion (Kilauea sands and gravel; map symbol Kkl), the other represents wind translocated and currently actively shifting dune-ash (Kilauea sand, dune phase; map symbol Kkk). Unfortunately the latter has not been mapped, thus the boundaries between the two types are rather uncertain. However, while most of the ash next and further south of Halemaumau is of the stationary or more settled type, much of the ash in the central Kau Desert is of the shifting ash-dune type (according to the observations of the writer). Both substrates are almost non-vegetated, but a map-separation of the two types would be ecologically important as the settled ash may provide a habitat for annuals in this summer-drought climate, while the shifting ash-dunes are lacking these, instead they are occupied here and there by an individual xerophytic perennial. Widely scattered small patch colonies of xerophytic perennials are found also on the settled ash. A small amount of incorporated organic matter can be found only in connection with the scattered, feeble plant individuals or groups. The ash is mostly of coarse to fine sand grain size, but gravelly and stony fragments are found as well. The color is dark to medium gray. Larger rock fragments of boulder size are found particularly on the surface of the settled ash next, southeast of Halemaumau and at Keamakakoi Crater. Apparently the rocks strewn over the surface have resulted (Chapter II) from the 1924 and 1790 explosive eruptions. The ash-substrates have a loose consistency and single-grain structure. Depth to underlying bedrock in both ash-soils varies from a few centimeters to several meters. The shifting ash-dunes may be as high as 7 m. Both soils are classified as Regosols.

(c) Somewhat modified ash-soils (2 types). Only one soil has been mapped on the 1955 map, a shallow-discontinuous ash-pocket soil with a weak A1 horizon (Haleakala family, very shallow phase; map symbol Hl). This soil is described as covering only 20-50% of the surface. The remaining area in the type would be outcropping bedrock. Its depth does not extend beyond 30 cm. However, a second, ecologically very interesting, modified ash-soil occurs in this area, which should also be mentioned; although it has not been recognized in the 1955 soil map. This is a dune soil complex, which is found at the southern and southwestern margin of the Kau Desert in the same general area of the shallow H1 soil. These dunes are densely vegetated with open *Metrosideros* tree patch stands and an undergrowth dominated by the tall grass *Andropogon*. Here a weak A1 layer can be recognized. Some of the dunes are up to 10 m high, and consist largely of dark-brownish gray, fine, sandy ash. They are more or less stabilized in contrast to the shifting ash-dunes. The term "somewhat modified" in these soils refers to the presence of a weak A1 layer, which is one of the more important features in separating these from the previous "raw" ash-soils. The soils are otherwise still typical Regosols.

(d) Deep loess-soil. This soil occurs only in a small area (about 100 acres) on top of Puu Kaone, the highest rise (780 feet elevation) in the coastal lowland, right near the coastline south of Hilina Pali. The soil consists of Pahala ash. This is an older light yellowish-brown, dusty (silt-clay textured) ash that was windborne and blown into this isolated position from the northwest. The upper seaward ridge of Puu Kaone (787 feet) apparently provided for a "collecting-bowl"-effect. Soil depth averages 75 cm and the soil is practically stone-free. The modal profile consists of well developed A and B horizons that overlie a D horizon at a 45 cm depth that appears to be ash of different origin. The soil is friable throughout and has a circum-neutral reaction from top to bottom. It has been classified as Reddish Prairie Soil (Appendix, see Pahala Series).

(e) Ash-pocket soil (1 type). On the next adjacent terrace below Puu

Kaone (southeast of it) occurs a shallow ash-pocket soil (Rockland with Kawaihae, Waikaloa or Naalehu soil material over pahoehoe; map symbol Rm). This soil is similarly local in distribution (about 100 acres) on the map, but according to observations of the writer, much of the pahoehoe lowland between Hilina and Puu Kaone is covered with ash pockets also. The soil coverage is described as being less than 50% and the depth of the ash-soil pockets averages 10-15 cm, maximum 25 cm. The soil profile consists essentially of an A1 horizon overlying bedrock. The A1 is similar to those found in Reddish Brown soils.

(3) Soils north, east and southeast of Kilauea

This geographic section begins right east of Kipuka Puaulu and goes around the north side of Kilauea caldera (Volcano House and Park Headquarters). It includes the area north of the village Volcano, outside the Park boundary, and there continues eastward, north and south of the Chain-of-Craters Road to Makaopuhi Crater. From Makaopuhi it continues along on both sides of the new Kalapana highway down into the coastal lowland at the east end of the Park to near Kalapana villlage. It also includes the Ainahou Ranch property, south of Heake Crater and the coastal lowland below the ranch, with Poliokeawe Pali, Holei Pali and Keauhou Landing.

The area shows three distinct rainfall climates. Firstly, a humid climate, in which the monthly rainfall is rarely less than 100 mm. This includes the area from the Park Headquarters to Volcano (and further north) around Kilauea Iki, and most of the area north of the Chain-of-Craters Road to Makaopuhi and Napau Craters, from there it descends in a southeasterly direction to about Queens Bath (southwest of Kalapana). Secondly, a summer-dry climate. This includes a small area near Kipuka Puaulu and the large area south of the Chain-of-Craters Road including the Ainahou Ranch and Poliokeawe Pali.

(a) Lithosols (3 types). This coastal lowland below Poliokeawe with a summer-drought climate contains only lithosols. These are of the same three types that were discussed in the preceding sections, the pahoehoe-lithosol, the a'a-lithosol and the pali-lithosol consisting largely of colluvial a'a. However, about 30% of the area with a summer-dry climate is also covered with these lithosols and a small percentage of lithosolic surfaces occurs also in the area with a humid climate. Here, however, it is restricted to the recent crater floors, such as the 1959 Kilauea Iki pahoehoe-lithosol, the 1965 Makaopuhi and Napau Crater floors and the 1965 flank eruption (pahoehoe-lithosol) between Makaopuhi and Napau and east of Napau (see Fig. 7). Here, again it is worth pointing out that the older lithosols in the coastal lowland are not completely without soil. The pahoehoe-lithosol is here occupied by a thin cover of Heteropogon (pili) grassland. The grasses root in soil material lodged in the pahoehoe cracks.

(b) Ash-pocket soils (2 types). One of these occurs in the humid climate north of the Chain-of-Craters Road and extends into the coastal lowland near Kalapana (Rockland, Pahoehoe lava with Kealakekua, Olaa, or Ohia soil material; map symbol Rn). The other type occurs in the summer-dry climate south of Ainahou Ranch above the pali (Rockland, pahoehoe lava with Puu Oo, Maile, or Olinda soil material; map symbol Ro; same soil unit as on east slope of Mauna Loa). Both soils occur on pahoehoe bedrock, where they cover less than 50% of the surface, and both are described as averaging from 10-15 cm depth in the pockets. However, the humid pocket soil (Rn) shows an almost black A1 horizon of silt-loam texture that is very high in organic matter, while the summer-dry pocket soil (Ro) consists of a dark A1 layer that is apparently relatively less enriched with organic matter. Moreover, while the outcropping pahoehoe mounds on the Rn soil are barren of vegetation, they are often covered with mosses or lichens or even mats of Gleichenia (false staghorn fern) in the soil areas. Here, even stagnating water can be found occasionally in the deeper depressions.

(c) Very shallow, discontinuous ash-soils (2 types). One of these occurs in the humid climate 1½ miles straight east of Kilauea Iki Crater and west of Volcano (Hilo family, very shallow phases—pahoehoe lava complex; map symbol H2k). The other occurs in the summer-dry climate, adjacent east of Kipuka Puaulu to near the Tree Molds, and in an area southeast of Makaopuhi Crater along the old Kalapana Trail (Heake gravelly loam, very shallow phase; map symbol H2f). Both soils occur in areas that have a high proportion of outcropping pahoehoe bedrock (up to 40% of the surface) and their depths average from 10-30 cm. However, in general the humid-area soil (H2k) may have more and deeper soil up to 60 cm in places, while the summer-dry area soil (H2f) may tend to have less soil in places, rather than more. The humid-area soil has an A1 horizon up to 24 cm deep that is reddish brown in color, has a granular structure, is of silty clay loam texture and has a pH of 5.2 to 5.7. The B horizon, where present, is a yellowish red silty clay loam, gritty due to rock fragments, and a pH of 5.3 to 5.8. Water may stagnate in depressions. The summer-dry area soil has a shallower A1 horizon (only 5 cm deep) of dark brown color and sandy loam texture that directly overlays a C horizon, a dark brown sandy loam. Thus, the texture is coarser in this soil. The summer-dry area soil is classified as Regosol, while the humid-area soil is classified as Hydrol Humic Latosol.

(d) Moderately deep, continuous ash-soils (2 types). A humid-area soil (Manu gravelly loam, gently sloping phase; map symbol M2m) occurs around Kilauea Iki, Volcano House, Park Headquarters and continues to Volcano village. The soil ranges in depth from 35 cm to 1 m or more. It has a very dark brown to black A1 horizon 20 cm deep, strongly enriched with organic matter and has a pH of 5.5 to 6.0. It is underlain by a C horizon of partly weathered ash. Overall texture is loam to clay-loam (see in Appendix, Manu Series).

A moderately deep ash-soil (Heake gravelly loam, gently sloping phase; map symbol H2e) occurs also in the summer-dry climate. Here it is found occupying a small area west of the Military Camp and the golf course in direction of Kipuka Puaulu, where it joins the very shallow, discontinuous ash-soil (H2f) near the Tree Molds. Another very large area occurs along both sides of the Chain-of-Craters Road from about Kokoolau Crater to Makaopuhi Crater. (Any extention of this area to about 2½ miles north of the Chain-of-Craters Road appears somewhat questionable as this area is already in the humid climate). A new type-soil for the Heake series has recently been described from a soil pit dug 25 m north of Bird Park road, 1/2 mile from the belt highway (see in Appendix, Heake Series).

The soil depth varies from 30 to 60 cm. A relatively shallow (5 cm deep) dark brown A1 horizon of sandy loam texture is underlain by a dark brown to grayish brown C horizon of loamy sand consisting of slightly weathered volcanic ash. Volcanic pumice commonly occurs below the ash next to lava bedrock. Both soils are classified as Regosols.

(e) Deep ash-soil (1 type). This soil occurs in the humid climate north of Kilauea and north of Volcano and outside the Park boundary. This soil has recently been described as of the Puaulu series (H. H. Sato, manuscript) and is shown on the 1955 map as P2d. This soil is of interest as it is very similar to the kipuka soils, but differs primarily by being in a humid climate, where it is stocked with tree ferns (Cibotium spp.) and old Metrosideros trees that are often heavily covered with epiphytes. The type-soil description was made from a pit dug 1.6 miles from the T intersection on Wright Road. The soil has a 15 cm deep nearly black A horizon of medium granular structure that is underlain by a C horizon. Below this occurs, what appears to be a buried A horizon from 23 to 33 cm, and this is again underlain by a C horizon, below which occurs a deep B horizon from about 40 cm on down to the bottom of the pit that was dug to a depth of 175 cm. The entire soil is of dark brown color of more or less friable consistency, blocky structure and clay-loam texture that feels like silt-loam. Many small volcanic ash and pumice fragments are present in the different layers. For further detail see Appendix (Puaulu Series). The soil has been reported to reach 5 m depth in the deepest places near Wright Road. The soil has been classified as Regosol.

F- RELATIONSHIPS

The literature review has shown that very little specific information, apart from a classification, is available on the soils in the Park. Most soil work after World War I was devoted to crop soils. Information on even such basic things as pH and organic carbon content is wanting. Some information can, however, be extropolated with some meaning to the Park soils.

(1) Seasonal variation in pH

Kaneshiro et al. (1951) made a study of seasonal variations in pH on Oahu by comparing low-elevation (20-150 feet) and high-elevation (300-920 feet) soils. They found in the slightly acid to basic low-elevation soils a tendency toward increasing acidity during the hot, dry summer months. Cultivated soils showed the same general trend as uncultivated soils. Surface soils showed somewhat greater variation than subsurface soils.

The average fluctuation for surface soils was .9 pH units, for subsurface soils .6 to .8 pH units. Upon air-drying they found a small increase in acidity of .1 pH unit for surface soil and .2 pH units for subsurface soil. High-elevation soils were acid in reaction and showed no seasonal variation in pH. This information may be of bio-ecological value in comparing the coastal summer-drought area of the Park with the more humid, higher-elevation areas.

(2) Organic nitrogen and C/N ratios

The problem of organic nitrogen in Hawaiian soils was studied by Kelley (1914). One of his sample soils was from Glenwood (near the Park) in a humid climate. This soil was described as a virgin soil from recently cleared tropical jungle. Other samples included several crop soils from Maui and Oahu. Total nitrogen in the Glenwood soils was .77%. Of this total nitrogen, .58% was nitrate-nitrogen, while ammonia ammounted to 2.86%. Thus, the nitrate and ammonia content constitutes only a small percentage of the total nitrogen. The remainder is in the form of amide and basic nitrogen. Of the total nitrogen, 76.6% was from the colloidal humus fraction, versus 64.4% for the average of all soils. The humus content of the Glenwood soil was 14.3%, of this 3.9% was nitrogen. This was the highest nitrogen percentage in his comparison. The next highest, 2.3%, was from an organic-rich, old pasture soil in a semi-arid region. Most others had between 1 and 2% nitrogen. In studying ammonification and nitrification in Hawaiian soils, Kelley (1915) concluded that plants growing on uncultivated soils probably absorb nitrogen largely in the form of ammonium compounds. He further remarked that the inactive state of nitrification in uncultivated soils is not due to absence of nitrifying organisms and acidity. He suggests as the limiting factor poor aeration.

Dean (1950) studied the effect of rainfall on carbon and nitrogen contents and the C/N ratios in Hawaiian soils. His data (Table VI) are of particular interest as he cites 6 soils among the 30 that are on Hawaii near the Park.

The data of Table VI indicate that total nitrogen increases with rainfall and elevation or decreasing temperature. While the C/N ratio increases with increasing rainfall and elevation, it appears to decrease above the elevation of maximum rainfall at 3500 feet. A similar study was carried out by Blomberg & Holmes (1959), but they sampled only up to 1360 feet. Their findings support those of Dean.

(3) Developmental trends

The developmental relationships in the Park as indicated from the previous discussion can be summarized as follows:

NEW LAVA

⇓

(Lithosols and local decomposition products, where exposed to acid-steaming, such as gypsum, alum and yellow silica present. No fine soil as yet reported; although this would need further study.)

NEW VOLCANIC ASH

⇓

(Regosols representing most of the soils in the Park today, regardless of climate; azonal.)

⇓

ZONAL SOILS

Latosolic Brown Forest soil	Hydrol Humic Latosol	Reddish Prairie soil
(from 4000 feet up on the slope of Mauna Loa in cool, summer-dry climate)	(in humid rain forest climate, currently only Hilo family, H2k, in Park east of Kilauea Iki)	(only a small area on Puu Kaone in warm, coastal summer-drought climate below Hilina Pali)

Table VI. Per cent carbon, total nitrogen and C/N ratios of soils near Hawaii Volcanoes National Park, Hawaii, arranged in order of decreasing amounts of rainfall (after Dean, 1950).

Location	Elev. (ft.)	Rain (mm)	% C	% total N	C/N ratio
Volcano	3,500	2500	12.82	.664	19.3
Kapapala	4,000	1500	1.83	.127	14.4
Humuula	6,500	750	9.08	.709	12.8
Pohakuloa	5,000	500	6.31	.566	11.2
South Pt.	100	380	1.43	.188	7.6

Cline *et al.* (1955) recognized the Latosolic Brown Forest soil as an intrazonal, calcimorphic soil. In a recent paper, however, Swindale & Sherman (1964) consider this soil as reflecting a definite climatic soil-forming trend, so that the soil can be considered zonal, as indicated above.

While the direction of development is rather clear, little information is available on the rate of development, except that weathering intensity is more or less directly related to the amount of rainfall. (Swindale & Sherman, 1964). It may be surmised also that the rate of weathering increases with increasing temperature, but that the effect of increasing temperature on rate of soil formation from mid-altitudes (4000 - 3500 feet) on downwards is confounded by the increasing rainfall up-slope. At higher elevations, above about 8500 feet, nocturnal night-frost may be an important agent of lava weathering. Breakage of surface layers into small cubicles, as observed by the writer and, undoubtedly, others is probably the result of alternate freezing and thawing. A study of lava weathering and soil formation at high altitudes (above about 8500 feet) on Mauna Loa would be of much interest.

G- APPENDIX

SOIL PROFILE DESCRIPTIONS

Olinda Series (Cline *et al.*, 1955, p. 545). Latosolic Brown Forest soil.

Soil pit location not given; representative for Od soil, although the Od soil is not as deep as this profile. A1 horizon characteristics apply also to the discontinuous Oe and Of soils, and to the Ro and Rd pocket soils.

A1	0-23 cm	Dark reddish brown loam; moderate medium crumb structure; very friable when moist, nonplastic when wet; pH 5.5 to 6.5; roots very numerous.
B	23-81 cm	Red silty clay loam; moderate fine blocky structure; friable when moist, weakly smeary when wet; pH 5.5 to 6.5; roots present; specific gravity apparently very low.
C	81 cm +	Reddish brown or brown silty clay loam; weathered volcanic ash similar in most properties to the B horizon; pH 6.0 to 7.0 grades to moderately to strongly weathered lava.

Ohaikea Series (H. H. Sato, Mss.) Latosolic Brown Forest soil.

Soil pit location: On Keauhou Ranch property, about 2.1 miles NW of Bird Park (Kipuka Puaulu) and about 0.1 miles NE of fence surrounding National Park. Surface convex, 4% slope.

A11	0-5 cm	Very dark brown (10 YR 2/2) material that feels like a loam, dark gray (10YR 4/1) when dry; weak fine and very fine granular structure; slightly hard, friable, non-sticky and non-plastic; roots matted; many very fine and fine interstitial pores; few 1-3 mm hard basalt fragments; clear wavy boundary. 2-5 cm thick.
A12	5-13 cm	Very dark brown (10YR 2/2) material that feels like a very fine sandy loam, dark gray (10YR 4/1) when dry; moderate fine and very fine granular structure; slightly hard, friable, non-sticky and non-plastic; roots matted; many very fine and fine interstitial pores; common 1-2 mm basalt fragments; abrupt smooth boundary. 8-10 cm thick.
C	13-18 cm	Dark reddish brown (5YR 3/4) volcanic ash layer that feels like a fine sandy loam, reddish brown (5YR 5/4) when dry; massive structure; very friable, non-sticky and non-plastic; many roots; many very fine and fine pores; common 3 mm or less volcanic cinders and basalt

fragments; few bits of charcoal; abrupt smooth boundary. 5-10 cm thick.

Ab-Cb?	18-28 cm	Very dark brown (7.5YR 2/2) material that feels like a fine sandy loam, single grain structure; loose, non-sticky and non-plastic; many roots; many very fine and fine pores; few 1-3 mm basalt fragments; abrupt wavy boundary. 8-18 cm thick.
Cb?	28-33 cm	Dark reddish brown (5YR 5/4) material that feels like a fine sandy loam, single grain structure; loose, non-sticky and non-plastic; many roots; many very fine and fine pores; many 1-3 mm basalt fragments, volcanic ash nodules and volcanic cinder; abrupt wavy boundary. 5-13 cm thick.
B21	33-50 cm	Dark reddish brown (5YR 3/2, 3/3) material that feels like a silt loam; massive structure; friable, non-sticky and non-plastic; many roots; many very fine and fine pores; few 1-5 mm basalt fragments and volcanic ash nodules; clear wavy boundary. 13-24 cm thick.
B22	50-66 cm	Dark reddish brown (5YR 3/2, 3/3) material that feels like a gritty silt loam; massive structure; friable, non-sticky and non-plastic; many roots; many very fine and fine pores; few fine basalt fragments and volcanic ash nodules; clear wavy boundary. 10-14 cm thick.
B23	66-81 cm	Dark brown (7.5YR 3/2) material that feels like a silt loam; massive structure; friable, non-sticky and slightly plastic; common roots; many very fine and common fine pores; few basalt fragments up to 5 cm size; clear wavy boundary. 13-26 cm thick.
B24	81-100 cm	Dark brown (7.5YR 3/3) material that feels like a heavy silt loam; massive structure; friable, slightly sticky and slightly plastic; few roots; many very fine, fine and common medium pores; abrupt wavy boundary. 16-32 cm thick.
D	100 cm+	Hard unweathered pahoehoe lava.

Remarks: Color names are for the moist soil unless otherwise stated.

Kapapala Series (H. H. Sato, 1965, Mss.) Latosolic Brown Forest soil.

Soil pit location: Near Half-Way House on Kapapala Ranch, surface convex, 18% slope.

A1	0-10 cm	Black (5YR 2/1) loam; weak fine and very fine granular structure; soft, friable, non-sticky and non-plastic; many roots; many fine pores; abrupt smooth boundary.

B1	10-15 cm	Very dark grayish brown (10YR 3/2) loam; weak medium and fine subangular blocky structure; soft, friable, non-sticky and non-plastic; many roots; many very fine pores; abrupt smooth boundary.
C1	15-38 cm	Dark grayish brown (10YR 4/2), dark brown (10YR 3/3) and black (10YR 2/1) volcanic fine and very fine sand; massive; loose, non-sticky, and non-plastic; many roots; abrupt smooth boundary.
C2	38-57 cm	Very dark brown (7.5YR 2/2) loamy fine sand; massive; loose, non-sticky and non-plastic; many roots; many fine pores; clear wavy boundary.
IIA1b	57-65 cm	Very dark grayish brown (10YR 3/2) loam; massive; soft, very friable, non-sticky and non-plastic; many roots; many very fine pores; clear wavy boundary.
IIC1	65-100 cm	Dark brown (7.5YR 3/3) light silt loam; weak coarse prismatic structure; soft, very friable, non-sticky and non-plastic; many roots; many very fine and fine pores; clear wavy boundary.
C2	100-120 cm	Dark brown (7.5YR 3/4) loam; weak medium and coarse subangular blocky; soft, friable non-sticky and non-plastic; common roots; many fine and very fine pores; abrupt wavy boundary.
R	120 cm+	Pahoehoe lava.

Kipuka Puaulu, forest soil, P1 (D. Mueller-Dombois, Mss.) Latosolic Brown Forest soil.

Soil pit location: Kipuka Puaulu (Bird Park) under closed forest, 10 meters S of "Giant Koa", on level ground. Preserved as monolith P1 in Botany Department, University of Hawaii. (See Chapter VII, Vegetations, for diagram.)

01[a]	1-2 cm deep	Predominantly fermenting foliage of *Acacia koa*, *Osmanthus* (leaf skeletons) and *Microlepia setosa*.
A1	0-5 cm	Very dark brown (black 10YR 3/1, when dry) loam; weak, fine crumb structure, very friable, upper 0-5 cm held together as a sheet by fibrous roots, from 5-15 cm more loose fewer fibrous roots; pH 4.8[b]; %C 10.4[c].
C1	15-22 cm	Gray brown (10YR 5/2, when dry) sandy loam; fine blocky structure; slightly firm, fine rootlets, pH 5.5; %C 3.3.

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a/ Nomenclature of horizons after 1962 Supplement to Agriculture Handbook No. 18, Soil Survey Manual.

b/ Measured electrometrically

c/ Walkley-Black Values

Ab	22-25 cm	Brownish black (dark gray brown 10YR 4/2, when dry) gritty loamy sand and cristalline ash; single grain structure; loose; incipiently cemented; roots above and below, not in it; pH 5.8; %C 12.1.
A3	25-38 cm	Very dark brown (very dark gray brown 10YR 3/2, when dry) sandy loam; fine blocky structure; friable; roots increasing, abundant, pH 5.6; %C 10.5.
B1	38-60 cm	Dark brown with reddish hue (brown 10YR 4/3, when dry) sandy loam; blocky structure; friable; roots abundant; pH 5.6; %C 7.8.
A1b	60-80 cm	Dark brown (no reddish hue; very dark brown 10YR 2/2, when dry) loam; blocky structure, friable; abundant rooting; buried A1 horizon; few scattered charcoal fragments; pH 5.7; %C 12.1.
B3	80-135 cm	Brown (10YR 4/3, when dry) loam; fine blocky structure; friable; well rooted; boulder of 40 cm diameter at 110 cm; pH 5.7; %C 6.9.
C2	135 cm+	Dark reddish brown (7.5YR 4/3, when dry) sandy loam to loam; blocky structure, weak in places; friable to firm; red pumice layer 2-5 cm thick between 140 and 150 cm depth; loose, but incipiently cemented, very light weight, 1-3 cm diameter stonelets; soft soil continuous beyond 2 m, pH 5.7; %C 7.6.

Kipuka Puaulu, savannah soil, P2 (D. Mueller-Dombois, Mss.). Latosolic Brown Forest soil.

Soil pit location: Kipuka Puaulu (Bird Park), in area covered with dense, tall grass and scattered trees, about 70 meters ESE of "Giant Koa". Soil pit under a tall koa tree, on level ground. Preserved as monolith P2 in Botany Department, University of Hawaii. See Chapter VII, Vegetations, for diagram.

O		Absent, except for few koa phyllodes that are entangled in the dense grass mat; a dense network of stolons of *Cynodon* at surface.
A1	0-15 cm	Black (10YR 3/1, when dry) loam; weak crumb structure, grading from coarse to fine; friable; full of grass rhizomes and earth worms; pH 5.7; %C 14.3.
C1	15-24 cm	Dark gray (gray brown 10YR 5/2, when dry) sandy loam; blocky structure; friable to slightly firm rather dense; pH 5.4; %C 1.1.
A12b	24-28 cm	Olive (2.5YR 3/2, when dry) pumice (like fibreglass foam); single grain structure, loose;

		organic colloids around pumice particles; grades into gravelly ash layer below; pH 6.4; %C 15.7.
A13b	28-33 cm	Dark brownish black (dark gray brown 10YR 4/2, when dry) gravelly ash; single grain, loose; pH 5.9; %C 15.4.
A3	33-41 cm	Dark brown (very dark gray brown 10YR 3/2, when dry) loam; fine blocky structure; friable; pH 6.4; %C 7.2.
A14b	41-48 cm	Black (10YR 3/1, when dry) loam; fine blocky structure; friable; pH 5.7; %C 12.0.
A15b	48-51 cm	Dark gray brown (10YR 4/2) gravelly ash with some loam; single grain to weak blocky structure, friable; pH 6.5; %C 3.0.
B1	51-63 cm	Dark reddish brown (brown 10YR 4/3, when dry) loam; blocky structure; friable; pH 5.7; %C 5.7.
A16b	63-68 cm	Black (10YR 3/1, when dry) loam; crumb structure; friable; pH 6.1; %C 13.5.
A17b	68-75 cm	Dark gray brown (10YR 4/2, when dry) gravely ash; single grain structure; loose; pH 6.3; %C 7.8.
A1b	75-90 cm	Very dark brown (10YR 2/2, when dry) loam; crumb structure; friable; this is the largest buried A1 horizon in this profile; (few red pumice fragments), lower part of horizon not horizontal to surface but sloping (wedge-shaped); pH 5.7; %C 10.1.
B3	90-135 cm	Brown (10YR 4/3, when dry) loam; blocky structure; friable; pH 5.9; %C 5.4.
C2	135 cm+	Gray brown (10YR 5/3, when dry) sandy loam; very weak blocky structure; friable; layer includes a discontinuous red pumice horizon (7.5YR 4/3, when dry) at 145 cm depth, it occurs mostly in pockets; soft soil continues beyond 2 cm depth; pH 6.0; %C 1.9.

Kipuka Ki, forest soil (D. Mueller-Dombois, Mss.) Latosolic Brown Forest soil.

Soil pit location: In Kipuka Ki under closed forest, 20 meters N of paved road at main curve. Level position beneath a large koa. Preserved as monolith Ki in Botany Department, University of Hawaii. See Chapter VII, Vegetation, for diagram.

O1	1-2 cm deep	Mostly decaying fern fronds of *Microlepia setota* and koa phyllodes, not very dense, occasionally A1 layer exposed.
A1	0-17 cm	Black (10YR 3/1, when dry) loam, crumb structure, very friable; 0-6 cm thoroughly rooted with fibrous roots abundant earth worms (3 per shovel); 6-17 cm somewhat less abundant rootlets; pH 5.2; %C 11.1.
C1	17-20 cm	Gray brown (10YR 5/2, when dry) sandy loam; fine blocky to massive structure; friable to slightly firm; not continuous, more or less restricted to pockets; pH 5.7; %C 4.2.
Ab	20-23 cm	Black (dark gray brown 10YR 4/2, when dry) gritty sandy loam; single grain structure; loose; incipiently cemented; discontinuous; pH 5.9; %C 9.6.
A3	20-39 cm	Very dark brown (very dark gray brown 10YR 3/2, when dry) somewhat gritty sandy loam; fine blocky structure, friable; pH 6.2; %C 9.9.
B1	39-50 cm	Dark reddish brown (dark brown 10YR 4/2-4/3, when dry) sandy loam, blocky structure; friable; contains a few coated, vesicular basaltic ash granules that break on pressure in hand, inside grayish yellow; pH 5.9; %C 7.7.
A1b	50-68 cm	Very dark brown (10YR 2/2, when dry) loam; very fine blocky structure; friable to loose; with many fine rootlets; buried A1 horizon; charcoal fragments at lower border (70 cm+), were C^{14} dated as 200 B.C., pH 5.7; %C 12.7.
B3	68-150 cm	Dark yellowish brown (brown 10YR 4/3, when dry) loam; weak coarse blocky structure; friable to somewhat firm (in lower portion); at 100 cm depth red pumice (7.5YR 4/3, when dry) layer, about 3-5 cm thick; pH 6.0; %C 9.0.
C2	150 cm+	Gray brown (10YR 4/5 - 5/3, when dry) loam, blocky to prismatic structure; somewhat firm; soft soil continues beyond 2 m depth; pH 6.0; %C 9.0.

Pahala Series (Cline *et al.*, 1955, p. 495). Reddish Prairie soil.

Soil pit location not given; essentially similar to *Pg* soil on Puu Kaone in coastal lowland of National Park.

A1	0-20 cm	Dark brown or dark grayish brown loam or fine sandy loam; moderate fine crumb structure; very friable when moist, non-plastic when wet; pH 6.5 to 7.5; roots very numerous.

B	20-45 cm	Brown loam or fine sandy loam; moderate fine crumb structure; very friable when moist, nonplastic when wet; pH 6.5 to 7.5; roots numerous.
D1	45 cm+	Reddish yellow, yellowish red, or reddish brown silty clay; weak medium blocky structure; friable when moist, nonplastic when wet; pH 6.5 to 7.5; roots present; this horizon appears to be weathered volcanic ash much older than that from which the A and B horizons have developed; rests on unconformable lava bedrock at depths mainly more than 75 cm but locally as little as 45 cm.

Heake Series (H. H. Sato, Mss.) Regosol.

Soil pit location: In National Park, 25 miles North of Bird Park Road 1/2 mile from Belt highway, Kau SCD. Surface convex, 3% slope.

A1	0-5 cm	Dark brown (7.5YR 3/2) sandy loam, brown (7.5YR 4/2) when dry; weak fine and very fine granular structure; soft and slightly hard, friable, non-sticky and non-plastic; many roots; many very fine and fine pores; common hard basalt fragments 1 to 4 mm in size; abrupt smooth boundary. 2 to 8 cm thick.
C1	5-13 cm	Dark brown (7.5YR 2/2) sandy loam; massive structure; friable, non-sticky and non-plastic; many roots; many very fine and fine pores; common hard basalt fragments 1 to 4 mm size; abrupt smooth boundary. 5 to 10 cm thick.
C2	13-18 cm	Dark brown (7.5YR 3/2) sandy loam, with pockets of firm, gray loamy sand material; massive structure; friable, non-sticky and non-plastic; common roots; many ver fine and fine pores; common hard basalt fragments 1 to 4 mm size; abrupt smooth boundary. 2 to 8 cm thick.
C3	18-25 cm	Very dark grayish brown (10YR 3/2) loamy fine sand; massive structure; firm, non-sticky and non-plastic; few roots; many very fine and fine pores; many very firm and firm pisolites; abrupt wavy boundary. 5 to 10 cm thick.
C4	25-45 cm	Very dark gray (10YR 3/1) pumice; many hard basalt grits; occasional roots; abrupt smooth boundary. 16 to 24 cm thick.
D	45 cm+	Hard pahoehoe basalt.

Manu Series (Cline *et al.*, 1955, p. 620) Regosol.

Soil pit location not given; but applicable to moderately deep ash-soil in humid area of National Park around Kilauea Iki, etc.

A1	0-20 cm	Very dark brown to almost black gravelly loam, high in organic matter; consists of moderately weathered volcanic ash mixed with organic matter.
C1	20-38 cm	Brown partly weathered volcanic ash; clay loam to loam with inclusions of sandy loam.
C2	38 cm+	Sandy loam to loam; partly weathered volcanic ash.
D		Lava bedrock at depths from 15 inches to several feet.

Puaula Series (H. H. Sato, Mss.) Regosol.

Soil pit location: 1.6 miles from T intersection on Wright Road, Puna SCD, north of Volcano. Surface slightly convex, 3% slope.

A	0-15 cm	Dark reddish brown (5YR 3/2) clay that feels like a silt loam; weak medium granular structure; friable, slightly sticky, slightly plastic and weakly smeary; many roots; many very fine and fine interstitial pores; common worm casts and common worm holes; many fine sand-size gritty materials; abrupt wavy boundary. 10 to 20 cm thick.
C	15-23 cm	Dark brown (7.5YR 3/3) volcanic ash and pumice that feels like a sandy loam; massive structure; firm, non-sticky, non-plastic and non-smeary; few roots; many very fine pores; many fine pieces of volcanic glass; abrupt irregular boundary. 5 to 20 cm thick.
ACb	23-35 cm	Dark reddish brown (5YR 3/3 and 3/2) material that feels like a gritty silt loam; weak very fine subangular blocky structure; friable, slightly sticky and slightly plastic; common roots; many very fine and fine tubular pores; many pieces of unweathered pumice, cinders and volcanic glass; abrupt wavy boundary. 10 to 20 cm thick.
Cb	35-40 cm	Dark grayish brown (2.5YR 4/2) material that feels like a silt loam, with many fine prominent yellowish red (5YR 5/6) mottles; massive structure; firm to very firm, slightly sticky and slightly plastic; few roots; common very fine pores; many fine pieces of volcanic glass and unweathered pumice; abrupt broken boundary. 2 to 10 cm thick.
B21b'	40-76 cm	Alternating bands of reddish brown (5YR 4/3) and dark reddish brown (5YR 3/3) clay that feels like a silt loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, slightly plastic and moderately smeary; common roots; many very fine and fine tubular pores; continuous gelatinous-like coating on ped faces; many ped ash

		nodules and basalt fragments; abrupt wavy boundary. 25 to 42 cm thick.
B22-Cb'	76-100 cm	Dark reddish brown (2.5YR 3/4) clay that feels like a gritty silt loam; massive structure; firm, slightly sticky, slightly plastic and weakly smeary; few roots; many very fine and fine tubular pores; many ash nodules; pumice and cinders; abrupt wavy boundary. 16 to 30 cm thick.
Cb'	100-106 cm	Dark brown (10YR 4/3) and dark grayish brown (2.5YR 4/2) clay that feels like a silt loam; massive; firm to very firm, slightly sticky, slightly plastic and non-smeary; few roots; common very fine and fine pores; abrupt wavy boundary. 5 to 13 cm thick.
B21b"	106-175 cm	Bands of dark brown (7.5YR 4/4) and reddish brown (5YR 4/4) clay that feels like a silty clay loam; moderate very fine subangular blocky structure; friable, sticky, plastic and smeary; few roots; many very fine and fine tubular pores; many ash nodules; common pockets of bluish gray material which were probably developed from weathered basalt fragments.

<u>Remarks</u>: Color names are for the moist soil.

Part Two: Biological factors in the environment

Chapter VI- Park Organisms

When scientifically approaching a biologically unknown area the first thing to do is determine what kinds of things grow there. This is the biotic, the faunistic and the floristic, stage of biology. A second step is recording and organizing the observational aspects of ecological and morphological information on the biota. This is the biogeography and biology unique to the area. With this done the next phase is, then, developing reliability in our theoretical understanding of the phenomena seen. This would be done by repetitive application of the scientific method, i.e., pursuing the experimental method in respect to successive refinements of the initial hypotheses and eventually-arising theories. Much of this last phase might be done in laboratories remote from the Park, but the Park itself is the greatest natural laboratory for such studies.

Our goal in studying ecology within the Park is understanding the more intimate interrelationships between the living organisms and their environment, both biological and physical, and this is ecology. A major purpose of this Atlas is to point out the gaps in the more elementary areas of knowledge of the Park's biota and its ecology. Thus, the general status of our knowledge of each of the major kinds of organisms is taken up in this chapter under the following headings:

A- ALGAE
B- FUNGI AND LICHENS
C- BRYOPHYTES
D- FLOWERING PLANTS AND FERNS
E- INVERTEBRATES OTHER THAN INSECTS
F- INSECTS
G- VERTEBRATES OTHER THAN BIRDS
H- BIRDS

Nothing is known specifically about the bacteria or fungi of the Park, though recently collections have been made in some of the ecologically different areas. Actually, except for the birds and the flowering plants, very little has been done specifically on the Park biota. A beautiful exception is the nicely illustrated booklet, available at Park Headquarters, by Douglas H. Hubbard (1952) on the ferns. For other biotic elements, even more useful are the books and papers by Degener (1945), Hubbard & Bender (1960) and that on the Haleakala Park (Ruhle, 1959). The latter contains much of value to anyone interested in Hawaii and Hawaii Volcanoes National Park.

Finally, this chapter should be expanded and improved greatly in time. It is to be noted that many organisms, e.g., insects listed in Zimmerman's (1948-60) "Insects of Hawaii" and mosses listed in Miller's publications (1963a,-b) on bryophytes, are known to occur in the Park. However, when we have not found a published record of them of scientific nature with a specific locality reference, they are not listed in the generic index which forms the last chapter of this Atlas.

A- ALGAE

A few terrestrial, fresh water, epiphyllous and aerial algae have been reported in the literature. In view of the extremely uncertain nature of the taxonomy of these organisms, only a few classical forms are listed in the generic index. In the case of identity of such algae one must follow one or another authority and there is little agreement between the authorities. There has been as yet little monographic or comparative study of variation within the different taxa. When this is done, phycologists have hopes for a better understanding of them.

Table I provides a list of the more useful basic publications.

The Park with its wide range of climates over short distances makes an ideal field area in which to study variations in the different species as a function of climatic change. At least two splendid examples of opportunities for studying distribution and variation in these organisms exist within the Park. These are both discussed below in the next chapter on vegetations. One of these is the littoral area along the shores. The other is the recent flows and such hot soil areas as that near Puhimau Crater (Figs. 8 & 23) which has been sampled and reported on informally by Dr. Malcolm Brown, University of Texas, Austin, Texas. While not yet published he has provided a list (Table II, List B) of genera isolated and contributed the comment that there are distinct relationships between the distribution of the algae found and the roughly concentric zones of different temperature existing across this area. The area is visible on Aerial Photo 8-0104 just south of Puhimau Crater as a light spot about the size of the crater itself.

In the preliminary studies made of the marine algae of the Park it is only largely the common species that have been collected and thus any collections are desirable, especially west of Kaena Point, and could be expected to add to the check list (Table II, List A) of collected species. Little ecological study has been made of the algae within the Park, and anything well done in this direction would be worthy of publication.

B- FUNGI AND LICHENS

Like the other organisms whose dissemules are air-borne or wind-distributed, the algae, protozoa, bacteria, mosses, lichens and to a lesser extent the ferns, the fungi of the Park are those to be found in

Table I. List of useful publications concerning the simpler plant-like organisms. None of these has been studied within the Park in any significant detail nor are there any publications that dwell in any detail on these organisms as they occur in the Park.

Algae	Fungi
Boergesen, 1913	Ainsworth, 1963
Boergesen, 1940-57	Bessey, 1950
Dawson, 1954	Clements & Shear, 1954
Dawson, 1956	Ramsbottom, 1953
Dawson, 1957	Stevens, 1913
Palmer, 1959	Stevens, 1925
Prescott, 1951	**Bryophytes**
Segawa, 1957	Bartram, 1933
Smith, 1950	Brotherus, 1927
Taylor, 1950	Evans, 1900
Tilden, 1910	Miller, 1963
Lichens	Miller, *et al.*, 1963
Magnuson & Zahlbruckner, 1943	
Magnuson, 1955	

<u>Table II</u>. List A: marine algae known from within the Park. List B: algal genera isolated from the soils of the hot area just south of Puhimau Crater during the summer of 1965 by Dr. Malcolm Brown.

<u>LIST A</u>

Acetabularia moebii

Ahnfeltia concinna

Amansia glomerata

Anacystis aeruginosa

Anacystis dimidiata

Anacystis marina

Anacystis montana

Boodlea composita

Calothrix crustacea

Calothrix pilosa

Cladophora socialis

Codium arabicum

Codium edule

Colpomenia sinuosa

Dictyosphaeria versluysii

Ectocarpus indicus

Entophysalis deusta

Erythrotrichia carnea

Gomphosphaeria aponina

Hemitrema fragilis

Hypnea pannosa

Jania capillacea

Jania pumila

Laurencia parvipapillata

Lyngbya aetuarii

Mastigocoleus testarum

Microcoleus chthonoplastes

Oscillatoria chalybea

Oscillatoria laetevirens

Padina japonica

Phormidium crosbyanum

Polysiphonia howei

Polysiphonia savatieri

Polysiphonia sphaerocarpa

Porolithon onkodes

Rhizoclonium hookeri

Rosenvingea orientalis

Sargassum echinocarpum

Sargassum obtusifolium

Schizothrix thelephoroides

Scytonema hofmannii

Sphacelaria tribuloides

Tolypiocladia calodictyon

Turbinaria ornate

Valonia aegagropila

Table II. (continued)

LIST B

Anabaena	Eucapsis	Palmella
Botrydiopsis	Gloeocystis	Phormidium
Botrydium	Gomphosphaeria	Pinnularia
Calothrix	Heterococcus	Plectonema
Chlamydomonas	Hormidium	Polycystis
Chlorella	Lyngbya	Scenedesmus
Chlorococcum	Nannochloris	Scytonema
Chlorosarcina	Neochloris	Stichococcus
Chlorosarcinopsis	Netrium	Stichogloea
Chroococcus	Nostoc	Stigonema
Cylindrocapsa	Oocystis	Symploca
Cylindrospermum	Oscillatoria	Tetracystis

the same habitats elsewhere in the world. There are no specific publications on the Park fungi. Though Dr. G. E. Baker of the University of Hawaii has initiated studies of the soil and epiphyllous fungi, none of this work has as yet reached the publication stage. The fungi may be approached through Table I, the general literature. The so-called "leaf spots" were studied seriously (Stevens, 1925) and are one of the few groups of Hawaiian fungi upon which a major publication has appeared.

The mycologist will know the literature for those fungi on which he wants to work so only an effort has been made (Table I) to list a few "old standbys" for those who wish to familiarize themselves with the kinds of fungi to be found or expected within the Park.

The lichens of Hawaii are known largely through the publications of Magnusson & Zahlbruckner (1943, etc.) and incidental mentions (e.g., Skottsberg, 1941) of one or more species. Magnusson (1955) has produced a second edition of his work. A number of species are mentioned in the section on lowland vegetation in Chapter VII, below, on vegetations. Dr. Carroll W. Dodge of the University of Vermont made collections in and near the Park early in 1965 and provided (Table III) a list of the species found. See Table I as a guide to other literature.

Probably the most conspicuous lichen in the Park is that which forms whitish to greyish erect match-stick-sized thalli on the otherwise barren older lava flow surfaces where there is no shade. This is the genus Sterocaulon. While the above mentioned people recognize a number of species and varieties in this genus, Dr. I. Mackenzie-Lamb of the Farlow Herbarium, Harvard University, Cambridge, Massachusetts, has referred all the lowland collections to S. vulcani. It is a pioneer organism on the surfaces of both pahoehoe and a'a lava flows. As shade from the primary

<u>Table III</u>. Lichens from Hawaii Volcanoes National Park or just outside its boundaries found by Dr. Carrol W. Dodge in 1965.

Catillaria trachonoides (Nyl.) Zahlbr.
Cladonia coniocraea (Floerke) Sandst.
Cladonia fimbriata (L.) Fr. v. simples (Wesis) Flotow
Cladonia leiodea (Magn.)
Cladonia leprosula Magn.
Cladonia mauiensis Magn.
Cladonia oceanica Vainio
Cladonia pityreoides Krmplhbr.
Cladonia skottsbergii (Magn.)
Coccocarpia fuscata Zahlbr.
Collema rupestre (Sw.) Rabh.
Cyanisticta hawaiiensis (Magn.)
Erioderma marginatum (Zahlbr.)
Erioderma pulchrum Müll. Arg.
Erioderma sandwicense Zahlbr.
Lecanidium hawaiiensis (Erichs.)
Lecanora chlaronella Nyl.
Lecanora cinereocarnea (Eschw.) Vainio
Lecanora flavovirens (Fée) v. aeruginosa (Nyl.) Vainio
Megalospora papillifera Magn.
Microthelia thelena (Ach.) Trev.
Nephroma tomentellum Inumaru
Nephroma tropicum (of Magnusson; probably not of others)
Ocellularia multilocularis Zahlbr.
Pannaria cinerata Zahlbr.
Parmelia (Amphigymnia) capitulifera Zahlbr.
Parmelia (Amphigymnia) cristifera Taylor
Parmelia (Amphigymnia) dominicana Vainio?
Parmelia (Hypotrachynae) fallax Zahlbr.
Parmelia (Amphigymnia) hawaiiensis Magn.
Parmelia (Hypotrachynae) isidiophora Zahbr.
Parmelia (Hypotrachynae) reticulata Taylor
Parmelia (Hypotrachynae) subbahiana Zahlbr.
Pertusaria faurieana Zahlbr.
Pyrenula insularum Magn.
Pyrenula rockii Zahlbr.
Ramalina leiodea Nyl.?
Stereocaulon maunae-loae Magn.
Stereocaulon roccelloides Th. Fr.
Stereocaulon supervestiens Magn.
Stictina lutescens (Taylor) Nyl.
Stictina plumbicolor (Zahlbr.)
Usnea australis Fr.
Usnea hawaiiensis Motyka
Usnea lutea Motyka
Usnea pruinosa Motyka
Usnea rockii Zahlbr.
Usnea steineri (of Magnusson)
Xanthoria sp.

flowering plant populations appears such lichens as Cladonia replace it.

The Park is an admirable and easy place to study lichens in correlation with climate and age of the different types of lichen substrata.

C- BRYOPHYTES

Though a good many mosses have been collected and identified from the Park area there seems to be no publication which mentions localities more precisely than those of Miller (Table I) in which some such locality as "Kilauea" is that usually found. Dr. Howard Crum has identified mosses (Table IV) for Dr. Dieter Mueller-Dombois during the preparation of this Atlas. Dr. Harvey Miller has many collections identified in his herbarium from within the Park. See Table I for several of the more useful publications regarding the Bryophyta of the Hawaiian Islands and which have in them leads to the other pertinent literature.

One thallose liverwort, Lunularia cruciata, forms a mat under the porch of the home of Chester and Juliette Wentworth. This genus forms such mats commonly under greenhouse benches in temperate regions. Mosses form their characteristic colonies such as Macromitrium on tree trunks of Metrosideros in damper areas along with the leafy, often lejeunioid, liverworts. Not all bryophytes are in high humidity areas. Certainly the grey tufts of Rhacomitrium lanuginosum in cavities on the higher otherwise rather barren lavas are in very xerophytic circumstances. Campylopus exasperatus, a pioneer on the uppermost parts of a lava flow in the open sun, is also in a xerophytic situation.

<u>Table IV</u>. Mosses collected in the Park by Dr. Dieter Mueller-Dombois during the summer of 1965 and identified by Dr. Howard Crum in January 1966.

Acroporium fusco-flavum (C. M.) Broth.

Amphidium cyathicarpum (Mont.) Broth.

Brachymenium exile Dozy & Molk.

Brachythecium hawaiicum Bartr.

Campylopus exasperatus Brid.

Ceratodon purpureus (Hedw.) Brid.

Dicranum speirophyllum Mont.

Distichophyllum freycinetii (Schwaegr.) Mitt.

Homaliodendron flabellatum (Sm.) Fl.

Leucobryum hawaiiense var. fumaroli (C. M.) Bartram

Polytrichum piliferum Hedw.

Rhacomitrium lanuginosum var. pruinosum H. f. & W.

Thuidium hawaiiense Reich.

Thuidium plicatum Mitt.

D- VASCULAR PLANTS

by F. R. Fosberg

The check list of the plants of the Park prepared by Fagerlund and Mitchell (1944) and issued in mimeographed form by the National Park Service has long been unavailable, and many plants have since been added to this list of those known from the Park in the past.

The present list is a partial revision of the 1944 list. It was specifically prepared for inclusion in this Atlas but with the additional feature of citations of the collection numbers of the specimens on which it is based being given, underscored and in parentheses, after each entry. Further information on these plants can be found in the scientific literature and in this Atlas by use of the index chapter, below, Chapter VIII.

It was not considered necessary to give precise localities for the collections on which the list is based, as all are from within the Park or in its immediate vicinity. Certain materials that should have been included, as well as reports from Hawaiian botanical literature were not included for reasons of time. It is hoped this check list will be published in more finished form later, at which time these defects can be remedied. Thus, while the present list can serve as an interim list noting most new additions, it should not be regarded as thoroughly complete.

Many of the additions to this list were brought to light by Mr. Garrett Smathers, former Park Naturalist, HVNP, now of Lava Beds National Monument, Tulelake, California, and his assistance and stimulus in the present project is gratefully acknowledged.

Many of the specimens cited are in the herbarium maintained by the

Hawaii Volcanoes National Park. Duplicates of some are in the Bernice P. Bishop Museum, Honolulu. Other collections cited are in the U. S. National Herbarium, some in the New York Botanical Garden, others still in the author's possession. Unfortunately, many of those in the Park herbarium lack or almost lack data as to locality and collector. The recent effort to correct this situation made by the Park in engaging Mrs. Eva G. Hecht-Poinar to put the Park collections in better order could not alter this situation entirely.

Certain species included in the list have no specimens cited with them. These are plants known to exist in the Park, either from the 1944 or 1947 lists by Fagerlund and Mitchell, from other published sources, or from personal observation.

The symbols in parentheses following the names in the list, along with any applicable Hawaiian or common name in quotation marks, have these meanings:

E = endemic to the Hawaiian Islands

I = indigenous to the Hawaiian Islands but not endemic

X = exotic

P = probably of aboriginal introduction

Abbreviations in the specimen citations in parentheses at the end of each entry are:

B & F = Baldwin & Fagerlund

CJE = Charles J. Engard

F & M = Fagerlund & Mitchell

M-D = Mueller-Dombois

PHB & GOF = Baldwin & Fagerlund

s. coll. = without collector

OPHIOGLOSSACEAE
(Adder's Tongue Family)

OPHIOGLOSSUM CONCINNUM Brack. (E, "pololoi")

Rare. Reported by Fowler to be in earthquake cracks near rim of Halemaumau. Could be the following species. (F & M 1061)

OPHIOGLOSSUM NUDICAULE L. f. (I)

Uncommon or inconspicuous; found in fumaroles and steam cracks in Kilauea Caldera and along the Chain-of-Craters Road. (Degener 9278, Horner in 1950)

OPHIOGLOSSUM PENDULUM var. FALCATUM (Presl) Fosberg (I, "puapuamoa")

Ophioglossum pendulum ssp. falcatum (Presl) Clausen

Ophioderma falcatum Degener

Ophioderma pendulum var. falcatum Presl

Ophioglossum falcatum (Presl) Fowler

Epiphyte in moist or wet forests. (Baldwin in 1949)

MARATTIACEAE

MARATTIA DOUGLASII (Presl) Baker (E, "pala" "kapuai hoki")

Rare in wet forests. (F & M 889; Fowler 201)

GLEICHENIACEAE

GLEICHENIA LINEARIS (Burm. f.) C. B. Cl. (E, "uluhe, uluhi")

Gleichenia emarginata (Brack) Moore

Dicranopteris sandwicensis Degener

Abundant in moderately wet forest, around fumarole areas, and in disturbed places, forming dense tangles. (Morley 122-H; Eggler 265)

Most Park plants are of the hairy form frequently considered as specifically distinct.

HYMENOPHYLLACEAE
(Filmy-fern Family)

HYMENOPHYLLUM LANCEOLATUM Hook. & Arn. (E, "palaihinahina")

Frequent epiphyte in wet forest. (Fowler in 1937; M-D H-83)

HYMENOPHYLLUM OBTUSUM Hook. & Arn. (E, "palailaulii")

Infrequent. On moss-covered trunks in wet forest. (Degener in 1922)

HYMENOPHYLLUM RECURVUM Gaud. (E, "ohiaku")

Frequent. On moss-covered trunks and damp rocks in wet forest. (Olson in 1939; Fowler 202; M-D H-160a)

TRICHOMANES CYRTOTHECA Hillebr. (E)

Puna, lower Pulama between Punalu'u and Wahaula; in deep lava crack, on moist vertical rock walls in shade.

TRICHOMANES DAVALLIOIDES Gaud. (E, "kilau" "palaihihi")

Frequent in damp woods and on shady cliffs. (Morley 114-H)

TRICHOMANES SAXIFRAGOIDES Presl.(I)

Trichomanes parvulum Poir. of Hillebrand, Fl. Haw. Is., p. 635

Infrequent. On moss-covered trunks in Makaopuhi Crater. (F & M 590)

POLYPODIACEAE
(Fern Family)

(Sensu lato; the numerous segregate families recognized in recent years are not yet subject to sufficient agreement among experts, or founded on characters very evident to non-experts. Therefore the family Polypodiaceae is here adopted in the traditional sense.)

ADIANTUM CAPILLUS-VENERIS L. (I, "iwaiwa" "maidenhair fern")

"Frequent in moist, rocky places, and in earthquake cracks at Hilina Pali and vicinity." This species may exist in the Park, but the specimen on which the F. & M. record was probably based seems to be A. cuneatum.

ADIANTUM CUNEATUM Langsd. & Fisch. (X, "*maidenhair fern*")

Widely naturalized in the Hawaiian Islands. Uncommon in Park. (Fowler 214)

ADIANTUM HISPIDULUM Sw. (I, "rough maidenhair fern")

Collected in cave near Hilina Pali. (F & M 1058; Olson in 1938)

ASPLENIUM ADIANTUM-NIGRUM L. (I, "iwaiwa")

Frequent in open dry places from about 1700 to 9500 feet. (Fowler 219, 19; Stone 2959; Poinar in 1963; M-D H-320; Eggler 149, 271)

ASPLENIUM CONTIGUUM Kaulf. (E)

Frequent in moderately wet and wet forests. (Fowler 208, 245; F & M 38; Morley 128-H)

ASPLENIUM FRAGILE var. INSULARE Morton (E)

On moist wall of lava tube *at* Three Trees Kipuka, 6250 *feet*. (F & M 894)

ASPLENIUM HORRIDUM Kaulf. (I, "alae" "alaea" "iwa" "kumauna")

Asplenium pseudofalcatum Hbd.

Recorded by Rock, Indigenous trees, p. 27, from vicinity of Kilauea.

ASPLENIUM LOBULATUM Matt. (I, "piipiilau manamana")

Abundant in the wet and moderately wet forests. (Morley 40-H; Fowler 246, 217; F & M 11; Olson in 1938)

ASPLENIUM MACRAEI Hook & Grev. (E)

Frequent in shady, rocky cliffs in Kipuka Puaulu.

ASPLENIUM MACRAEI var. STRICTA (Brack.) Hieron. (E)

Collected in Kipuka Ki, 4300 feet. (Fowler 204; Olson in 1939)

ASPLENIUM NIDUS L. (I, "*ekaha*" "birdsnest *fern*")

Kapaahu, Kalapana, 1/4 miles east of Heiau. (F & M 921)

ASPLENIUM NITIDULUM Hbd. (E)

Rare. Reported from Byron Ledge by both Skottsberg and Degener.

ASPLENIUM RHIPIDONEURON W. J. Robinson (E, "iwaiwa o kane")

Frequent in open, dry kipukas, and in moderately wet forests. (Fowler 20, 220; F & M 37)

ASPLENIUM SPHENOLOBIUM Zenker var. DIPLAZIOSORUM Hieron. (I)

Infrequent. In moderately damp places at Hilina Pali.

ASPLENIUM TRICHOMANES L. (I, "owalii" "maidenhair spleenwort")

Asplenium densum Brack.

Frequent on dry rocky soil from about 3000 to 10,000 feet. (Poinar in 1963; M-D H-306)

ASPLENIUM UNILATERALE Lam. (I, "pamoho")

Infrequent. On shady, wet cliffs near Thurston Lava Tube. (Fowler 206)

ATHYRIUM MICROPHYLLUM (Sm.) Alst. (E)

A. poiretianum (Gaud.) Presl

Infrequent. In wet forests and craters. (F & M 832; Fowler 209)

ATHYRIUM SANDWICHIANUM Presl (E)

Diplazium sandwichianum (Presl) Diels

Frequent in shady moist localities, especially in craters. (F & M 862, 863; Morley 126-H; Fowler 210)

CONIOGRAMME PILOSA (Brack.) Hieron. (E, "loulu")

Infrequent on wet cliffs from about 3000 to 5000 feet; frequent near Thurston Lava Tube. (Morley 112-H)

CYRTOMIUM CARYOTIDEUM (Wall.) Presl (I)

Frequent along edge of lava flow in Kipuka Puaulu. (Morley 77-H; Lamoureux 2496)

DORYOPTERIS DECORA Brack. (E)

Abundant in lava cracks, especially at Hilina Pali and the Kau Desert, down to sea level. (F & M 341, 148, 157; Fosberg 41586a; Fowler 215; M-D H-254)

DORYOPTERIS DECORA var. DECIPIENS (Hook.) Tryon (E)

(Eggler 41)

DRYOPTERIS*/ CYATHEOIDES (Kaulf.) Kuntze (E, "kikawaeo")

Abundant in wet forest. (Baldwin in 1944; Fowler 224; Morley 142-H)

DRYOPTERIS DENTATA (Forsk.) C. Chr. (I)

Cyclosorus dentatus (Forsk.) Ching

In deep shaded lava crack in Puna, lower Pulama between Punalu'u and Wahaula. (Stone 3009)

DRYOPTERIS GLABRA (Brack.) Kuntze (E, "kilau")

Frequent in open, moderately wet forests. (F & M 53; Fowler 236; Morley 149-H)

DRYOPTERIS GLOBULIFERA (Brack.) Kuntze (E, "palapalai o kaumaapua")

Abundant in wet forest near Thurston Lava Tube. (Fowler 216)

DRYOPTERIS HAWAIIENSIS (Hbd.) H. Christ. (E, "palaa")

Infrequent. In open forest in Kipuka Puaulu. (Fowler 234)

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*/ Many of the species traditionally referred to Dryopteris should be placed in the genus Thelypteris. However, there is considerable doubt as to the legitimacy of the name Thelypteris and it is probable that this name may be replaced by Lastrea. Since this is not certain, and since combinations are not yet available for certain species in Lastrea, all are here retained in Dryopteris, even though this is admittedly an improper arrangement.

DRYOPTERIS KERAUDRANIANA (Gaud.) C. Chr. (E, "akolea" "waimakanui")

Skottsberg reports it at Kilauea along the road to Hilo.

DRYOPTERIS PALEACEA (Sw.) C. Chr. (I, "laukahi")

Rare. In open forest in Kipuka Puaulu. Also collected in a lava tube on Mauna Loa at 8800 feet. (Lamoureux 2459; Morley 69; F & M 774, Fowler 235)

DRYOPTERIS PARASITICA (L.) Kuntze (X, "downy woodfern")

Frequent in shady, damp places at Hilina Pali, and in the craters along the Chain-of-Craters-Road. (Fowler 212, 213)

DRYOPTERIS SETIGERA (Bl.) Kuntze (I)

Frequent. In openings to lava tubes in Kau Desert, Hilina Pali, and along the shore. (Fowler 230, 231; F & M 173, 366)

DRYOPTERIS STENOGRAMMOIDES (Baker) C. Chr. (E)

Frequent in shady, moist localities along Kilauea Iki trail. (Fowler 217, 207)

DRYOPTERIS UNIDENTATA (Hook & Arn.) C. Chr. (E, "akole")

Rare. Found in dry rocky gulch near Halfway House. (Fowler 237)

ELAPHOGLOSSUM ALATUM Gaud. (I, "ekaha" "Maui's Paddle")

Elaphoglossum aemulum (Kaulf.) Brack.

Frequent on rocks and trees in wet and moderately wet forest from about 1000 to 4500 feet. (Morley 32-H, 139-H; F & M 695; Baldwin in 1949)

ELAPHOGLOSSUM GORGONEUM (Kaulf.) Brack. (E, "ekaha")

Recorded by Rock, Indigenous trees, p. 27, from the vicinity of Kilauea.

ELAPHOGLOSSUM HIRTUM (Sw.) C. Chr. ("ekaha")

Frequent on Metrosideros trunks and on exposed ridges, 3000 to 4000 feet. (Morley 4-H; Eggler 287)

ELAPHOGLOSSUM MICRADENIUM (Fée) Moore (E, "ekaha ula" "Maui's paddle")

Collected by Degener near Waldron Ledge.

ELAPHOGLOSSUM RETICULATUM (Kaulf.) Gaud. (E, "ekaha" "pusakuhinia")

Abundant on rocks and trees in wet forests. (Morley 8-H; Stone 2961; M-D H-51; Eggler 217)

ELAPHOGLOSSUM WAWRAE (Luerssen) C. Chr. (E, "ekaha" "laukahi")

Reported by Rock from vicinity of Kilauea; Kipuka Ki. (F & M 685)

MICROLEPIA SETOSA (Sm.) Alston (I, "palapalai")

Frequent in moderately wet areas and at lower elevations in moist transition forest. (Fowler 232; Olson in 1938; Stone 2958B; Lamoureux 2453, 2501; F & M 864)

NEPHROLEPIS CORDIFOLIA (L.) Presl (X, E, "nianiau" "pamoho" "sword fern")

Degener reports that it is "rather common on the trunks of trees and on the ground in the open forest near Makaopuhi Crater". Commonly said to be introduced by there is certainly a native form of this species in wet forests. (Fowler 238; Morley 78-H; F & M 916 (cult. form))

NEPHROLEPIS EXALTATA (L.) Schott (I, "nianiau" "okupukupu" "sword fern")

Frequent in moderately wet to dry areas. (Lamoureux 2468; Fowler 275; Stone 3008)

NEPHROLEPIS HIRSUTULA (Forst. f.) Presl (X)

Puna, upper Kealahoma, near border of Panau Nui; in transition forest; common in lava tubes and fissures; also in Wahaula Heiau, and above Kalapana along Park boundary. (Stone 3002, 2911; Poinar in 1963; Eggler 42)

PELLAEA TERNIFOLIA (Cav.) Link (I, "laukahi" "cliff brake" "kalamoho laulii")

Frequent in arid regions and in crevices in bare lava. (Morley 83-H; Stone 2957; Fosberg 4159a; Degener & Wiebke 3972)

PITYROGRAMMA CALOMELANOS (L.) Link (X, "silver fern" "gold fern")

Frequent in Kau Desert, occasional in open places elsewhere. Some plants have a silvery, waxy powder on undersides of fronds, others golden. (M-D H-255, H-114; Olson in 1938, 1939; F & M 77, 147; Stone 3025; Fowler 222; Eggler 90)

POLYPODIUM*/ HOOKERI Brack. (E, "makue laulii")

Infrequent epiphyte in wet forest. (Fowler 211)

POLYPODIUM HYMENOPHYLLOIDES Kaulf. (E, "palaihuna")

Infrequent on moss-covered rocks and trees in wet forest. (Fowler 233)

POLYPODIUM THUNBERGIANUM (Kaulf.) C. Chr. (I, "ekaha akolea" "pakahakaha"

P. lineare Thunb. "lanakio wahine"

Frequent on rocks and trees. (Lamoureux 2452; Morley 3-H, 67-H; M-D H-108, H-190; Wentworth in 1963; Eggler 40)

POLYPODIUM PELLUCIDUM Kaulf. (E, "ae")

Frequent. An epiphyte in wet forests; terrestrial in open woods and on new lava flows, up to 9500 feet; dwarfed in unfavorable places. (M-D H-221, H 63; Stone 146; Fowler 30-H; Morley 30-H)

POLYPODIUM SCOLOPENDRIA Burm. f. (X, "laua'e")

(Polypodium phymatodes L.)

Infrequent. Near steaming cracks in Kilauea Caldera and in steaming area near Kokoolau Crater. Also near Nalapana Shelter. (Stone 2850; F & M 146; Poinar in 1963)

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*/ Certain of the species traditionally referred to Polypodium should be transferred to Grammitis, but this cannot be attempted here.

POLYPODIUM PSEUDO-GRAMMITIS Gaud. (E, "kolokolo" "mahinalua")

(= Grammitis tenella Kaulf.)

Frequent epiphyte in wet forest. (Morley 6-H)

POLYPODIUM SAFFORDII Maxon (E, "kihi")

Infrequent on moss-covered trunks in wet forest. (Fowler 223; M-D H-162)

POLYPODIUM SARMENTOSUM Brack. (E)

Infrequent epiphyte in wet forest. (Fowler 205)

POLYPODIUM TAMARISCINUM Kaulf. (E, "wahine noho mauna")

(Morley 5-H)

PTERIDIUM AQUILINUM var. DECOMPOSITUM (Gaud.) Tryon (E, "kilau" "kilauapueo" "paia" "bracken")

Frequent in moderately dry or open regions from Hilina Pali to about 9500 feet. Abundant in Kipuka Nene. (Lamoureux 2484; Morley 79-H; Poinar in 1963; Eggler 15)

PTERIS CRETICA L. (I, "owalii")

Infrequent in wet and moderately wet forest. (Fowler 228, 229; Morley 72-H; Lamoureux 2472)

PTERIS EXCELSA Gaud. (E, "kaimakanui" "iwa")

Infrequent. In Kipuka Puaulu. (Morley 236)

PTERIS LONGIFOLIA L. (X, "kilauapueo" "paia")

(or P. vittata L.)

Frequent in moderately dry areas and steam cracks. (M-D H-113; Fowler 221; Eggler 190)

SADLERIA CYATHEOIDES Kaulf. (E, "amaumau")

Abundant generally. (Morley 35-H; Fowler 227; Stone 2578)

SADLERIA HILLEBRANDII W. J. Rob. (E, "amau")

Locally frequent in moderately wet regions. (Fowler 226; Morley 35-H)

SADLERIA SOULEYTIANA (Gaud.) Moore (E)

Rare in wet forest. (Olson in 1939)

SPHENOMERIS CHUSANA (L.) Copel. (I, "palapalaa" "palaa")

(Stenoloma chinensis (L.) Bedd.)

(Sphenomeris chinensis (L.) Maxon)

Frequent generally in open places and around steam cracks. (Morley 31-H; M-D H-40; Fowler 203; Olson in 1938; Eggler 158)

TECTARIA GAUDICHAUDII (Mett.) Maxon (E, "iwaiwa launui")

Rare. Collected in damp cave near Hilina Pali. (Olson in 1939)

DICKSONIACEAE

CIBOTIUM GLAUCUM H. & A. (E, "hapu" "tree fern")

Common in wet forests; in Kipuka Puaulu. (Fowler 239)

CIBOTIUM MENZIESII Hook. (E, "hapu iii" "tree fern" "amahu")

Frequent in wet forest. (Fowler 240; Morley 125-H)

CIBOTIUM SPLENDENS (Gaud.) Krajina (E, "hapuu" "pulu ula-ula" "tree fern"

(Cibotium chamissoi Kaulf.)

Abundant in wet forest. (Fowler 241; Stone 2948)

LYCOPODIACEAE

LYCOPODIUM CERNUUM L. (I, "wawaeiole" "huluhuluaiole")

Abundant in open and semi-open places in moderately wet regions. Gametophytes have been found in steam cracks at Kilauea. (F & M 672; s. coll. 252, 388; M-D H-46; Eggler 129)

LYCOPODIUM PHYLLANTHUM H. & A. (E)

Rare, usually epiphytic, in Makaopuhi and Napau Crater areas. (s. coll. 253; F & M 595, 192)

LYCOPODIUM POLYTRICHOIDES Kaulf. (E, "wawaeiole")

Infrequent. Epiphytic on moss-covered trees near Napau Crater. (Fowler 243)

LYCOPODIUM VENUSTULUM Gaud. (I, "wawaeiole")

Terrestrial; along Napau Crater Trail. (Morley 185-H; s. coll. 386)

SELAGINELLACEAE

SELAGINELLA ARBUSCULA (Kaulf.) Spring (E, "lepelepeamoa")

Frequent in wet and moderately wet forests. (s. coll. 369; Morley 186-H; M-D H-102)

SELAGINELLA KRAUSSIANA (Ktze.) A. Br. (X)

Well established around the Park residence area and in Kilauea Caldera below the Volcano House. (Olson in 1938; Fosberg 41762)

SELAGINELLA MENZIESII (Hook. & Grev.) Spring (E)

Infrequent. Collected in wet forest near Napau Crater, and from wet shady cliff in Kilauea Caldera. This may not be distinct from S. arbuscula, though it differs some in habit. (Baldwin in 1949; F & M 121; Fowler 242)

PSILOTACEAE

PSILOTUM "COMPLANATUM" Sw. (I, "moa")

Infrequent epiphyte in wet forest. The Hawaiian plants are incorrectly referred to this species and are being described elsewhere. (s. coll. 250; Morley 163-H; F & M 45; M-D H-160)

PSILOTUM NUDUM (L.) Beauv. (I, "moa" "pipi")

Frequent on trees in moderately wet to dry regions in the Park below 4500 feet. (M-D H-160; Lamoureux 2477; Olson in 1940; Morley 27-H; s. coll. 251)

ARAUCARIACEAE

ARAUCARIA EXCELSA R. Br. (X, "Norfolk Island pine")

Occasionally planted in the Kilauea region.

PODOCARPACEAE

PODOCARPUS IMBRICATUS Bl. (X)

Planted near Old Volcano House. (F & M 223)

TAXODIACEAE

CRYPTOMERIA JAPONICA (L. f.) D. Don (X)

Planted near Old Volcano House. (F & M 221)

CUNNINGHAMIA LANCEOLATA (Lamb.) Hook. (X)

Planted near Park Residences. (F & M 113)

CUPRESSACEAE

JUNIPERUS BARBADENSIS L. (X)

Planted near Old Volcano House. (F & M 220)

THUJA ORIENTALIS L. (X)

Planted near Old Volcano House. (F & M 234)

PANDANACEAE

FREYCINETIA ARBOREA Gaud. (E, "ieie")

Abundant in wet forests below 4000 feet; Kilauea Iki. (F & M 195)

PANDANUS TECTORIUS Park. (I, "hala" "puhala" "lauhala" "screw pine")

(Pandanus odoratissimus L. f.)

Along the coast in moister places. (F & M 880)

GRAMINEAE

AGROSTIS AVENACEA Gmel. (X)

Frequent in lawns, along roadsides, and around fumaroles. (F & M 561; M-D H-73, H-330; Fosberg 41769, 41773)

AGROSTIS SANDWICENSIS Hbd. (E, "pilihale")

Dry grasslands; Kau Desert. (F & M 561)

AGROSTIS STOLONIFERA L. (X, "red top")

Along roadsides

AIRA CAPILLARIS Host (X, "silver hairgrass")

Frequent in moderately wet to dry areas. (Morley 106-H; F & M 495)

ANDROPOGON GLOMERATUS (Walt.) BSP. (X, "broom sedge")

Occasional in open places, becoming abundant in the Hilina Pali area, only recently noticed. (M-D H-3, H-29; Fosberg 42065; Eggler 252, 193)

ANDROPOGON VIRGINICUS L. (X, "broom sedge")

Abundant generally in open places, except in the very lowest and driest areas and above 4500 feet. (F & M 905; M-D H-28; Eggler 278)

ANTHOXANTHUM ODORATUM L. (X, "sweet vernal grass")

Abundant, especially in Kipuka Luaula and on lower slopes of Mauna Loa. (Lamoureux 2491; F & M 266; M-D H-303; Olson 439; Fosberg 41619)

ARUNDINARIA sp. ? (X)

One or two clumps near Old Volcano House.

AVENA FATUA L. (X, "wild oats")

Infrequent, at Kilauea Military Camp and at Park residential area. (F & M 623)

AVENA SATIVA L. (X, "oats")

Infrequent. In horse corrals, also at Uwekahuna. (Olson in 1939—with straight awns; F & M 320—awnless)

AXONOPUS AFFINIS Chase (X, "narrow-leafed carpet grass")

Abundant in lawn near Old Volcano House. (F & M 227)

BRIZA MINOR L. (X, "little quaking grass")

Frequent on lower grassy slopes of Mauna Loa, in Kipuka Puaula, and in Park residential area. (M-D H-37; Morley 84-H; Olson in 1938)

BROMUS CATHARTICUS Vahl (X, "rescue grass" "brome" "wild oat grass")

Frequent on slopes of Mauna Loa. (Fagerlund 54; Olson in 1938; F & M 429; Fosberg 41618)

BROMUS COMMUTATUS Schrad. (X)

Found in Kipuka Puaulu. (s. coll. 1244)

BROMUS MADRITENSIS L. (X)

South of Kipuka Nene, 2600 feet, in grassland in transition forest. (F & M 1011)

BROMUS MOLLIS L. (X, "soft chess")

Infrequent on slopes of Mauna Loa. (F & M 428, and possibly 1069; s. coll. D)

BROMUS RIGIDUS Roth (X, "ripgut grass")

Infrequent. Hilina Pali; Kipuka Puaula to end of Mauna Loa Truck Trail. (Fagerlund 1067, 1072; F & M 431)

BROMUS SECALINUS L. (X, "chess")

Kipuka Puaula. (F & M 657)

BROMUS STERILIS L. (X)

3 Trees Kipuka, 6280 feet, on Mauna Loa, in depressions where lava tubes have caved in. (F & M 893; Poinar in 1963)

CENCHRUS ECHINATUS L. var. ECHINATUS (X, "umealu" "sandbur")

Chain-of-Craters-Road near Kokoolau Crater. (F & M 722)

CENCHRUS ECHINATUS var. HILLEBRANDIANUS (Hitchc.) F. Br. (I, "umealu" "hairy sandbur")

Frequent throughout moderately dry and somewhat moist areas. (Olson in 1939; M-D H-333; F & M 23, 129; Fosberg 41769)

CHLORIS GAYANA Kunth (X, "Rhodes grass")

Frequent at Kipuka Nene and along roads at Kilauea. (F & M 218; Fosberg 44480)

CHLORIS INFLATA Link (X, swollen finger grass")

Abundant in dry coastal areas, at Kalue and Kaaha. (M-D H-258)

CHRYSOPOGON ACICULATUS (Retz.) Trin. (X, "pilipiliula" "piipii")

Frequent to abundant below about 2700 feet; forms almost pure cover on Puu Kaone. (M-D H-22, H-256, H-195; F & M 205; Eggler 157)

COIX LACHRYMA-JOBI L. (X, "Job's tears" "kukae kolea")

Along roadside near Thurston Lava Tube (F & M 402)

CYNODON DACTYLON (L.) Pers. (X, "manienie" "mahiki" "Bermuda grass")

Abundant in moderately wet to dry areas. (M-D H-259, H-332; F & M 460, 659; Lamoureux 2462)

DACTYLIS GLOMERATA L. (X, "orchard grass" "cocksfoot")

Frequent in Kipuka Puaula and found on lower slopes of Mauna Loa. (s. coll. 404)

DESCHAMPSIA HAWAIIENSIS (Skottsb.) St. John (E)

Slopes of Mauna Loa, collected by Skottsberg.

DESCHAMPSIA NUBIGENA Hbd. (E)

Frequent from Kilauea to the middle slopes of Mauna Loa. (Olson in 1940; F & M 562; Fosberg 41617, 41759; s. coll. E or 408; M-D H-288, H-300, H-315; Eggler 75)

DIGITARIA PRURIENS (Trin.) Buese. (I, "crabgrass" "kukaipua'a")

Common in moist weedy places. (F & M 153; Olson #1)

DIGITARIA SANGUINALIS (L.) Scop. ? (X, "kukaipua'a" "crabgrass")

Weed in Volcano House garden. (F & M 224)

DIGITARIA VIOLASCENS Link. (X, "kukaipua'a" "crabgrass")

Frequent in moderately dry areas. (F & M 612; Fagerlund 36, 47; Eggler 125)

ECHINOCHLOA CRUSGALLI var. CRUS-PAVONIS (H.B.K.) Hitchc. (X, "barnyard grass")

Park residential area. (F & M 642, 676)

ELEUSINE INDICA (L.) Gaertn. (X, "goose-grass")

Around shelter at Halape, also at Kilauea. (F & M 333)

ELYMUS TRITICOIDES Buckl. (X)

One bunch seen at Buck Hill Rest House at 10,035 ft on Mauna Loa; probably introduced with hay for horses. (M-D H-304)

ERAGROSTIS BROWNEI (Kunth) Nees (X)

In open grassland at 4000 feet elevation. (s. coll. 67)

ERAGROSTIS GRANDIS Hbd. (E)

Infrequent. In grasslands on Mauna Loa from 4000 to 6000 feet. (s. coll. 402; F & M 138, 699, 866)

This is too close to E. variabilis.

ERAGROSTIS PECTINACEA (Michx.) Nees (X, "Carolina lovegrass")

Around buildings at Kilauea. (F & M 818)

ERAGROSTIS TENELLA (L.) Beauv. (X)

Eragrostis amabilis (L.) W. & A.

Abundant in dry areas of Park below 2000 feet. (M-D H-261)

ERAGROSTIS VARIABILIS (Gaud.) Steud. (E, "emoloa" "kalamalo")

Frequent in wet to moderately dry areas. (Olson in 1938, 1939; F & M 172; M-D H-231; s. coll. 34 (or 367); Eggler 273)

FESTUCA BROMOIDES L. (X)

Frequent on lower slopes of Mauna Loa. (F & M 272, 437; Fagerlund 53; Baldwin in 1949; Morley 157-H; s. coll. in 1936; Eggler 92)

FESTUCA MEGALURA Nutt. (X)

Frequent in Koa-shrub kipuka near Na Makani Paio. (F & M 610)

Very close to F. bromoides, spikelets somewhat more puberulent or scabrous.

GASTRIDIUM VENTRICOSUM (Gouan) Sch. & Thell. (X, "nit grass")

Infrequent; in Koa-shrub kipuka near Na Makani Paio. (F & M 609; Fagerlund 52)

HETEROPOGON CONTORTUS (L.) Beauv. (I, "pili" "pili hale" "twisted beard grass")

Frequent in drier sections, locally dominant at very low elevations. (F & M 550; M-D H-193, H-257)

HOLCUS LANATUS L. (X, "velvet grass" "Yorkshire fog")

Common around Kilauea and on lower slopes of Mauna Loa, has become much more abundant in the last several years. (Lamoureux 2464, 2469; Morley 156-H; Fagerlund 38; s. coll. 291; s. coll. in 1936; Fosberg 41620)

HORDEUM MURINUM L. (X,"wild barley" "mouse barley")

Around shelters and horse corrals. (F & M 430; Olson in 1939)

HORDEUM VULGARE L. (X, "barley")

Puu Ulaula, at 10.000 feet, on Mauna Loa. (F & M 907)

HYPARRHENIA RUFA (Nees) Stapf (X)

Keauhou Ranch, introduced from Africa. (F & M 390)

ISACHNE DISTICHOPHYLLA Munro (E, "ohe" "ma ohe ohe")

Frequent in wet and moderately wet forests. (Morley 21-H; M-D H-43; Olson in 1939; Eggler 219)

Two specimens (Olson in 1939 and Stone 2951) of smaller size and more slender habit, have been referred to Isachne pallens Hbd., of Oahu, but are probably merely depauperate I. distichophylla.

LOLIUM MULTIFLORUM Lam. (X, "Italian ryegrass")

Frequent along roads near Kilauea. (F & M 598, 605)

Another collection (F & M 671) with very short glumes may be var. diminutum Mutel

MELINIS MINUTIFLORA Beauv. (X, "molasses grass")

Along roadsides and in Steaming Flats at Kilauea, and near Hilina Pali. (Jaggar in 1930; F & M 254)

MICROLAENA STIPOIDES (Labill.) R. Br. (I, "puu lehua" "meadow ricegrass")

Found once on Mauna Loa at 4000 feet. (Fagerlund 45)

OPLISMENUS HIRTELLUS (L.) Beauv. (I, "honohono kukui")

In moist to moderately dry areas in shade; not common in Park. (F & M 613; Eggler 270)

PANICUM COLLIEI Endl. (E)

In dry open country between Kipuka Nene and Hilina Pali. (F & M 1013)

PANICUM DICHOTOMIFLORUM Michx. (X)

Around Old Volcano House. (F & M 638)

PANICUM MAXIMUM Jacq. (X)

Keauhou Ranch at 1500 feet. (F & M 391)

PANICUM NEPHELOPHILUM Gaud. (E, "konakona")

Frequent along Park boundary near Kapalapala corral, at 3500 feet, also below Poliokealoe Pali. (F & M 687; M-D H-264)

PANICUM PELLITUM Gaud. (E)

Great crack, at 2300 feet. (F & M 1057)

PANICUM PURPURASCENS Raddi (X, "para grass")

Park residential area. (F & M 858)

PANICUM REPENS L. (X, "torpedo grass")

Park residential area; also in sand at Kalapana. (F & M 857)

PANICUM TENUIFOLIUM H. & A. (E, "mountain pili")

Frequent in Kipuka Puaula and on lower Mauna Loa slopes. (F & M 576; Olson in 1939; Poinar in 1963; Fosberg 41614)

PANICUM XEROPHILUM (Hbd.) Hitchc. ? (E)

Coastal lowlands on pahoehoe lava below Hilina Pali toward Keauhou Landing. (M-D H-266)

PASPALUM CONJUGATUM Berg. (X, "hilo grass" "mau malihini")

Abundant in disturbed areas in wet and moderately wet forest; also in steaming areas. (Lamoureux 2489; Morley 164-H; F & M 715, 720)

PASPALUM DILATATUM Poir. (X, "Dallas grass")

Abundant in Kipuka Puaulu and on lower slopes of Mauna Loa. (Lamoureux 2465; PBH & GOF in 1941; M-D H-135)

PASPALUM ORBICULARE Forst. (P, "mau laiki" "rice grass")

In wet place near Hilo entrance and in Kilauea Caldera. (F & M 404; M-D H-94; Eggler 192)

PASPALUM URVILLEI Steud. (X, "Vasey grass")

Increasingly abundant in Kilauea region and other moderately wet areas, in open places and along roadsides. (F & M 624; M-D H-131, H-270)

PENNISETUM CLANDESTINUM Hochst. (X, "Kikuyu grass")

Forming dense mats, Kilauea area, Na Makani Paio, and Kipuka Nene. (F & M 711)

PENNISETUM PURPUREUM Schum. (X, "napier grass" "elephant grass")

Kilauea region; Keauhou Ranch; Apua near Ranch boundary at 2600 feet. (F & M 235, 1115)

PENNISETUM SETACEUM (Forsk.) Chiov. (X, "fountain grass")

P. ruppellii Steud.

Kilauea Caldera, on open lava and ash. (Fosberg 45143)

PHALARIS TUBEROSA L. (X, "bulb canary grass")

Rare; collected in corral at end of Mauna Loa Truck Road. (Mauna Loa Strip Road) (Olson in 1939)

PHLEUM PRATENSE L. (X, "timothy")

Rare; Park residential area. (F & M 667)

POA ANNUA L. (X, "annual blue-grass" "common blue-grass")

Frequent in moderately wet areas around Kilauea and on lower slopes of Mauna Loa. (Lamoureux 2514; Morley 401; F & M 181)

POA PRATENSIS L. (X, "Kentucky blue-grass")

At Puu Ulaula Shelter and at Kilauea. (F & M 906, 786; M-D H-302)

POLYPOGON MONSPELIENSIS (L.) Desf. (X, "huelo iole")

Around Kilauea. (F & M 310)

SACCHARUM OFFICINARUM L. (P, "ko" "sugar cane")

Rare; several stalks growing at Keanakakoi dump, 3750 feet, and at Makaopuhi Crater. (F & M 731)

SACCIOLEPIS INDICA (L.) Chase (X, "Glenwood grass")

S. contracta (W. & A.) Hitchc.

(I cannot see the difference between S. indica and S. contracta)

Abundant in lawns, along roadsides, and in open grasslands and fumarole areas in moderately wet regions. (F & M 288; Olson in 1938 and 1939; M-D H-153, H-54; Eggler 209)

SECALE CEREALE L. (X, "rye")

Near Puu Ulaula, on Mauna Loa at 10,000 feet. (F & M 905)

SETARIA GENICULATA (Lam.) Beauv. (X, "yellow foxtail")

Frequent and widespread in open or disturbed places. (Olson in 1939, Lamoureux 2498, Fosberg 41762; Eggler 195)

SETARIA PALMIFOLIA (Willd.) Stapf (X)

Infrequent; in wet forests along trails and in disturbed places. (Olson in 1938, Morley 166A-H; F & M 56, 273; B & F 28)

SETARIA SPHACELATA (Schum.) S. & H. ? (X)

Volcano House garden. This is a dwarf form which has been introduced into California and may belong to this species although it does not check with much of the extremely variable material from Africa, where the species is native. (F & M 643)

SPOROBOLUS AFRICANUS (Poir.) Rob. & Tourn. (X, "rattail grass" "smut grass")

S. elongatus R. Br.

S. capensis (Willd.) Kunth

Frequent to abundant in open or disturbed places, along roadsides, trails, and in grazed land. (Lamoureux 2515; F & M 560, 721; M-D H-30, H-72, H-214; Eggler 99)

SPOROBOLUS DIANDER (Retz.) Beauv. (X)

Near Queen's Bath. (M-D H-196)

STENOTAPHRUM SECUNDATUM (Walt.) Kuntze (X, "manienie makahikihiki" "Buffalo grass" "St. Augustine grass")

Infrequent; in Kilauea Area and in Kipuka Puaulu. (M-D H-208; F & M 236; Olson in 1939)

TRICHOLAENA ROSEA Nees (X, "natal redtop")

T. repens of Hawaiian authors

Abundant from Kipuka Nene to Hilina Pali; also about Kilauea. (F & M 139; Morley 160-H; Olson in 1938; Eggler 100)

TRISETUM GLOMERATUM (Kunth) Trin. (E, "heu pueo")

Frequent on slopes of Mauna Loa up to 10,000 feet or higher. (F & M 407; s. coll. 1; Eggler 291)

TRITICUM AESTIVUM L. (X, "wheat")

Several plants at KMC dump. (F & M 604)

CYPERACEAE

BULBOSTYLIS CAPILLARIS (L.) C. B. CL. (X)

Frequent on loose ash deposits around Kilauea, the Kau Desert, to Hilina Pali, and down to the coast. (M-D H-4, H-197, H-260, H-267; Stone 2878; Fosberg 41596b, 46018; Eggler 71; F & M 125, 126; s. coll. 280)

CAREX MACLOVIANA d'Urv. (I)

Frequent in Kipuka Puaulu and vicinity. (F & M 571, 575; Morley C; Fosberg 41615)

CAREX WAHUENSIS var. RUBIGINOSA Krauss (E)

Frequent in moderately wet open forest; also on slopes of Mauna Loa to near Puu Ulaula. (M-D H-36, H-307; Lamoureux 2508; s. coll. 423; F & M 44; Morley 155-H; Fosberg 41597a, 41616; Eggler 154, 293)

CYPERUS ALTERNIFOLIUS L. (X, "haole ahuawa" "puu kaa haole")

About Old Volcano House grounds. (F & M 323)

CYPERUS BREVIFOLIUS (Rottb.) Hassk. (X ?, "kaluha" "pipiwai")

Kyllinga brevifolia Rottb.

Frequent in moderately wet areas below 4500 feet, also on seacoast below Kaone. (Olson in 1938; Lamoureux 2463; M-D H-38; PHB & GOF 24; s. coll. 278; F & M 553, 570, 577)

CYPERUS COMPRESSUS L. (X)

Infrequent; seacost at Halape. (F & M 345)

CYPERUS HILLEBRANDII Boeckl. (E)

Infrequent in Kau, from Halfway House to Kipuka Puaulu. (F & M 130, 141; Morley B; M-D H-35, H-59)

CYPERUS JAVANICUS Houtt. (I)

About 1 mile east of Kupaahu Heiau. (F & M 927)

CYPERUS LAEVIGATUS L. (I, "ahuawa" "ehuawa" "makaloa")

Frequent; seacoast at Halape. (F & M 345)

CYPERUS PHLEOIDES var. HAWAIIENSIS (Mann) Kükenth. (E)

Rare; Park residential area. (F & M 846; Fosberg 47730)

CYPERUS POLYSTACHYOS Rottb. (X, "kilioopu" "kulukulua")

Abundant generally along roads and trails in wet to somewhat dry areas; in fumarole areas, and other disturbed areas. (Morley 91-H; F & M 166, 165, 167; M-D H-119 (part), H-5, H-52, H-115, H-152; Fosberg 41766; Eggler 213)

CYPERUS ROTUNDUS L. (X, "kilioopu" "nut-grass")

Old Volcano House grounds. (F & M 637)

ELEOCHARIS OBTUSA (Willd.) Schult. (I, "pipiwai")

Infrequent; in wet ground in Kilauea vicinity. (F & M 697)

FIMBRISTYLIS CYMOSA R. Br. (I)

F. cymosa var. pycnocephala (Hbd.) Kük.

F. cymosa var. umbellato-capitata (Mann) Hbd.

Common along the shore, especially in the spray zone; also found in the Kau Desert at about 3000 feet. (F & M 336, 347, 346, 164; Olson in 1938; Stone 2863; Fosberg 46015)

FIMBRISTYLIS DICHOTOMA (L.) Vahl (I)

F. annua (All.) R. & S.

F. polymorpha Vahl

Infrequent in moderately wet areas and on ash dunes in the Kau Desert. (F & M 243, 54, 802; M-D H-119 (part), H-194, H-329; Eggler 222)

FIMBRISTYLIS DICHOTOMA var. (E)

A prostrate dwarfed plant found around fumaroles. (Fosberg 41771, 47733, 46060, 46055)

FIMBRISTYLIS HAWAIIENSIS Hbd. (E)

In dry ash deposits on lava near coast, on pahoehoe flow, Apua, at 200 feet, and in Kau Desert. (F & M 371; Fosberg 46021)

GAHNIA GAHNIAEFORMIS (Gaud.) Heller (E)

G. gaudichaudii Steud.

Common in moist to moderately wet forests. (s. coll. 279; Stone 2965; Morley 20-H, 34-H; M-D H-12, H-18, H-286; Eggler 121)

MACHAERINA ANGUSTIFOLIA (Gaud.) Koyama

Chain-of-Craters region. (Eggler 133)

MACHAERINA MARISCOIDES ssp. MEYENII (Kunth) Koyama (E)

Occasional on relatively young pahoehoe flows and in open Metrosideros forests, Chain-of-Craters area and old Kalapana trail. (M-D H-98)

OREOBOLUS FURCATUS Mann (E)

Ainapo Trail, water tank area at 7750 feet. (F & M 263)

RHYNCHOSPORA GLAUCA var. CHINENSIS (Boeckl.) C. B. Cl. (I)

Collected by Skottsberg in 1926 in Kilauea Iki.

RHYNCHOSPORA LAVARUM Gaud. (E)

Frequent in marshy area near Hilo entrance to Park and along Kalapana Trail at about 2300 feet. (F & M 675, 789; M-D H-71, H-53 (part); Fosberg 41997)

UNCINIA UNCINATA (L.) Kükenth. (I)

U. lindleyana Kunth

Frequent in wet forests. (s. coll. 289, and in 1931; Morley 110-H; F & M 563; Fosberg 38641)

PALMAE

COCOS NUCIFERA L. (P, "niu" "coconut palm")

Locally along seacoast from Halape to Kalapana. (F & M 881)

PRITCHARDIA sp. (E, "loulu kuahiwi")

Old Volcano House. (F & M 868)

ARACEAE

ANTHURIUM sp. (X, "anthurium")

In gardens.

COLOCASIA ESCULENTA (L.) Schott (P, "kalo" "taro")

About Old Volcano House grounds. (F & M 635)

ZANTEDESCHIA AETHIOPICA (L.) Spreng. (X, "calla lily")

Volcano House garden. (F & M 640)

COMMELINACEAE

COMMELINA DIFFUSA Burm. f. (X)

C. nudiflora of Hawaiian authors.

Abundant in disturbed places, gardens, and along roads and trails in wet regions. (Morley 101-H, 173-H; M-D H-151)

JUNCACEAE

JUNCUS BUFONIUS L. (X, "toad rush")

Occasional in open places in Kilauea area. (F & M 817)

JUNCUS TENUIS Willd. (X)

J. macer S. F. Gray

Along roads and trails in Kilauea area. (F & M 666; s. coll. 290)

JUNCUS PLANIFOLIUS R. Br. (X)

Frequent along roadsides near Thurston Lava Tube. (F & M 564)

JUNCUS XIPHOIDES var. TRIANDRUS Engelm. (X)

Marshy area near Hilo entrance to Park. (F & M 820)

LUZULA HAWAIIENSIS Buch. (E)

L. campestris var. hawaiiensis (Buch.) Deg. & Fosb.

Common in more open forests and brush. (M-D H-44, H-68, H-287, H-53 (part); Fosberg 34608, 41760; Eggler 294)

LILIACEAE

AGAPANTHUS UMBELLATUS L'Hér. (X, "African blue lily")

Park residence area. (F & M 494)

ALLIUM PORRUM L. (X, "leek")

A perennial from Eurasia, in gardens only.

ALLIUM sp. (X, "onion")

A perennial in gardens only.

ASPARAGUS PLUMOSUS Baker (X, "fern asparagus")

A South African perennial vine in gardens only.

ASPARAGUS OFFICINALIS var. ALTILIS L. (X, "asparagus")

A Eurasian perrenial herb in gardens only.

ASTELIA MENZIESIANA Sm. (E)

A. veratroides of Park records.

Abundant in wet to moist forests around Kilauea. (Morley 147-H, 23-H; M-D H-158; Fosberg 41758; F & M 838)

CORDYLINE FRUTICOSA (L.) Goepp. (P, "ti" "ki" "la-i")

C. terminalis (L.) Kunth

Taetsia fruticosa (L.) Merr.

Infrequent in moderately wet to rather dry areas; in lava tube "cave-ins". (Morley 63-H)

DIANELLA SANDWICENSIS H. & A. (E)

D. lavarum Deg.

Occasional in moist to moderately dry open or semi-open places.

(Olson in 1938; F & M 795)

DRACAENA HAWAIIENSIS (Deg.) Fosb. (E, "hala pepe")

Pleomele aurea sensu 1944 check list.

Pleomele hawaiiensiis Degener

Infrequent along Poliokeawe Pali. (F & M 559)

HEMEROCALLIS AURANTIACA var. MAJOR Baker (X, "yellow day lily")

Park residence area. (F & M 287)

HEMEROCALLIS FULVA var. KWANSO Regel (X, "day lily")

Park residence area. (F & M 480)

KNIPHOFIA UVARIA Hook. (X, "common torchlily")

A perennial South African herb in gardens only.

LILIUM LONGIFLORUM var. EXIMUM Nichols (X, "Bermuda easter lily")

A perennial Japanese herb in gardens only.

PHORMIUM TENAX Forst. (X, "New Zealand flax")

Growing in clumps or as individual plants at several places near the road through the forest.

SMILAX SANDWICENSIS Kunth (E, "uhi" "ulehihi" "hoi" "pioi")

Frequent in moderately wet forest. (Olson in 1938; s. coll. 351; F & M 196; Morley 18-H; M-D H-69)

YUCCA FILAMENTOSA L. (X, "Adam's needle")

Old Volcano House. (F & M 853)

AMARYLLIDACEAE

AGAVE cf. SISALANA Perr. (X)

Several plants at top of Poliokeawe Pali. (F & M 534)

HIPPEASTRUM X JOHNSONII Bury (X, "amaryllis")

Old Volcano House. (F & M 636)

NARCISSUS sp. (X)

In gardens only.

DIOSCOREACEAE

DIOSCOREA ALATA L. (P, "hoi" "greater yam")

At Stone's place in Panau Nui. (F & M 1099)

IRIDACEAE

FREESIA REFRACTA Klatt (X, "Freesia")

Park residence area. (F & M 455)

GLADIOLUS PRIMULINUS Baker (X, "Gladiolus")

Park residence area. (F & M 478)

GLADIOLUS PSITTACINUS Hook. (X, "Gladiolus")

Park residence area. (F & M 601A, 601B)

IRIS cf. GERMANICUS (X, "German iris")

Park residence area. (F & M 473)

SISYRINCHIUM ACRE Mann (E, "mauualili")

Frequent on Mauna Loa at about 6000 feet and in open places lower down. (s. coll. 257, 408)

SISYRINCHIUM MICRANTHUM Cav. (X)

Around Kilauea area in disturbed places. (F & M 816; Poinar in 1963)

TRIGRIDIA PAVONIA var. WATKINSONII Hort. (X, "Tigerflower")

Park residence area. (F & M 677)

TRITONIA CROCOSMAEFOLIA Lem. (X, "Tritonia")

Abundant in disturbed places and along roads in Kilauea area. (F & M 97; Lamoureux 2520; M-D H-142)

WATSONIA IRIDIFOLIA Ker. var. O'BRIENI N.E. Br. (X)

Park residence area. (F & M 482)

ZINGIBERACEAE

ALPINIA PURPURATA (Vieill.) K. Schum. (X, "red ginger")

Stone's place in Panau Nui. (F & M 1101)

HEDYCHIUM CORONARIUM Koenig (X, "white ginger")

Along roads in Kilauea region, especially around Park residence area. (F & M 631)

HEDYCHIUM FLAVUM Roxb. (X, "yellow ginger")

Old Volcano House. (F & M 634)

HEDYCHIUM GARDNERIANUM Roscoe (X, "Kahili ginger")

Park residence area. (F & M 743)

CANNACEAE

CANNA INDICA L. (X, "liipoe" "Indian shot")

Near Volcano House. (F & M 673)

CANNA (ORNAMENTAL HYBRID) (X)

Park residence area. (F & M 173)

ORCHIDACEAE

ANOECTOCHILUS SANDWICENSIS Lindl. (E, "Honohono orchid")

Rare in wet or moist forest, Napau Trail; 1 mile east of Kane Nui o Hamo. (F & M 943, 969)

ARUNDINA BAMBUSAEFOLIA Lindl. (X, "bamboo orchid")

Recently very abundant along roads and trails, and in steaming areas. (M-D H-33; Eggler 187)

LIPARIS HAWAIIENSIS Mann (E, "awapuhiakanaloa" "twayblade")

Rare in wet forest, Kilauea area and near Napau Crater. (F & M 200; Morley 41-H; s. coll.)

PHAJUS TANKERVILLIAE (Banks) Bl. (X, "Chinese ground orchid")

Common in open moist forests, Kilauea Iki and Chain-of-Craters. (Olson in 1938; F & M 860; s. coll.; M-D H-64)

SPATHOGLOTTIS PLICATA Bl. (X, "Phillippine ground orchid")

Frequent on recent lava flows in wet areas, and around Kilauea. (F & M 400; Eggler 186)

PIPERACEAE

PEPEROMIA COOKIANA C. DC. (E, "alaalawainui")

Damp places about Kilauea.

PEPEROMIA EXPALLESCENS C. DC. (E, "alaalawainui")

Kilauea.

PEPEROMIA EXPALLESCENS var. BREVIPILOSA Yuncker (E, "alaalawainui")

Kilauea.

PEPEROMIA HAWAIIENSIS C. DC. (E, "alaalawainui")

Kau.

PEPEROMIA HYPOLEUCA Miq. (E, "alaalawainui")

Several localities around Kilauea. (F & M 193; Baldwin in 1949; s. coll. 143; Degener et al. 3892; Degener & Iwasaki 3883)

PEPEROMIA HYPOLEUCA var. PLUVIGAUDENS (C. DC.) Yuncker (E)

Trail, Kilauea-Kilauea Iki, 3900 feet.

PEPEROMIA LATIFOLIA Miq. (E, "alaalawainui")

Kilauea.

PEPEROMIA LEPTOSTACHYA H. & A. (I, "alaalawainui")

Frequent and widespread. (F & M 549; s. coll. 264; Morley 109; Stone 3010)

PEPEROMIA LILIFOLIA var. OBTUSATA Yuncker (E, "alaalawainui")

Kilauea.

PEPEROMIA MACRAEANA C. DC. (E, "alaalawainui")

Kilauea.

PEPEROMIA MEMBRANACEA var. PUUKUKUIANA Yuncker (E, "alaalawainui")

Kilauea.

PEPEROMIA TETRAPHYLLA var. PARVIFOLIA (C. DC.) Deg. (I)

Peperomia reflexa var. parvifolia C. DC.

Peperomia reflexa var. parviflora C. DC. ex Fagerlund & Mitchell, Check list 1944 (error)

Peperomia reflexa sensu Fagerlund & Mitchell

Common in Kipuka Puaulu, both terrestrial and epiphytic. (Morley 70-H, 175-H; Degener 2435; Degener et al. 3899; s. coll. 265; Lamoureux 2492, 2456; Rock 16027, 10397; Rock & Copeland 12594; Meebold in 1932)

MYRICACEAE

MYRICA FAYA Ait. (X)

A single small tree was found on the Crater Rim Trail between KMC and the Volcano Observatory in 1961. (Fosberg 41782)

URTICACEAE

PILEA MICROPHYLLA (L.) Liebm. (X, "artillery plant")

Park residence area. (F & M 474)

NERAUDIA OVATA Gaud. (E)

Neraudia melastomaefolia sensu Fagerlund & Mitchell, non Gaud.

Near Halfway House, 3000 feet. (F & M 842)

PIPTURUS ALBIDUS (H. & A.) Gray (E, "mamaki" "mamake")

P. brighamii Skottsb.

P. gaudichaudianus Wedd.

P. gaudichaudianus var. asperrimus Skottsb.

P. hawaiiensis Lev.

P. pachyphyllus Skottsb.

A perplexingly variable group, here referred to a single species, though perhaps some varieties could be recognized.

Occasional to common in moist to wet forests. (F & M 586; s. coll. 887, 888, 1056; Stone 3026; Morley 50-H; M-D H-133, H-39)

URERA SANDVICENSIS Wedd. (E, "opuhe")

Infrequent in moist forests, Kipuka Puaulu, Makaopuhi Crater, and Kane Nui o Hamo. (F & M 574, 584; Lamoureux 2519; Morley 60-H, 61-8)

MORACEAE

ARTOCARPUS ALTILIS (Park.) Fosb. (P, "ulu" "breadfruit")

A. incisa L. f.

A. communis Forst. f.

A grove at Naulu Village, Kaalakomo, at about 800 feet. (F & M 380)

BROUSSONETIA PAPYRIFERA (L.) Vent. (P, "wauke")

Apua, brink of Pali, at 2000 feet in transition forest. (Fagerlund 1214)

FICUS CARICA L. (X, "fig")

Occasionally persisting, Kipuka Puaulu, Na Makani Paio, and Fern Jungle. (F & M 271; Morley 168-H)

FICUS PUMILA L. (X, "climbing fig")

Planted and persisting in Kilauea region.

MORUS ALBA f. TATARICA (L.) Loudon (X, "kilika" "mulberry")

Old Volcano House grounds. (F & M 845)

PROTEACEAE

GREVILLEA ROBUSTA A. Cunn. (X)

Stylurus robusta (A. Cunn.) Deg.

Old Volcano House, and near Halfway House on Pahala Road. (F & M 124)

<u>MACADAMIA INTEGRIFOLIA</u> Maiden & Betche (X, "Queensland nut" "Macadamia nut")

<u>M. ternifolia</u> of most Hawaiian authors.

Old Volcano House. (<u>F & M 633</u>)

SANTALACEAE

<u>SANTALUM ELLIPTICUM</u> var. <u>PANICULATUM</u> (H. & A.) Fosb. (E, "iliahi" "sandalwood")

<u>S. paniculatum</u> H. & A.

Common in moist to moderately wet forest, especially open forest, also dry forests, as low as Hilina Pali and in Kipuka Kulalio at 6700 feet. (<u>F & M 877</u>, <u>155</u>; <u>Olson</u> in 1939; <u>Stone 2937</u>; <u>Poinar</u> in 1963)

LORANTHACEAE

<u>KORTHALSELLA COMPLANATA</u> (van Tieghem) Engl. (I)

<u>Viscum articulatum</u>, <u>sensu</u> Hbd.

Parasite on <u>Psychotria</u>, <u>Sophora</u>, <u>Vaccinium</u> and other woody plants. (<u>s. coll.</u>; <u>s. coll. 353</u>; <u>Lamoureux 2460</u>; <u>Morley 62-H</u>)

POLYGONACEAE

<u>MUEHLENBECKIA AXILLARIS</u> Walp. (X, "matbush" "wirevine")

Roadsides and in Park residence area, Kilauea. (<u>F & M 750</u>; <u>Olson</u> in 1939; <u>Poinar</u> in 1963; <u>Fosberg 44468</u>)

<u>RHEUM RHAPONTICUM</u> L. (X, "rhubarb")

In gardens.

<u>RUMEX ACETOSELLA</u> L. (X, "sheep sorrel")

Frequent and widespread in open and semi-open places. (<u>F & M 183</u>; <u>Fagerlund 993</u>; <u>Poinar</u> in 1963; <u>Morley 103-H</u>)

<u>RUMEX CRISPUS</u> L. (X, "curly dock")

Lawns and damp waste places around Kilauea. (<u>F & M 599</u>, <u>602</u>)

<u>RUMEX GIGANTEUS</u> Ait. (E, "pawale" "uhaohako")

Occasional in Kilauea Caldera, Kau Desert, and other dry bare areas. (<u>M-D H-130</u>; <u>F & M 17</u>, <u>294</u>, <u>534</u>; <u>Lamoureux 2448</u>; <u>Eggler 276</u>; <u>Baldwin</u> in

1941; Fosberg 41775)

CHENOPODIACEAE

BETA VULGARIS var. CICLA L. (X, "Swiss chard")

An annual European herb in gardens only.

BETA VULGARIS var. CRASSA Alef. (X, "beet")

An annual European herb in gardens only.

CHENOPODIUM AMBROSIOIDES L. (X, "wormseed" "Mexican tea")

Disturbed areas about Kilauea. (F & M 611)

AMARANTHACEAE

AMARANTHUS TRICOLOR L. (X, "Chinese spinach")

KMC dump, Kilauea. (F & M 606)

AMARANTHUS VIRIDIS L. (X)

A. gracilis Desf.

Disturbed areas. (F & M 331, 228; s. coll. 1217)

CHARPENTIERA OBOVATA Gaud. (I, "papala")

Rare in Kipuka Puaulu. (Lamoureux 2486; Morley 178-H, F & M 851, 658; s. coll. 1245, Eggler 20)

NOTOTRICHIUM SANDWICENSE (Gray) Hbd. (E, "kuku'i")

Poliokeawe Pali. (Hamilton in 1964)

NYCTAGINACEAE

BOERHAVIA MUTABILIS R. Br. (I, "alena")

B. diffusa sensu Fagerlund & Mitchell, in part

At Kalue (F & M 653)

BOERHAVIA REPENS L. (I, "alena")

B. diffusa sensu Fagerlund & Mitchell, in part

Keaoi Island (F & M 356)

BOUGAINVILLEA GLABRA Choisy (X, "bougainvillea")

In gardens.

MIRABILIS JALAPA L. (X, "four-o'clock")

Abundant herb in Apua, at about 1600 feet.

PISONIA UMBELLIFERA (Forst.) Seem. (I)

Heimerliodendron brunonianum (Endl.) Skottsb.

In Kipuka Puaulu. (F & M 253; Olson in 1940; Morley 100-H, 65-H; Lamoureux 2500, 2521)

PHYTOLACCACEAE

PHYTOLACCA SANDWICENSIS Endl. (E)

P. brachystachys Moq.

Kipuka Ki, at about 4300 feet. (Christ in 1939)

AIZOACEAE

MESEMBRYANTHEMUM sp. (X, "akulikuli")

Park residence area. (F & M 107)

SESUVIUM PORTULACASTRUM L. (I, "akulikuli")

In marshy areas and on spray-wet rocks at sea level. (F & M 348)

TETRAGONIA TETRAGONIOIDES (Pallas) Kunth (X, "New Zealand spinach")

In gardens.

PORTULACACEAE

PORTULACA CYANOSPERMA Egler (E)

Along the coast. (Stone 2872; M-D H-198 ?)

PORTULACA HAWAIIENSIS Deg. (E)

A very dubious species, not really recorded from Park but included by Fagerlund and Mitchell checklist because Degener thought it might be found all along Kau Desert shore.

PORTULACA OLERACEA L. (X, "ihi" "purslane" "pigweed")

Infrequent in gardens and disturbed places. (F & M 105)

PORTULACA SCLEROCARPA Gray (E, "ikimakole" "poe")

Frequent in ash soil in transition between forest and desert, also in and around steaming ground near Kokoolau Crater. (M-D H-2)

CARYOPHYLLACEAE

CERASTIUM VULGATUM L. (X, "mouse-ear chickweed")

Infrequent in lawns and disturbed places. (F & M 408; s. l., s. coll. 23 or 251)

DIANTHUS BARBATUS L. (X, "sweet-william")

In gardens.

DIANTHUS CARYOPHYLLUS L. (X, "carnation")

Park residence area. (F & M 104)

DIANTHUS CHINENSIS L. (X, "pink")

Park residence area. (F & M 753)

DRYMARIA CORDATA (L.) Willd. (X, "ihi kukaihipa")

Frequent in lawns and gardens about Kilauea. (F & M 106)

POLYCARPON TETRAPHYLLUM L. (X)

Near shelter in Kalapana. (Poinar in 1963; Eggler 88)

SILENE GALLICA L. (X, "windmill pink")

Rare in moderately dry areas between 2000 and 3000 feet. (Olson in 1939; F & M 539; M-D H-61)

SILENE STRUTHIOLOIDES Gray (E)

On open ash in Kau Desert and floor of Kilauea Caldera. (F & M 701; M-D H-333; s. coll. 356; Fosberg 41775; Eggler 188)

STELLARIA MEDIA (L.) Cyrill. (X, "chickweed")

Frequent in gardens and waste places. (F & M 873, 318)

RANUNCULACEAE

ANEMONE JAPONICA S. & Z. (X, "Japanese anemone")

Established near Park residence area. (F & M 219; M-D H-272; Ruhle in 1961)

RANUNCULUS MURICATUS L. (X, "spiny-fruited buttercup")

Infrequent in Kipuka Puaulu and horse corral. (Olson in 1939; F & M 417; s. coll.)

RANUNCULUS REPENS L. (X, "creeping buttercup")

Reported by Degener, Plants of Hawaii National Park, as probably in Park, and more definitely by Fagerlund (1947).

DELPHINIUM sp. (X, "larkspur")

In gardens.

MENISPERMACEAE

COCCULUS FERRANDIANUS Gaud. (E, "huehue" "hueie")

Frequent vine in moderately wet to dry forests. (F & M 39, 134; s. coll. 270; Stone 2938; Baldwin & Fagerlund 32)

LAURACEAE

CASSYTHA FILIFORMIS L. (I, "kaunoa pehu" "love-vine")

Parasite on other plants in dry areas of Park, especially near ocean. (F & M 377; s. coll. 260; M-D H-247, H-192)

PERSEA AMERICANA Mill. (X, "avocado" "pear")

Several trees in Kilauea area and in Kipuka Puaulu. (F & M 445, 869, 632)

PAPAVERACEAE

ARGEMONE GLAUCA (Prain) Deg. & Deg. (E, "puakala" "prickly poppy")

Argemone alba var. glauca Prain

Infrequent; in Kipuka Puaulu. (F & M 175)

ESCHSCHOLTZIA CALIFORNICA Cham. (X, "California poppy")

Hunnemannia fumariaefolia of 1944 check list.

In gardens. The specimen on which the record of Hunnemannia was based is Eschscholtzia.

CAPPARIDACEAE

CAPPARIS SANDWICHIANA DC. (I, "Hawaiian caper" "maiapilo")

Keaoi Island. (F & M 885)

CRUCIFERAE

BRASSICA CAMPESTRIS L. (X, "field mustard")

Old Volcano House, also on Mauna Loa at 6000 feet. (Olson in 1939; F & M 467)

BRASSICA CHINENSIS L. (X, "pakchoi")

In gardens.

BRASSICA JUNCEA (L.) Cosson (X, "Indian mustard")

Infrequent; around Kilauea. (F & M 229, 901)

BRASSICA NIGRA (L.) Koch (X, "black mustard")

Infrequent; in grasslands on slopes of Mauna Loa. (Olson in 1939)

BRASSICA OLERACEA var. BOTRYTIS L. (X, "cauliflower")

A European herb, in gardens only.

BRASSICA OLERACEA var. CAPITATA L. (X, "cabbage")

A European herb in gardens only.

BRASSICA RAPA L. (X, "turnip")

An herb originated in cultivation, in gardens only.

CARDAMINE FLEXUOSA f. UMBROSA (Cor. & Gods.) O. E. Sch. (X)

Rare or infrequent, KMC Area. (F & M 309)

CARDAMINE SARMENTOSA Forst. (I)

In opening of lava-tube near sea at Kealakomo. (F & M 375; s. coll. 934)

CORONOPUS DIDYMUS (L.) Smith (X, "wart-cress")

Kilauea area, in disturbed places. (F & M 452)

IBERIS sp. (X, "candytuft")

In gardens.

LEPIDIUM VIRGINICUM L. (X, "pepperweed")

Frequent along roads, trails and other disturbed places. (Fagerlund 36; F & M 29; Morley 108-H)

LOBULARIA MARITIMA (L.) Desv. (X, "sweet Alyssum")

Park residence area, also at Halemaumau. (F & M 119, 556; Olson in 1938)

MATTHIOLA sp. (X, "stocks")

In gardens.

RAPHANUS SATIVUS L. (X, "radish" "daikon")

In dry open disturbed areas, as at end of Mauna Loa Strip Road, also Hilina Pili. (F & M 441, 443; Poinar in 1963)

RAPHANUS SATIVUS var. LONGIPINNATUS Bailey (X, "Chinese radish")

In gardens and on slopes of Mauna Loa at 6700 feet.

SISYMBRIUM ALTISSIMUM L. (X, "tumble mustard" "Jim Hill mustard")

Pua Ulaula Shelter, Mauna Loa, 10,000 feet. (F & M 767)

SISYMBRIUM OFFICINALE (L.) Scop. (X, "hedge mustard")

Kipuka Ki. (Christ in 1939; s. coll. 1069)

RESEDACEAE

RESEDA sp. (X, "mignonette")

In gardens.

CRASSULACEAE

KALANCHOE TUBIFLORA (Harv.) Hamet (X)

Park residence area. (F & M 179)

SEMPERVIVUM TECTORUM L. ? (X, "hen-and-chickens" "house leek")

Park residence area. (F & M 112; s. coll. 112)

SAXIFRAGACEAE

BROUSSAISIA ARGUTA Gaud. (E, "puahanui" "kanawau")

Common in moist to wet forests. Several forms recognizable. (F & M 57, M-D H-66 f. arguta); (F & M 840 f. ternata); (F & M 8 f. pellucida)

ESCALLONIA MACRANTHA H. & A. (X)

Common around Kilauea region. (Olson in 1939; F & M 505, 629)

HYDRANGEA MACROPHYLLA (Thunb.) DC. (X, "Hydrangea")

Park residence area. (F & M 671, 61)

PHILADELPHUS sp. (X, "mock orange", "syringa")

In gardens.

PITTOSPORACEAE

PITTOSPORUM CONFERTIFLORUM Gray (E, "hoawa")

Rare or infrequent; Kalapana Trail at 2100 feet, also near Pauahi Crater, and from about 8000 feet on Mauna Loa. (F & M 719, 760, 1059, 1060; Stone 2947; Morley 194-H)

PITTOSPORUM HOSMERI var. SAINT-JOHNII Sherff (E)

Planted in Kipuka Puaulu. (Lamoureux 2506)

PITTOSPORUM HOSMERI var. LONGIFOLIUM Rock (E, "aawa hua kukui" "hoawa")

Infrequent, in small kipukas between Kipuka Puaulu and Kipuka Ki. (Lamoureux 2505; F & M 691; Baldwin (F & M) 823)

PITTOSPORUM SULCATUM var. REMYI Sherff (E, "hoawa")

Infrequent, near Kalapana Trail at about 2200 feet. (F & M 797, 794)

PITTOSPORUM TERMINALIOIDES Planch. (E, "hoawa")

Kipuka Maunaiu at about 5000 feet. (Olson in 1940; s. coll. 1060)

PITTOSPORUM TOBIRA (Thunb.) Ait. (X, "Japanese Pittosporum")

Park residence area. (F & M 650, 285)

PITTOSPORUM UNDULATUM Vent. (X, "Victorian box" "mock orange")

Park residence area. (F & M 283, 1008)

ROSACEAE

COTONEASTER PANNOSA Franch. (X, "silverleaf Cotoneaster")

Rim of Kilauea Iki Crater. (F & M 214, 628; Poinar in 1963)

CYDONIA OBLONGA Mill. (X, "quince")

Park administration building. (F & M 900)

ERIOBOTRYA JAPONICA (Thunb.) Lindl. (X, "loquat")

Kilauea. (F & M 856)

FRAGARIA VESCA f. ALBA (Ehrh.) Rydb. (X, "ohelo papa" "white strawberry")

Fragaria chiloensis sensu Fagerlund & Mitchell

Very common in moist open forests. (F & M 267; Morley 19-H; Lamoureux 2470; M-D H-91; St. John et al. 11252; Degener in 1922; Douglas 341)

OSTEOMELES ANTHYLLIDIFOLIA (Sm.) Lindl. (I, "ulei" "uulei")

In old moderately vegetated lava flows in dry areas between 2000 and 4000 feet. (Poinar in 1963; F & M 132, 472; M-D H-105, 205; Eggler 72)

PRUNUS PERSICA (L.) Batsch. (X, "peach")

Locally adventive in kipukas in Kilauea region. (F & M 268)

PYRACANTHA ANGUSTIFOLIA (Fr.) Schneid. (X)

Escaped from cultivation and established in the Kilauea region. (Fosberg 44463)

PYRACANTHA CRENATO-SERRATA (Hance) Rehd. (X)

Locally established in Kilauea region. (Fagerlund 1219; Fosberg 44463)

ROSA LAEVIGATA Michx. (X, "Cherokee rose")

Park residential area. (F & M 284)

ROSA MULTIFLORA Thunb. (X, "multiflora rose")

Roadsides and edges of forest in Kilauea area. (M-D H-178; F & M 85, 849)

ROSA POLYANTHA Hort. (X)

Park residence area. (F & M 597)

ROSA RUBRIFOLIA Vill. (X)

Kilauea area. (F & M 911)

ROSA sp. (X)

A number of other introduced roses persist from cultivation. (F & M 479, 908)

RUBUS ELLIPTICUS Sm. (X)

Established in clearings. (Fosberg 41609)

RUBUS HAWAIIENSIS Gray (E, "akala" "Hawaiian raspberry")

Infrequent; Kipuka Puaulu. (F & M 501; Morley 89-H)

RUBUS MACRAEI Gray (E, "akala")

Mauna Loa Strip Road. (F & M 569; C J E in 1945; s. coll. 898, 899)

RUBUS PENETRANS Bailey (X, "blackberry")

Abundant in open areas and disturbed forest about Kilauea. (Lamoureux 2502; F & M 630, 83 part; Swezey (Degener's) 8606)

RUBUS ROSAEFOLIUS Sm. (X, "ola'a" "thimbleberry")

Frequent and widespread in wet forest and open areas. (F & M 83 part; Morley 17-H; Olson in 1939)

RUBUS ULMIFOLIUS var. INERMIS (Willd.) Focke (X)

Occasionally planted and escaping (M-D H-155)

SPIRAEA JAPONICA L. f. (X)

Park residence area. (F & M 908)

SPIRAEA CANTONIENSIS Lour. (X)

Spiraea thunbergii Sieb. of some recent Hawaiian authors.

Park residence area. (F & M 215)

LEGUMINOSAE

ACACIA DEALBATA Link (X, "silver wattle")

One small tree found in Kilauea area.

ACACIA KOA var. HAWAIIENSIS Rock (E, "koa")

Frequent tree from Kipuka Puaulu to about 7000 feet on Mauna Loa, occasional in open forests at lower elevations. (Morley 76-H; s. coll. 352; F & M 656)

CAESALPINIA BONDUC (L.) Roxb. (I, "kakalaiaoa")

Puna, near Kupaaku in Pandanus grove on a'a lava; also in Kalapana. (s. coll. 931; Stone 3030)

CAJANUS CAJAN (L.) Millsp. (X, "pigeon pea")

Rare or infrequent; in disturbed places and along roads in Kilauea area. (F & M 828)

CASSIA BICAPSULARIS L. (X)

Near Hilina Pali. (M-D H-203)

CASSIA LAEVIGATA Willd. (X, "kalomona")

Near Halfway House, Kau. (Baldwin (F & M) 844)

CASSIA LESCHENAULTIANA DC. (X, "partridge pea")

C. mimosoides sensu Hawaiian authors

Along road near Halfway House, Kau, and in moderately dry seashore areas. (F & M 123; M-D H-204)

CASSIA OCCIDENTALIS L. (X, "coffee senna")

Apua; dry pali slopes in transition forest at 2000 feet. (Fagerlund 1212; M-D H-323)

CROTALARIA INCANA L. (X, "kukai hoki" "fuzzy rattlepod")

Roadsides, Kilauea area. (F & M 276)

CROTALARIA MUCRONATA Desv. (X)

C. saltiana Andr.

Roadsides, Kilauea area. (F & M 322, 1112; Poinar in 1963)

CYTISUS SCOPARIUS (L.) Link (X, "Scotch broom")

Park residence area. (F & M 622)

DESMODIUM CAJANIFOLIUM DC. (X)

Upper part of Ainahou Ranch in Metrosideros forest. (Fagerlund 1119)

DESMODIUM TORTUOSUM (Sw.) DC. (X, "Florida beggarweed")

Disturbed places, Kilauea area. (F & M 448)

DESMODIUM TRIFLORUM (L.) DC. (X, "ihi kikania")

Frequent in grassy areas near seacoast. (F & M 325; M-D H-250)

DESMODIUM UNCINATUM (Jacq.) DC. (X)

D. sandwicense E. Mey.

Infrequent in moderately dry areas. (Olson in 1939; Morley 80-H; F & M 16, 44, 131; Eggler 93)

DIOCLEA VIOLACEA Mart. (I, "maunaloa")

Seen near Kukalauula Pali.

DOLICHOS LABLAB L. (X, "papapa")

Infrequent; in disturbed areas about Kilauea and Pauahi Crater. (Olson in 1938; F & M 32)

ERYTHRINA SANDWICENSIS Deg. (E, "wiliwili")

E. monosperma Gaud.

In dry areas inland from Puu Kapukapu at about 1500 feet; planted at Hilina Pali. (F & M 883, 925)

INDIGOFERA SUFFRUTICOSA Mill. (X, "inikoa" "kolu" "indigo")

Frequent from sea-level to 1000 feet, also near Kipuka Puaulu. (F & M 265; M-D H-251, H-202, H-268)

LATHYRUS ODORATUS L. (X, "sweet pea")

In gardens only.

LEUCAENA LEUCOCEPHALA (Lam.) de Wit (X, "ekoa" "koaloi" "false koa")

L. glauca sensu Bentham

Frequent at Keauhou. (F & M 387)

LUPINUS sp. (X, "lupine")

In gardens only.

MEDICAGO POLYMORPHA L. (X, "bur clover")

Medicago denticulata Willd.

Medicago hispida Gaertn.

Along roadsides and in old gardens, and on Mauna Loa at 6600 feet. (Olson in 1939; F & M 409)

MELILOTUS INDICA (L.) All. (X, "yellow sweet-clover")

Horse corral on Mauna Loa at 6600 feet. (Olson in 1939)

MIMOSA PUDICA L. (X, "sensitive plant")

Kalapana; also upper Kealakomo. (Stone 2958; s. coll. 1098)

MUCUNA GIGANTEA DC. (I, "sea bean")

Puna, near coast at Wakaula. (Stone 2894)

PHASEOLUS sp. (X, "bean")

In gardens only.

PISUM SATIVUM L. (X, "garden pea")

In gardens only.

PITHECELLOBIUM DULCE (Roxb.) Benth. (X)

(M-D H-324)

PROSOPIS PALLIDA (Willd.) H.B.K. (X, "kiawe" "algaroba")

P. chilensis sensu Hawaiian authors

Several trees at Keauhou. (F & M 388)

SESBANIA TOMENTOSA H. & A. (E, "ohai")

Apua Point. (F & M 383)

SOPHORA CHRYSOPHYLLA (Salisb.) Seem. (E, "mamani")

Edwardsia chrysophylla Salisb.

Frequent from Kipuka Puaulu to 8000 feet on Mauna Loa, occasional in forests lower down. (Lamoureux 2473; Morley 56-H; Poinar in 1963; Stone 2986; M-D H-23)

TAMARINDUS INDICA L. (X, "tamarind")

Lae Apuki, near sea-level. (F & M 1094)

TEPHROSIA PURPUREA (L.) Pers. (I)

Kaena Point. (F & M 1090; s. coll. 1256)

TRIFOLIUM ARVENSE L. (X, "rabbitfoot clover")

Mauna Loa slopes at about 4000 feet. (F & M 822)

TRIFOLIUM PRATENSE L. (X, "red clover")

Near Old Volcano House. (F & M 458)

TRIFOLIUM PROCUMBENS L. (X, "hop clover")

Roadsides about Kilauea. (F & M 299; s. coll. 426)

TRIFOLIUM REPENS L. (X, "white clover")

Horse corral at 6700 feet on Mauna Loa, also around Park residential area. (F & M 432)

VICIA SATIVA L. (X, "vetch")

At Kaenakakoi and KMC dumps. (F & M 446, 730)

WISTERIA sp. (X, "wisteria")

In gardens only.

GERANIACEAE

ERODIUM CICUTARIUM L'Her. (X, "stork's bill" "clockseed")

Puu Ulaula shelter, also at Hilina Pali. (F & M 516, 769, 895)

GERANIUM CAROLINIANUM var. AUSTRALE (Benth.) Fosb. (X, "cranesbill")

Frequent in moderately wet areas. (Lamoureux 2482; F & M 468; M-D H-138; Olson in 1938; PHB & GOF 29)

GERANIUM CUNEATUM var. HYPOLEUCUM Gray (E, "hinahina" "nohuanu")

Frequent on Mauna Loa from 7000 to 8000 feet. (F & M 259, 426, 756; M-D H-222, H-318; Poinar in 1963)

GERANIUM DISSECTUM L. (X)

Horse corral at 6700 feet on Mauna Loa. (F & M 1068)

PELARGONIUM GRAVEOLENS L'Her. (X, "okupukupu" "rose geranium")

Park residence area. (Olson in 1939; F & M 102, 695)

PELARGONIUM HORTORUM Bailey (X, "naniuma")

Park residence area. (F & M 91, 696)

OXALIDACEAE

OXALIS CORNICULATA L. (SENSU LATO) (X, "lady's sorrel")

Disturbed places around Kilauea, in Kipuka Puaulu, near Puu Kapele, and at Hilina Pali. (Morley 177-H, 150-H; s. coll. 428, 266; F & M 522; Lamoureux 2513; Olson in 1939; Fosberg 41366)

OXALIS MARTIANA Zucc. (X)

Park residence area. (Olson in 1938; F & M 228; Fosberg 41365)

TROPAEOLACEAE

TROPAEOLUM MAJUS L. (X, "pohe" "Nasturtium")

Park residential area. (Lamoureux 2481; F & M 96; Olson in 1938)

RUTACEAE

CITRUS LIMON Osb. (X, "lemon")

Old Volcano House. (F & M 870)

CITRUS SINENSIS (L.) Osb. (X, "sweet orange" "Waialua orange")

Several trees at Naulu Village, about 800 feet. (F & M 381)

PELEA CLUSIAEFOLIA var. CUNEATA St. John & Hume (E, "alani")

Frequent tree in wet forest, as near Napau Crater. (Morley 45-H; F & M 12; M-D H-159; Eggler 105)

PELEA HAWAIIENSIS var. GAUDICHAUDII (St. John) Stone (E, "manena")

P. cinerea sensu Rock

Kipuka Puaulu. (Morley 53-H; F & M 572, 690)

PELEA OBLANCEOLATA St. John (E)

East of Makaopuhi Crater. (F & M 831)

PELEA PUAULUENSIS St. John (E)

Kipuka Puaulu. (Morley 52-H)

PELEA RADIATA St. John (E)

Widespread in open forests. (F & M 683, 825, 796, 798)

PELEA ZAHLBRUCKNERI Rock (E)

Kipuka Puaulu. (F & M 662; Morley 191-H, 91-H)

ZANTHOXYLUM DIPETALUM var. GEMINICARPUM Rock (E, "a'e")

Fagara dipetala var. geminicarpa (Rock) St. John

Rare, Kipuka Puaulu and vicinity. (Lamoureux 2449; s. coll. 1073; Morley 104-H; F & M 850; Baldwin (F & M) 827)

ZANTHOXYLUM HAWAIIENSE Hbd. (E, "a'e" "hea'e")

Fagara hawaiiensis (Hbd.) Engler

Reported by Judd in 1921.

ZANTHOXYLUM MAUIENSE (Mann) Engler (E, "a'e" "hea'e")

Fagara mauiensis (Mann) Engler

Rare; in Kipuka Puaulu.

ZANTHOXYLUM MAUIENSE var. ANCEPS f. PETIOLULATUM Rock (E)

Fagara mauiensis var. anceps f. petiolulata (Rock) St. John

Rare; in Kipuka Puaulu. (Olson in 1940; F & M 779; Morley 190-H)

MELIACEAE

MELIA AZEDARACH L. (X, "inia" "Pride of India" "Chinaberry tree")

Persisting in old homestead by Kalapana Trail at about 500 feet. (Olson in 1939)

EUPHORBIACEAE

ALEURITES MOLUCCANA (L.) Willd. (P, "kukui" "candlenut")

Dry to moist forests from 500 to 2000 feet. (F & M 370, 542; Stone 2896)

ANTIDESMA PULVINATUM Hbd. (E, "haa" "mehame")

Dry forest above Naulu Village. (Horner (F & M) 736)

EUPHORBIA CHAMAESYCE L. (X, "prostrate spurge")

E. prostrata Ait.

Sea level at Kalapana.

EUPHORBIA HIRTA L. (X, "kokokahiko")

Disturbed places; hot areas. (F & M 128; M-D H-120, H-334)

EUPHORBIA PULCHERRIMA Willd. (X, "poinsettia")

Park residence area. (F & M 664)

EUPHORBIA THYMIFOLIA L. (X, "thyme-leaved spurge")

Disturbed places, and in dry section of Park between sea level and 1000 feet. (F & M 324, 652; Poinar in 1963)

JATROPHA CURCAS L. (X, "physic nut")

Lae a Puki, near sea level. (F & M 1096)

RICINUS COMMUNIS L. (X, "koli" "kaapea" "kaliali" "castor bean")

Established at low elevations. (F & M 340)

BUXACEAE

BUXUS SEMPERVIRENS L. (X, "box" "boxwood")

Park residence area. (F & M 749)

ANACARDIACEAE

MANGIFERA INDICA L. (X, "mango")

Local, Kilauea area; Kipuka Puaulu; Queen's Bath. (F & M 859; Stone 2928)

RHUS JAVANICA L. (E, "neneleau" "neleau" "Hawaiian sumac")

Rhus semialata var. sandwicensis (Gray) Engler

Frequent in several areas near Kalapana Trail at about 2300 feet. (F & M 787)

SCHINUS TEREBINTHIFOLIUS Raddi (X, "wililaiku" "Christmas berry" "Brazilian pepper-tree")

Along road to Pahala at about 3400 feet. (F & M 618)

AQUIFOLIACEAE

ILEX ANOMALA H. & A. (I, "kawaii")

Ilex sandwicensis (Endl.) Loesn.

Frequent in moist to wet forests. (F & M 398; s. coll; Morley 44-H; M-D H-89; Eggler 279)

ILEX AQUIFOLIUM L. (X, "English holly")

In gardens.

CELASTRACEAE

PERROTTETIA SANDWICENSIS Gray (E)

Infrequent; Kipuka Puaulu and on Kane Nui o Hamo. (Morley 189-H; Olson in 1940; F & M 833; Lamoureux 2509; Eggler 108)

SAPINDACEAE

CARDIOSPERMUM HALICACABUM L. (X, "poniu" "poniuniu")

C. microcarpum HBK.

Kalapana Trail at 1100 feet. (Olson in 1939)

DODONAEA ERIOCARPA Sm. (E, "aalii" "aaliikumakua")

A species insufficiently distinct from D. viscosa, but the exact status of which is uncertain. (All specimens are cited under D. viscosa)

DODONAEA VISCOSA L. (I, "aalii" "aaliikumakani")

A species with innumerable variations; some of them forest trees, others shrubs of open ash beds and dry lava flows, found throughout the Park except at the highest elevations. (Ruhle in 1961; Poinar in 1963; Morley 14-H; Olson in 1939; s. coll. 982, 1092; M-D H-10, H-16, H-17, H-26, H-27, H-100, H-321, H-327)

SAPINDUS SAPONARIA L. (I, "a'e")

S. saponaria f. inaequalis (DC.) Radlk.

S. thurstonii Rock

Lower slopes of Mauna Loa, forms dense canopy in lower part of Kipuka Puaulu. (Morley 58-H; M-D H-134, H-322)

BALSAMINACEAE

IMPATIENS SULTANII Hook f. (X)

Park residence area. (Olson in 1938; F & M 120)

RHAMNACEAE

ALPHITONIA PONDEROSA Hbd. (E, "kauila")

A. excelsa sensu Hawaii authors

Infrequent in dry forests. (F & M 558; Stone 2956; Stone & Pearson 3017; M-D H-218)

VITACEAE

VITIS sp. (X, "grape")

Kilauea Iki Crater floor. (F & M 704)

MALVACEAE

ABUTILON MOLLE Sweet (X)

A. mollisimum sensu Hawaii authors

Occasional in rather dry disturbed places. (Olson in 1939; F & M 843)

ABUTILON PICTUM Walp. (X)

Park residence area. (F & M 621)

ALCEA ROSEA L. (X, "hollyhock")

Althaea rosea (L.) Cav.

In gardens.

HIBISCADELPHUS GIFFARDIANUS Rock (E, "hau kuahiwi")

One of the rarest trees in the world. The single original tree, from just outside the Park, is now dead. Several individuals from cuttings are growing in Kipuka Puaulu. (s. coll. 1062; Bender in 1950; Fosberg 41777)

HIBISCADELPHUS HUALALAIENSIS Rock (E)

An almost extinct tree from the Hualalai dry forest, several individuals planted in Kipuka Puaulu. (Fosberg 41778)

HIBISCUS ROSA-SINENSIS L. (X, "red Hibiscus")

Old Volcano House. (F & M 462)

HIBISCUS TILIACEUS L. (I, "hau")

Pariti tiliaceum (L.) Britt.

Planted in Park residence area, spontaneous along coast in Kalapana area. (Stone 3027; F & M 217)

KOKIA ROCKII Lewt. (E)

Planted near Hilina Pali; also in Kipuka Nene and in Kipuka Puaulu. (Poinar in 1963)

MALVA PARVIFLORA L. (X, "mallow" "cheeses")

Frequent in open disturbed places, old gardens, around dwellings. (Olson in 1939; F & M 518, 434, 492)

MALVASTRUM COROMANDELIANUM (L.) Garcke (X, "false mallow")

M. tricuspidatum Gray

Frequent on dry lava flows near sea level and in open forests higher up. (F & M 330, 367, 350, 1121)

MODIOLA CAROLINIANA (L.) G. Don. (X)

Abundant in Kipuka Puaulu; frequent in lawns, old gardens, and around buildings. (F & M 312; Olson in 1939; Fagerlund 55; Morley 171-H)

SIDA FALLAX Walp (SENSU LATO) (I, "ilima" "lei ilima")

S. cordifolia sensu Hawaii authors

A variable aggregation, best referred to this species, at least until a revision in preparation by Prof. H. St. John is completed. Frequent to infrequent in moderately dry areas from sea level to 4000 feet. (F & M 680, 353, 663, 133; Stone & Pearson 3024)

SIDA RHOMBIFOLIA L. (X, "ilima papa")

Frequent along roadsides and in disturbed places, both in Kilauea area and near sea level at Keauhou. (Poinar in 1963; F & M 370, 368, 63)

THESPESIA POPULNEA (L.) Sol. ex Correa (I, "milo")

Along more moist sections of coast, such as at Kalapana. (s. coll. 1103; Stone 2890; Poinar in 1963)

STERCULIACEAE

WALTHERIA INDICA L. (X, "alaalapuloa")

W. americana L.

Frequent and widespread in moderately dry open country and open forest from sea level to about 4000 feet; dominant on certain old lava flows near sea. (F & M 140; s. coll. 252; M-D H-121)

THEACEAE

CAMELLIA JAPONICA L. (X, "camellia")

Park residence area. (F & M 755)

EURYA SANDWICENSIS Gray (E, "anini" "wanini")

Infrequent in wet forest north of Makaopuhi Crater. (Horner (F & M) 169; s. coll. 944)

GUTTIFERAE (HYPERICACEAE)

HYPERICUM JAPONICUM Thunb. (X, "St. Johns wort")

A very general weed in moist disturbed places in Kilauea and Chain-of-Craters regions. Has been confused by some authors with H. mutilum L. Our plant has narrower, more oblong leaves than typical H. japonicum. (F & M 14; s. coll. 254; Lamoureux 2512; M-D H-74)

HYPERICUM MOSERIANUM Andr. (X)

Park residence area. (F & M 1086)

HYPERICUM MUTILUM L. (X, "St. Johns wort")

An erect plant which has been confused with the prostrate H. japonicum. Occasional around dwellings at Kilauea. (F & M 1117, 748)

VIOLACEAE

VIOLA ODORATA L. (X, "violet")

Park residence area, and at Thurston Lava Tube. (F & M 456; Olson in 1938; Fosberg 46053)

FLACOURTIACEAE

DOVYALIS HEBECARPA (Gardn.) Warb. (X)

At Stone's place in Panau Nui. (F & M 1102)

XYLOSMA HAWAIIENSIS var. HILLEBRANDII (Wawra) Sleumer (E, "maua")

X. hillebrandii Wawra

Infrequent in Kipuka Puaulu; frequent in Naulu Forest, Kealakomo. (F & M 661, 808; s. coll. 1213; Stone & Pearson 3020; Morley 179-H; Eggler 116; Shear in 1928)

PASSIFLORACEAE

PASSIFLORA EDULIS Sims (X, "lilikoi" "passion fruit")

Rare in vicinity of Kilauea. (Olson in 1938; F & M 660; M-D H-246)

PASSIFLORA FOETIDA L. (X, "pohapoha")

Infrequent; in dry areas up to about 2500 feet. (Olson in 1939; F & M 358; M-D H-216)

PASSIFLORA LIGULARIS Juss. (X, "lomiwai" "liliwai" "yellow water lemon")

P. laurifolia sensu Wilder

Park residence area; also near Kipuka Puaulu. (F & M 627)

CARICACEAE

CARICA PAPAYA L. (X, "papaya")

A very few planted trees here and there. (F & M 724)

CUCURBITACEAE

CUCUMIS SATIVUS L. (X, "cucumber")

In gardens.

CUCURBITA PEPO L. (X, "pumpkin")

In gardens.

SICYOS HILLEBRANDII St. John (E, "anunu")

Park boundary with Kapalapala Ranch, at about 3500 feet. (F & M 526, 681)

SICYOS MICROCARPUS Mann (E, "anunu")

Near Kipuka Nene, also in Apua at 2000 feet. (F & M 544, 588)

BEGONIACEAE

BEGONIA FUCHSIOIDES Hook. (X)

Park residence area. (F & M 92; M-D H-147, H-156)

BEGONIA SEMPERFLORENS Link & Otto (X)

Park residence area. (F & M 103)

BEGONIA sp. (X)

Park residence area. (F & M 275)

THYMELEACEAE

WIKSTROEMIA BUXIFOLIA Gray (E)

In dry areas. (Degener 10355; M-D H-325)

WIKSTROEMIA PHILLYRAEFOLIA Gray (E, "akia")

Infrequent but widespread in dry to wet areas from 2000 to 4000 feet. (s. coll. 276, 277; F & M 127; Stone 2941; Morley 29-H, 86-H)

WIKSTROEMIA SANDWICENSIS Meisn. (E, "akia")

Frequent in forest and scrub generally. (Olson in 1939; Poinar in 1963; F & M 10, 791; Morley 161-H; M-D H-48, H-87)

ELAEAGNACEAE

ELAEAGNUS UMBELLATA Thunb. (X)

Near Park residence area and near Thurston Lava Tube. (Poinar in 1963; Fosberg 44457)

LYTHRACEAE

CUPHEA CARTHAGINENSIS (Jacq.) Macbr. (X, "tarweed")

Cuphea balsamona sensu St. John

Disturbed places. (PHB & GOF in 1941; Morley 192-H; F & M 13, 316; s. coll. 261)

CUPHEA HYSSOPIFOLIA HBK. (X, "false heather")

Park residence area and along Kalapana Trail at 2500 feet. (F & M 213; Stone 2939)

CUPHEA IGNEA A. DC. (X, "puakiki" "cigar flower")

C. platycentra Lem.

Park residence area. (Olson in 1939; F & M 99)

LYTHRUM MARITIMUM HBK. (X, "pua kamoli")

Frequent on Mauna Loa slopes, in Kipuka Puaulu and Kilauea area. (Olson in 1939; s. coll. 262, 425; F & M 237; Lamoureux 2518; M-D H-137)

MYRTACEAE

CALLISTEMON RIGIDUS R. Br. (X, "bottle brush")

Park residence area. (Hamilton in 1963)

EUCALYPTUS GLOBULUS Labill. (X, "nuhulani" "blue gum" "eucalyptus")

Na Makani Paio and Old Volcano House grounds. (F & M 909)

EUCALYPTUS ROBUSTA Sm. (X, "swamp mahogany" "eucalyptus")

Old Volcano House grounds. (F & M 909)

EUGENIA CUMINI (L.) Druce (X, "Java plum")

Above Stone's place in Panau Nui. (F & M 1104; M-D H-199)

EUGENIA JAMBOS L. (X, "Rose apple")

Found once in rain forest near Kilauea Crater. (Eggler 101)

EUGENIA MALACCENSIS L. (P, "ohia ai" "mountain apple")

Puna, near Kupaahu, near sea level, in earthquake fissure. (Stone 3005)

LEPTOSPERMUM SCOPARIUM Forst. (X, "Australian tea")

Jaggar's House. (F & M 450)

METROSIDEROS COLLINA var. INCANA (Levl.) Rock (E, "ohia lehua")

Commonest tree in most of the forests in the Park. (s. coll. 268; Morley 141-H, 36-H, 54-H, 182-H; Morley 181-H is intermediate with var. macrophylla; Fosberg 44470, 44471, 44472)

METROSIDEROS COLLINA var. MACROPHYLLA Rock (E, "ohia lehua")

Common in forests. (Morley 159-H, 166-H, 135-H)

PSIDIUM CATTLEIANUM Sabine (X, "strawberry guava" "waiawi ulaula")

Abundant locally in wet areas, invading native vegetation; also along coast at Kalapana. (Lamoureux 2485; Poinar in 1963; F & M 648, 270, 407)

PSIDIUM GUAJAVA L. (X, "kuawa" "guava")

Widely distributed in wet areas. (Morley 140-H)

MELASTOMACEAE

HETEROCENTRON SUBTRIPLINERVIUM (L. & O.) A. Br. & Bouché (X)

H. roseum A. Br. & Bouché of Hawaiian authors

Abundant in disturbed places in Kilauea area; both white and pink-flowered forms found together. (F & M 27; Fosberg 41767, 47738, 47739)

TIBOUCHINA URVILLEANA (DC.) Cogn. (X, "tibouchina" "princess flower" "lasiandra" "pleroma")

T. semidecandra (Schrank & Mart.) Cogn. of Hawaiian authors

Abundant around Kilauea area. (F & M 177, 649; M-D H-56)

ONAGRACEAE

EPILOBIUM CINERIUM A. Rich. (X, "willow weed")

E. oligodontum of Hawaiian authors

Common in open places; Kilauea Iki. (Morley A; M-D H-174; Eggler 199)

FUCHSIA ARBORESCENS Sims. (X, 'lilac fuchsia")

Park residence area. (F & M 108; M-D H-185)

FUCHSIA HYBRIDA Voss (X)

Park residence area. (F & M 110)

FUCHSIA MAGELLANICA var. DISCOLOR Bailey (X, "kula pepeiao" "fuchsia")

Generally naturalized in Kilauea area. (Olson in 1939; F & M 87; M-D H-41)

OENOTHERA LACINIATA Hill (X)

Park residential area and around Old Volcano House. (F & M 466)

OENOTHERA SPECIOSA var. CHILDSII (Bailey) Munz (X)

Grassy area near Mauna Loa Strip Road, at about 4000 feet. (F & M 568)

OENOTHERA STRICTA Ledeb. (X)

Raimannia odorata (Jacq.) Sprague & Riley ("evening primrose")

Frequent in disturbed places and on ash beds in Kilauea region. (F & M 176, 277; M-D H-154, H-128, H-42; Fosberg 44466)

ARALIACEAE

BRASSAIA ACTINOPHYLLA F. Muell. ? (X, "octopus tree")

Kipuka Puaulu (Olson in 1940)

CHEIRODENDRON TRIGYNUM Gaud. (E, "olapa" "mahu")

C. gaudichaudii (DC.) Seem.

Frequent in wet and moist forests; Kipuka Puaulu. (F & M 249, 775; Stone 3045; Lamoureux 2522; Morley 176-H, 66-H; Eggler 103)

HEDERA HELIX L. (X, "English ivy")

Park residence area. (F & M 281)

REYNOLDSIA SANDWICENSIS Gray (E, "ohe" "ohe makai")

In dry areas at lower elevations. (F & M 548)

TETRAPLASANDRA HAWAIIENSIS Gray (E, "ohe")

Rare; Naulu Forest. (F & M 799)

UMBELLIFERAE

APIUM GRAVEOLENS L. (X, "celery")

In gardens.

APIUM PETROSELINUM L. (X, "parsley")

Petroselinum crispum (Mill.) Nyman

In gardens.

CENTELLA ASIATICA (L.) Urb. (X)

Occasional in moist to wet areas, especially in disturbed places. (F & M 1080; M-D H-168)

DAUCUS CAROTA L. (X, "carrot")

In gardens only.

DAUCUS PUSILLA Michx. (X)

Near Kipuka Nene. (F & M 512, 577)

HYDROCOTYLE SIBTHORPIOIDES var. OEDIPODA Deg. & Greenw. (E, "pennywort")

Kipuka Puaulu and slopes of Mauna Loa, in grassy places. (F & M 442; Morley 88-H; Fosberg 41755)

HYDROCOTYLE VERTICILLATA Thunb. (X, "pohepohe" "marsh pennywort")

Kalapana, in edge of pond.

PASTINACA SATIVA L. (X, "parsnip")

CCC Camp dump. (F & M 1088)

SPERMOLEPIS HAWAIIENSIS Wolff (E)

Infrequent; Apua about 2000 feet. (F & M 557)

ERICACEAE

RHODODENDRON cf. INDICUM Sweet (X, "azalea")

Park residence area. (M-D H-186; F & M 280, 754, 98, 752)

VACCINIUM CALYCINUM f. FAUREI (Lév.) Skottsb. (E, "ohelo kaulaau")

Frequent in wet forests, as along Chain-of-Craters. (Stone 2974; M-D H-47, H-31; Morley 32-H; F & M 1; Fosberg 44460; Eggler 131)

VACCINIUM PAHALAE Skottsb. (E, "ohelo")

Wet forest areas, Kilauea region. (Fosberg 44482)

VACCINIUM PELEANUM Skottsb. (E, "ohelo")

Mauna Loa slopes, 8000 to 10,000 feet in open scrub, intergrades with V. reticulatum at lower edge of range. (F & M 422, 762, 763, 258, 771; Poinar in 1963)

VACCINIUM RETICULATUM Sm. (E, "ohelo")

Frequent to abundant from about 2800 to 8000 feet. (Morley H-9; F & M 423; Stone 2975; M-D H-25; Fosberg 41763, 44461, 44469, 44481, Eggler 167)

EPACRIDACEAE

STYPHELIA DOUGLASII (Gray) F. Muell. (E, "pukeawe")

Abundant on upper middle slopes of Mauna Loa, forming scrub. (F & M 764; Poinar in 1963; Morley 167-H)

STYPHELIA TAMEIAMEIAE (Cham.) F. Muell. (E, "pukeawe" "maieli" "kawau")

Cyathodes tameiameae Cham.

Frequent to abundant generally, from dry desert areas and lava flows to moderately wet forests, and in scrub or lower slopes of Mauna Loa. (Poinar in 1963; Morley 15-H; s. coll. 366; Eggler 68)

MYRSINACEAE

ARDISIA CRISPA (Thunb.) A. DC. (X)

Park residence area. (F & M 286)

EMBELIA PACIFICA Hbd. (E, "kilioe")

Kipuka Puaulu. (F & M 269)

MYRSINE LANAIENSIS Hbd. (E)

Suttonia lanaiensis (Hbd.) Mez

Infrequent in dry forest from 1500 to 2500 feet. (F & M 521, 541, 531; Stone 2960; M-D H-216; Eggler 120)

MYRSINE LESSERTIANA A. DC. (E, "kolea")

Suttonia lessertiana (A. DC.) Mez

Frequent generally in wet to moist or moderately dry forests, especially between 1500 and 4500 feet. (F & M 499, 689, 804, 396, 240; Morley 43-H; Stone 2943; Lamoureux 2487; M-D H-85, H-177; Eggler 227, 137)

MYRSINE SANDWICENSIS A. DC. (E)

Suttonia sandwicensis (A. DC.) Mez

Frequent in moist to wet forests along Chain-of-Craters. (F & M 397; Morley 42-H; M-D H-86)

PLUMBAGINACEAE

PLUMBAGO ZEYLANICA L. ? (I)

Rare in dry coastal areas. (M-D H-265 - sterile, almost unidentifiable)

PRIMULACEAE

ANAGALLIS ARVENSIS L. (X, "Scarlet Pimpernel" "Shepherds weatherglass")

Frequent around Kilauea and Kipuka Puaulu. (Olson in 1938; F & M 464)

EBENACEAE

DIOSPYROS FERREA var. PUBESCENS Fosb. (E, "lama")

Maba sandwicensis A. DC.

Abundant in dry forest and coastal scrub. (Eggler 114, 44)

DIOSPYROS FERREA var. SANDWICENSIS (A. DC.) Fosb. (E, "lama")

Maba sandwicensis A. DC.

Kamoamoa, in coastal scrub forest. (Poinar in 1963; Stone 2884; Olson in 1940; s. coll. 729; F & M 812, 327; M-D H-206, H-107, H-200)

OLEACEAE

JASMINUM HUMILE L. (X, "jasmine")

Old Volcano House. (F & M 461, 225)

JASMINUM MULTIFLORUM Andr. (X, "star jasmine")

J. pubescens (Retz.) Willd.

Park residence area. (F & M 648)

LIGUSTRUM OVALIFOLIUM Hassk. (X, "privet")

Old Volcano House. (F & M 674)

LIGUSTRUM VULGARE L. (X, "privet")

East of Kilauea Iki in semi-open forest. (M-D H-23)

LINOCIERA LIGUSTRINA Sw. (X)

Ainahou Ranch, in grazing land. (M-D H-210, H-211)

OSMANTHUS SANDWICENSIS (Gray) B. & H. (E, "pua" "olopua" "Hawaiian olive")

Nestegis sandwicensis Deg. & Johns.

Frequent in Kipuka Puaulu and in other mixed forest areas.

(F & M 684-b, 684-a, 655; Lamoureux 2488, 2474)

LOGANIACEAE

BUDDLEJA ASIATICA Lour. (X, "butterfly bush")

Common on new scoria and road cuts in fairly wet areas. (F & M 498; Olson in 1939; M-D H-164, H-148, H-149; Eggler 194)

BUDDLEJA DAVIDI Franch. (X, "summer lilac")

Near Hilo entrance to Park. (F & M 274, 647)

LABORDIA HEDYOSMIFOLIA var. GRAYANA (Hbd.) Sherff (E, "kamakahala")

Vicinity of Kilauea Iki.

LABORDIA HEDYOSMIFOLIA var. KILAUEAE Sherff (E)

Between Makaopuhi and Napau Craters.

LABORDIA HEDYOSMIFOLIA var. MAGNIFOLIA Deg. & Sherff (E)

Kilauea area.

POLYPREMUM PROCUMBENS L. (X)

Small colony on edge of Kilauea caldera opposite KMC. (Fosberg 39279)

GENTIANACEAE

CENTAURIUM UMBELLATUM Gilib. (X, "centaury")

Infrequent but widespread in grasslands. (Morley 107-H; s. coll. 422; F & M 293; M-D H-212, H-252)

APOCYNACEAE

ALYXIA OLIVAEFORMIS Gaud. (E, "maile" "maile laulii")

Occasional in moist to wet forests, 1500 to 5000 feet. (Lamoureux 2467; F & M 201; s. coll. 255; Morley 68-H; Stone 2998)

CATHARANTHUS ROSEUS (L.) G. Don (X, "Madagascar periwinkle")

Vinca rosea L.

In gardens

OCHROSIA SANDWICENSIS Gray (E, "holei")

At least formerly in Kipuka Puaulu.

PLUMERIA RUBRA L. (X, "plumeria" "frangipani")

Lae Apuki near sea level. (F & M 1097)

RAUWOLFIA SANDWICENSIS A. DC. (E, "hao")

R. remotiflora Deg. & Sherff

The Hawaii form, called R. remotiflora by Sherff, seems no more than varietally distinct from R. sandwicensis from Oahu.

Infrequent along Poliokeawe Pali. (Smathers in 1963; Poinar in 1963; Fagerlund 1089; s. coll. 1089; F & M 546, 379; Eggler 87)

VINCA MAJOR L. (X, "periwinkle")

Park residence area. (F & M 282)

ASCLEPIADACEAE

ASCLEPIAS CURASSAVICA L. (X, "kilika" "laulelo" "nuumela" "pua anuhe" "milkweed")

Frequent in moderately dry grasslands, from 2000 to 3000 feet. (M-D H-20, H-191; Poinar in 1963; Olson in 1939; F & M 22)

CONVOLVULACEAE

CUSCUTA SANDWICHIANA Choisy (E, "pololo" "kaunoa" "kaunaoa" "dodder")

Parasitic on Ipomoea pes-caprae at Kalue. (F & M 651)

IPOMOEA BATATAS (L.) Lam. (P, "uala" "sweet potato")

Abandoned gardens. (F & M 447)

IPOMOEA INDICA (Burm.) Merr. (I)

I. congesta R. Br.

I. insularis Steud.

Infrequent but widespread in open and semi-open places; frequent in Kipuka Puaulu.

IPOMOEA PES-CAPRAE (L.) R. Br. (I, "pohuehue" "beach morning-glory")

Along seashore at Halape. (Stone 2866; F & M 332)

JACQUEMONTIA SANDWICENSIS Gray (E, "pauohiiaka")

Apua Point and other coastal areas. (F & M 384, 554)

MERREMIA AEGYPTIA (L.) Urb. (X)

Ipomoea aegyptia L.

Operculina aegyptia (L.) House

In a lava-tube opening near sea-level in Keauhou. (F & M 364)

STICTOCARDIA TILIAEFOLIA (Desr.) Hall. f. (I)

Stictocardia campanulata sensu House

not Ipomoea campanulata L.

Abundant at foot of Pali at Kalue. (F & M 654)

POLEMONIACEAE

PHLOX DRUMMONDII Hook. (X)

Park residence area. (F & M 744)

BORAGINACEAE

AMSINCKIA INTERMEDIA F & M ? (X)

Amsinckia douglasiana sensu 1941 check list

Puu Ulaula, on Mauna Loa at 10,000 feet. (F & M 903)

CYNOGLOSSUM ZEYLANICUM (Vahl) Thunb. (X, "stick-tight")

Abandoned gardens in Kilauea area, also on Mauna Loa and at Hilina Pali. (F & M 100)

HELIOTROPIUM ARBORESCENS L. (X, "heliotrope")

Heliotropium corymbosum R. & P.

Park residence area. (F & M 182)

HELIOTROPIUM CURASSAVICUM L. (I, "hinahina Ku-kahikai" "nena" "kipu-kai")

In brackish marshes along shore. (F & M 362)

MYOSOTIS AZORICA Wats. (X, "forget-me-not")

Gardens at Kilauea and established in nearby forests. (F & M 279)

TOURNEFORTIA ARGENTEA L. f. (X)

Messerchmidia argentea (L. f.) Jtn.

Along shore at Keauhou, probably planted. (F & M 385)

VERBENACEAE

LANTANA CAMARA var. ACULEATA (L.) Mold. (X, "lantana" "lakana")

Several plants observed and destroyed near Hilina Pali shelter and one at Halape. (F & M 874)

LANTANA MONTEVIDENSIS (Spreng.) Briq. (X)

Park residence area. (F & M 115)

STACHYTARPHETA DICHOTOMA (R. & P.) Vahl (X, "oi" "false Vervain")

S. cayennensis sensu Hawaiian authors.

Frequent in moderately wet disturbed places and along Mauna Loa Strip Road.

VERBENA X HYBRIDA Voss (X, "hanupepe" "verbena")

Park residence area. (F & M 109)

VERBENA LITORALIS HBK. (X)

V. bonariensis sensu Hawaiian authors

Frequent about Kilauea, Kipuka Puaulu and vicinity. (F & M 308; Morley 82-H; M-D H-132; Lamoureux 2490)

LABIATAE

COLEUS SCUTELLARIOIDES L. (X, "coleus")

C. blumei Benth. of most authors

In gardens.

LEONURUS SIBIRICUS L. (X, "Siberian motherwort")

Along boundary trail between Ainahou and Park at about 2200 feet. (Olson in 1939)

MENTHA PIPERITA L. ? (X, "peppermint")

Old Volcano House, also in Kipuka Puaulu. (F & M 463; Lamoureux 2455; Morley 97-H; all sterile)

PHYLLOSTEGIA FLORIBUNDA Benth. (E, "ulihi")

Kilauea.

PHYLLOSTEGIA VESTITA Benth. (E, "ulihi")

Lava Tree Trail near Napau Crater. (F & M 567)

PLECTRANTHUS AUSTRALIS R. Br. (I)

P. parviflorus of Hawaiian authors

In dry areas from sea level to about 3000 feet. (F & M 372, 540; M-D H-111; Fosberg 41585a)

SALVIA COCCINEA Juss. (X, "lili-lehua" "crimson sage")

Frequent along roadsides near Kipuka Nene. (Poinar in 1963; M-D H-213; F & M 25)

SALVIA LEUCANTHA Cav. (X, "Mexican bush sage")

In gardens.

SALVIA OCCIDENTALIS Sw. (X, "ki hohono" "West Indian sage")

Priva aspera sensu Hawaiian authors

Frequent in moderately dry areas, as about Hilina Pali Shelter. (F & M 151; Olson in 1939)

SALVIA SPLENDENS var. ATROPURPUREA Hort. (X, "scarlet sage")

Park residence area. (F & M 186)

STENOGYNE ANGUSTIFOLIA var. SALICIFOLIA Sherff (E)

Collected in 1868 between Kilauea and Kapalapala.

STENOGYNE CALAMINTHOIDES Gray (E)

Kilauea Iki. (F & M 246; Olson in 1939)

STENOGYNE KAALAE var. CORIACEA Deg. & Sherff (E)

Kokolau Crater.

STENOGYNE RUGOSA Benth. (E, "maohihi")

Kilauea. (F & M 1063; Degener 5393)

STENOGYNE RUGOSA var. SUBULATA Sherff (E, "maohiohi")

Above Kipuka Ki and near Puu Huluhulu. (Stone 3001; F & M 3, 15; Olson in 1938)

STENOGYNE SESSILIS Benth. (E)

Collected a hundred years ago at Kilauea.

SOLANACEAE

CESTRUM AURANTIACUM Lindl. (X)

Old Volcano House. (F & M 600)

CESTRUM NOCTURNUM L. (X, "alaaumoe" "lady of the night")

Park residence area. (F & M 702, 117)

NICANDRA PHYSALODES (L.) Gaertn. (X, "apple of Peru")

Near Old Volcano House. (F & M 202, 644)

NICOTIANA TABACUM L. (X, "paka" "tobacco")

In lava-tube opening in Apua at about 500 feet. (F & M 373)

NOTHOCESTRUM BREVIFLORUM Gray (E, "aiea")

Infrequent; in Kipuka Puaulu, Kipuka Ki, Naulu Forest, and along Napau Trail. (Judd & Olson in 1939; Morley 174-H; F & M 778, 734)

NOTHOCESTRUM LONGIFOLIUM Gray (E, "aiea")

Kipuka Puaulu.

PHYSALIS PERUVIANA L. (X, "poha" "Cape gooseberry")

Frequent generally in moderately dry areas in Park from Kipuka Nene to 6700 feet on Mauna Loa. (Lamoureux 2471; F & M 86; Poinar in 1963; Morley 99-H)

SOLANUM LYCOPERSICUM L. (X, "tomato")

Lycopersicon esculentum Mill.

In gardens.

SOLANUM MURICATUM Ait. (X, "pepino")

In gardens.

SOLANUM NIGRUM L. (P, "popolo")

S. nodiflorum Jacq.

Frequent in dry to moderately wet areas from sea level to 4000 feet, infrequent higher up. (F & M 295, 344, 185; Morley 7-H; Poinar in 1963)

SOLANUM PSEUDO-CAPSICUM L. (X, "Jerusalem cherry")

Frequent on Mauna Loa slopes around 4500 feet, especially in Koa groves and in Kipuka Ki. (Lamoureux 2480; F & M 170; Morley 51-H; Fosberg 44459)

STREPTOSOLEN JAMESONII (Benth.) Miers (X)

Park residence area. (F & M 600)

SCROPHULARIACEAE

ANTIRRHINUM MAJUS L. (X, "snapdragon")

In gardens.

ASARINA ERUBESCENS (Don) Pennell (X)

Maurandya erubescens (Don) Gray

Volcano House. (F & M 483)

DIGITALIS PURPUREA L. (X, "fox-glove")

Park residence area and Olaa Forest Reserve. (F & M 1074; M-D H-179)

LINARIA BIPARTITA Willd. (X, "clover-lip toadflax")

Park residence area. (F & M 745)

LINARIA CANADENSIS var. TEXANA (Scheele) Pennell (X, "blue toadflax")

Local in open dry or semi-dry areas. (Olson in 1939; s. coll. in 1938; Poinar in 1963; F & M 296; Morley 102-H; Fosberg 41586a, 41594a)

LINDERNIA CRUSTACEA (L.) F. Muell. (X, "false pimpernel")

Local in fumarole areas near Halemaumau. (Fosberg 46054)

ORTHOCARPUS PURPURASCENS Benth. (X, "paint brush" "owl's clover")

Horse corral on Mauna Loa at 6700 feet. (F & M 1045)

PENSTEMON COBAEA Nutt. (X)

Park residence area. (F & M 216)

VERBASCUM VIRGATUM With. (X)

Volcano House garden. (F & M 641)

VERONICA X ANDERSONII Lindl. & Paxt. (X)

Hebe X andersonii (Lindl. & Paxt.) Cock.

Old Volcano House. (Olson in 1938)

VERONICA PLEBEIA R. Br. (X, "speedwell")

Widespread in open and semi-open places at least up to 6700 feet on Mauna Loa, frequent in Kipuka Puaulu. (Lamoureux 2461; Fosberg 41588a; s. coll. 271; F & M 536, 85, 439, 440)

VERONICA SALICIFOLIA Forst. f. (X)

Hebe salicifolia (Forst. f.) Pennell

Park residence area. (F & M 79; M-D H-184)

VERONICA SERPYLLIFOLIA L. (X, "thymeleaf speedwell")

In open places from Kilauea up to considerable elevations on Mauna Loa. (F & M 314, 768; Lamoureux 2516; Fosberg 44453)

GESNERIACEAE

CYRTANDRA GIFFORDII Rock (E)

Kilauea.

CYRTANDRA LYSIOSEPALA (Gray) C. B. Cl. (E)

Infrequent; Kane Nui o Hamo. (F & M 835; Morley 134-H; Olson in 1939)

CYRTANDRA MONTIS-LOA Rock (E)

Kilauea.

CYRTANDRA PALUDOSA Gaud. (E, "kanawao-keokeo" "piohia" "mapele")

Chain-of-Craters area. (F & M 190, 834, 829, 410, 566; Eggler 106; Morley 158-H)

CYRTANDRA PLATYPHYLLA Gray (E)

Frequent in wet fern forests, especially in vicinity of Kilauea Iki and Thurston Lava Tube. (Morley 126-H, 37-H; F & M 491, 199; M-D H-67; Olson in 1938)

CYRTANDRA RAMOSISSIMA Rock (E)

Makaopuhi Crater. (F & M 580; Baldwin in 1949)

BIGNONIACEAE

JACARANDA ACUTIFOLIA H. & B. (X, "jacaranda")

Ainahou Ranch, cultivated. (M-D H-209)

ACANTHACEAE

JUSTICIA BETONICA L. (X)

Park residence area. (F & M 475)

MYOPORACEAE

MYOPORUM SANDWICENSE (A. DC.) Gray (E, "naio" "bastard sandalwood")

Very general in Park, especially at middle elevations on Mauna Loa, Kipuka Ki, Kipuka Puaulu, and in forests between 1500 and 2000 feet.

(F & M 876, 800; Stone 2958; Morley 57-H; Baldwin & Fagerlund 501; Poinar in 1963; Lamoureux 2517; M-D H-110, H-215, H-219, H-220, H-163; s. coll. 1111; Eggler 289, 37)

PLANTAGINACEAE

PLANTAGO LANCEOLATA L. (X, "narrow-leafed plantain" "ribbed plantain")

Frequent in lawns and grasslands from Kilauea to 6700 feet on Mauna Loa. Kipuka Nene. (Eggler 52)

PLANTAGO MAJOR L. (X, "lau-kahi" "broad-leafed plantain")

Park residence area. (F & M 626; Stone 2869)

PLANTAGO VIRGINICA L. (X, "Virginia plantain" "hairy plantain")

Frequent in Kilauea region. (F & M 596, 616, 406; s. coll. 263)

RUBIACEAE

BOBEA TIMONIOIDES (Hook. f.) Hbd. (E, "ahakea")

Frequent in Naulu Forest, Kealakoma, at about 1600 feet. (F & M 806, 807, 732; Eggler 115; Stone & Pearson 3090)

CANTHIUM ODORATUM (Forst.) Seem. (I, "alahee" "walahee")

Plectronia odorata (Forst.) B. & H.

Abundant in dry forest, up to 1700 feet. (F & M 376, 778, 810; Olson in 1939, 1940; M-D H-21, H-106, H-201, H-215)

COPROSMA ERNODEOIDES Gray (E, "kukainene" "leponene")

Frequent on lava flows and in semi-open forests from Napau Crater up to at least 8000 feet on Mauna Loa. (Morley 39-H, 145-H; Stone 2976; M-D H-8; Eggler 268, 237)

COPROSMA MENZIESII Gray (E, "pilo" "kopa")

Frequent to abundant, Pauahi Crater and Chain-of-Craters Road. (F & M 717, 718; M-D H-88, H-101; Ruhle in 1958; Olson in 1941; Stone 2967; Eggler 134)

COPROSMA MONTANA Hbd. (E, "pilo" "kopa")

Frequent to abundant in scrub on Mauna Loa at about 7500 feet. (F & M 427, 757, 260; M-D H-319)

COPROSMA ORCHRACEA var. ROCKIANA Oliver (E, "pilo" "kopa")

Frequent in wet forest, as near Thurston Lava Tube, Olaa Forest Preserve. (M-D H-167, H-172; F & M 241; Morley 40-H; Eggler 281)

COPROSMA RHYNCHOCARPA Gray (E)

C. cymosa sensu 1944 check list.

Frequent in Kipuka Puaulu and vicinity. (Olson in 1939; Morley 180-H; Lamoureux 2458, Fosberg 44452, 44456; Eggler 29)

GOULDIA TERMINALIS f. ACUTA Fosb. (E, "manono")

Kipuka Puaulu. (Fosberg 10125; Lamoureux 2495)

GOULDIA TERMINALIS f. ANTIQUA Fosb. (E, "manono")

Kipuka Puaulu and Naulu Forest. (Skottsberg 549, 537; Degener 9457; Rock 8744)

GOULDIA TERMINALIS var. FORBESII Fosb. (E, "manono")

In wet forests. (M-D H-180, 165)

GOULDIA TERMINALIS var. HOSAKAI Fosb. (E, "manono")

Naulu Forest, Kealakomo, 1600 feet. (F & M 809; Eggler 107)

GOULDIA TERMINALIS f. KONAENSIS Fosb. (E, "manono")

Kipuka Puaulu and Kalapana Trail at 2400 feet. (F & M 687, 788, 801; Degener et. al. 9453; Skottsberg 1918; Fosberg 10090; Rock 8785)

GOULDIA TERMINALIS f. KAUENSIS Fosb. (E, "manono")

Great Crack, Kau Desert. (Olson in 1939; Skottsberg 608)

GOULDIA TERMINALIS f. PITTOSPOROIDES Fosb. (E, "manono")

Upper Kealakomo, near Kalapana Trail, 2500 feet. (Stone 2962)

GOULDIA TERMINALIS f. RIGIDIFOLIA Fosb. (E, "manono")

Makaopuhi Crater and vicinity. (F & M 194, 399, 583; Fosberg 10093, 10109; Oliveira 3; Eggler 225, 218; M-D H-207)

GOULDIA TERMINALIS f. KONAENSIS X f. RIGIDIFOLIA (E)

Near Makaopuhi Crater. (Fosberg 10103; Degener et. al. 9454; Oliviera 2)

HEDYOTIS CENTRANTHOIDES (H. & A.) Steud. f. CENTRANTHOIDES (E)

Kadua centranthoides H. & A.

Generally common in moist to wet areas in open forest and on lava flows. (Olson in 1937, 1938, 1939; Stone 2877; Morley 2-H, 111-H; M-D H-93; Hitchcock 14608; Degener 1597, 11655; Faurie 377; Rock 8766, L, M; Forbes et. al. in 1908; Skottsberg 556, 1901; Neal in 1927, 1929; Fosberg 58, 10101, 10108, 10110; Macrae in 1825; Eggler 142)

HEDYOTIS CENTRANTHOIDES f. DIFFUSA Fosb. (E)

Kilauea. (Rechinger 2065; Hillebrand s. n., 203)

LUCULIA GRATISSIMA Sweet (X)

Park Headquarters.

MORINDA CITRIFOLIA L. ("noni") (P)

In openings in lava-tubes near seacoast. (F & M 359; Poinar in 1963)

PENTAS LANCEOLATA (Forsk.) Deflers (X)

Park residence area. (F & M 116)

PSYCHOTRIA HAWAIIENSIS (Gray) Fosb. var. HAWAIIENSIS (E, "kopiko")

Straussia hawaiiensis Gray

East of Makaopuhi Crater and in Naulu Forest, Kealakomo. (Stone 2954; F & M 803; M-D H-217; Eggler 112)

PSYCHOTRIA HAWAIIENSIS var. HILLEBRANDII (Rock) Fosb. (E, "kopiko")

Straussia hillebrandii Rock

Abundant in Kipuka Puaulu. (Morley 55-H; Lamoureux 2450, 2457, 2483; Fosberg 44454)

RICHARDIA BRASILIENSIS (Mog.) Gomez (X)

R. scabra sensu Hawaiian authors.

Along road, Kilauea. (F & M 865)

CAPRIFOLIACEAE

LONICERA JAPONICA Thunb. (X, "Japanese honeysuckle")

Park residential area. (Olson in 1938; F & M 114)

SAMBUCUS MEXICANA var. BIPINNATA (S. & C.) Schwerin (X, "elderberry")

Park residence area. (F & M 180; Poinar in 1963)

CAMPANULACEAE

CLERMONTIA COERULEA Hbd. (E)

Said to occur to the east of Kilauea at 2000 to 4000 feet.

CLERMONTIA HAWAIIENSIS (Hbd.) Rock (E, "ohewai" "ohawai")

Kipuka Puaulu and Chain-of-Craters region. (Morley 132-H; Olson in 1938; F & M 244, 321; Stone 2958; s. coll. 357)

CLERMONTIA MONTIS-LOA Rock (E, "ohewai")

Epiphyte in wet forests.

CLERMONTIA MONTIS-LOA f. GLOBOSA Rock (E)

Epiphyte in wet forests.

CLERMONTIA PELEANA Rock (E)

Kilauea in tall Metrosideros forests. (M-D H-166)

CLERMONTIA PARVIFLORA Gaud. ex Gray (E, "ohawai" "papaa kekili")

Wet forests, Kilauea Iki and Chain-of-Craters region. (F & M 578, 617, 841, 238; Olson in 1939; Eggler 8, M-D H-166)

CYANEA LONGIPEDUNCULATA Rock (E)

Kulani Trail. (Olson in 1939)

CYANEA PILOSA var. DENSIFLORA Rock (E)

Small crater above Napau. (F & M 973)

CYANEA PILOSA var. GLABRIFOLIA Rock (E)

Kulani Trail. (Olson in 1939)

TREMATOLOBELIA MACROSTACHYA (H. & A.) Zahlb. (E)

T. sandwicensis Deg.

In wet forest, Kilauea Iki. (F & M 847)

TRIODANIS BIFLORA (R. & P.) Greene (X)

Specularia biflora (R. & P.) F. & M.

In Kipuka in 1868 flow on ash and sand soil. (F & M 1050)

GOODENIACEAE

SCAEVOLA CHAMISSONIANA var. BRACTEOSA Hbd. (E, "naupaka" "naupaha kuahiwi")

In and around openings and sparse places in wet forest. (F & M 242, 135, 2; Morley 10-H; Stone 2971; Eggler 104)

SCAEVOLA KILAUEAE Deg. (E, "naupaka")

Perhaps too close to S. menziesiana.

Edge of Kau Desert on Hilina Pali road not far from Chain-of-Craters Road. (F & M 302; Stone 2970; Olson in 1938; M-D H-24; Fosberg 41598a, 41599a)

SCAEVOLA TACCADA (Gaertn.) Roxb. (I, "naupaka kahakai")

S. frutescens sensu Krause

S. frutescens var. sericea (Forst. f.) Merr.

Along seacoast just back of or in spray zone, Apua, Keaori Island, Halape. (Stone 2892 (pubescent); F & M 382 (glabrous))

DIPSACACEAE

SCABIOSA sp. (X, "scabious")

In gardens.

COMPOSITAE

ACANTHOSPERMUM AUSTRALE (Loefl.) O. Ktze. (X, "kukai hipa")

In disturbed places and in Park residential area. (Olson in 1938; F & M 142; Eggler 70)

ACHILLEA MILLEFOLIUM L. (X, "yarrow" "milfoil")

Infrequent in Park residence area. (Olson in 1940; s. coll. 250)

AGERATUM CONYZOIDES L. (X, "maile hohena" "ageratum")

Occasional in disturbed and weedy places, also about steam cracks. (M-D H-253; F & M 226, 145 (part))

ANTHEMIS COTULA L. (X, "mayweed camomile")

A. arvensis L. of previous Park authors

KMC dump and Mauna Loa at 6600 feet. (F & M 728; Jess in 1938; s. coll. in 1939)

ARGYROXIPHIUM SANDWICENSE DC. (E, "ahinahina" "silversword")

Rare; slopes of Mauna Loa, reported as low as 7000 feet, mostly higher. (F & M 271; M-D H-317)

ARTEMISIA VULGARIS L. (X, "mugwort")

Roadside near Park Headquarters. (F & M 1118)

ASTER sp. (X, "aster")

In gardens.

BIDENS CYNAPIIFOLIA HBK. (X, "kikuku" "beggars ticks")

Frequent on rocky areas near seashore at Keauhou. (F & M 360)

BIDENS PILOSA var. MINOR (Bl.) Sherff (X, "beggars ticks" "Spanish needles" "pilipili")

Kipuka Nene and Kipuka Puaulu. (F & M 1124; Lamoureux 2499; Fosberg 44467)

BIDENS PILOSA L. var. PILOSA (X, "beggars ticks" "Spanish needles" "pilipili")

New Kalapana Road. (M-D H-109, H-88)

BIDENS SKOTTSBERGII Sherff (E, "kokoolau")

Ainahou Ranch in Keauhou. (F & M 821)

CENTAUREA CYANUS L. (X, "cornflower" "bachelor's buttons")

In gardens.

CENTAUREA MELITENSIS L. (X, "star thistle")

South of Kipuka Nene at 2000 feet. (F & M 1047)

CHRYSANTHEMUM FRUTESCENS L. (X, "marguerite" "Paris daisy")

Park residence area. (F & M 665)

CHRYSANTHEMUM MAXIMUM Ramond (X, "Shasta daisy")

Frequent, established about Kilauea area. (F & M 94)

CIRSIUM VULGARE (Savi) Airy-Shaw (X, "puakala" "thistle")

C. lanceolatum (L.) Hill

Frequent in dry and moderately dry areas from Hilina Pali to 6100 feet on Mauna Loa. (Poinar in 1963; F & M 292, 892; Morley 92-H)

CONYZA CANADENSIS (L.) Cronq. (X, "iliohe" "ilioha" "ilioha laau")

(probably all var. pusilla (Nutt.) Cronq.)

Erigeron canadensis L.

Frequent in open or disturbed places from Kipuka Puaulu to sea level. (F & M 319, 71; Morley 81-H; Fosberg 41593a; Eggler 179; M-D H-60)

CONYZA BONARIENSIS (L.) Cronq. (X, "aheahea")

Erigeron albidus (Willd.) Gray

Frequent in moderately wet to dry disturbed or open areas. (F & M 291; Morley 152-H)

COREOPSIS LANCEOLATA L. (X, "tickseed" "Coreopsis")

C. nuecensis Heller of certain Hawaiian authors

Common around Kilauea area. (F & M 80; Fosberg 44465)

COSMOS BIPINNATUS Cav. (X, "cosmos")

Park residence area. (F & M 751)

DAHLIA EXCELSA Benth. ? (X, "tree Dahlia")

Park residence area. (F & M 454 (sterile))

DAHLIA PINNATA Cav. (X, "dahlia")

D. variabilis (Willd.) Desv.

Park residence area. (F & M 88, 89)

DUBAUTIA CILIOLATA (DC.) Keck (E, "kupaua" "kupaoa")

Railliardia ciliolata DC.

Railliardia ciliolata var. juniperoides Gray

Railliardia ciliolata var. laxiflora (DC.) Sherff

Railliardia ciliolata var. trinervia Hbd.

Common in open and semi-open areas from the Kau Desert and Chain-of-Craters up to about 9500 feet on Mauna Loa. The several varieties do not appear to be natural populations, but rather portions of a range of variations in a single population. (F & M 257, 740, 758, 713; M-D H-9; Stone 2972; Morley 38-H, 146-H; Fosberg 41772; Eggler 45)

DUBAUTIA LINEARIS (Gaud.) Keck (E, "kupaoa")

Railliardia linearis Gaud.

Collected at Kilauea in 1908.

DUBAUTIA SCABRA (DC.) Keck (E, "kupaoa")

Railliardia scabra DC.

Frequent in Kilauea region. (F & M 188, 144; M-D H-95, H-45; Morley 13-H; Fosberg 44483; Eggler 274)

DUBAUTIA SCABRA var. MUNROI (Sherff) Keck (E)

Railliardia scabra var. munroi Sherff

Kilauea Volcano, once collected.

DUBAUTIA X VAFRA (Deg. & Sherff) Keck (E)

Railliardia X vafra Deg. & Sherff

Once collected on Kau side of Kilauea.

EMILIA JAVANICA (Burm. f.) C. B. Rob. (X, "Flora's paintbrush")

E. sonchifolia sensu St. John and other Hawaiian authors

Frequent in open meadows near Hilina Pali and Kipuka Nene. (F & M 149; Fosberg 41592a; Eggler 159)

ERECHTITES HIERACIFOLIA (L.) Raf. (X, "hino-hana" "fireweed")

Infrequent; near Kipuka Nene. (F & M 24)

ERECHTITES VALERIANIFOLIA DC. (X, "hino-hana")

Infrequent; Napau Lava Trees Trail. (F & M 191)

ERIGERON KARVINSKIANUS DC. (X, "fleabane")

Kilauea area. (F & M 303)

EUPATORIUM RIPARIUM Regel (X, "spreading mistflower" "Hilo pamakani")

Very frequent in disturbed places, on cliffs, and open lava in wet areas. (F & M 581, 405; Eggler 144)

FILAGO GALLICA L. (X)

Found once in Kau Desert. (Eggler 160)

GAILLARDIA PICTA Sweet (X, "gaillardia")

Kilauea area, disturbed places. (M-D H-140)

GALINSOGA PARVIFLORA Cav. (X)

Near Hilina Pali, and Kilauea in weedy places. (F & M 1127; Fagerlund 510; Fosberg 39312)

GERBERA JAMESONII Bolus (X)

Arctotis gumbletonii Hook. of Fagerlund & Mitchell 1948.

Volcano House garden. (F & M 639)

GNAPHALIUM HAWAIIENSE Deg. & Sherff (E, "enaena")

G. luteo-album sensu Hawaiian authors

Ash beds in Kau Desert and around Kilauea. (F & M 61, 301, 168; s. coll. 283; M-D H-326)

GNAPHALIUM JAPONICUM Thunb. (X, "cudweed")

Moderately dry areas, Kilauea and Keanakakoi Craters. (F & M 137, 74)

GNAPHALIUM PURPUREUM L. (X, "purple cudweed")

Common in disturbed and dry, open areas. (Baldwin & Fagerlund 72; F & M 297, 73, 1053; Poinar in 1963)

GNAPHALIUM SANDWICENSE var. KILAUEANUM Deg. & Sherff (E)

G. luteo-album L. sensu some Hawaiian authors

Ash beds. (F & M 773; M-D H-328; Fosberg 42080, 41774; Webster & Wilbur 1794)

HELICHRYSUM BRACTEATUM Andr. (X, "straw flower")

In gardens.

HYPOCHAERIS GLABRA L. (X, "smooth cats-ear")

Rare, Hilina Pali-Kipuka Nene region. (F & M 1018)

HYPOCHAERIS RADICATA L. (X, "gosmore" "spotted cats-ear")

Frequent in open areas from Hilina Pali to upper slopes of Mauna Loa, at least to 9500 feet. (F & M 84, 290, 918; s. coll. 424; Morley 96-H; M-D H-96, H-289, H-308; Poinar in 1963, Eggler 53)

LACTUCA SATIVA L. (X, "lettuce")

In gardens.

LIPOCHAETA SUCCULENTA var. DECURRENS (Gray) Sherff (E, "nene")

Park Headquarters. (F & M 231, 1116; Morley 1-H)

PLUCHEA ODORATA (L.) Cass. (X, "shrubby fleabane")

Frequent from sea-level to Kilauea region, in open and semi-open places. (M-D H-117; F & M 152)

SENECIO MIKANIOIDES Otto (X, "German ivy")

Park residence area. (Olson in 1938; F & M 187)

SENECIO SYLVATICUS L. (X, "groundsel")

Infrequent, in kipukas and on slopes of Mauna Loa at least to 6600 feet. (F & M 686, 614; Fagerlund 519; M-D H-175)

SOLIDAGO ALTISSIMA L. (X, "goldenrod")

Kilauea area, in disturbed places. (F & M 852)

SONCHUS ASPER (L.) Hill (X, "sow thistle")

In Kipuka Puaulu. (2 sheets, s. coll; Lamoureux 2592)

SONCHUS OLERACEUS L. (X, "sow thistle" "yellow pualele")

Occasional in disturbed places. (F & M 361, 349, 245; Morley 98-H)

STOKESIA LAEVIS (Hill) Greene (X, "Stokes aster")

Park residence area. (F & M 625)

TAGETES ERECTA L. (X, "Aztec marigold")

In gardens.

TAGETES PATULA L. (X, "French marigold")

In gardens.

TETRAMOLOPIUM HUMILE (Gray) Hbd. (E)

Rare; at Devil's Throat, 3400 feet. (F & M 42)

TETRAMOLOPIUM HUMILE var. SKOTTSBERGII Sherff (E)

Frequent, 7500 to 9000 feet, on Mauna Loa. (F & M 770; Poinar in 1963; M-D H-316, H-293)

VERNONIA CINEREA var. PARVIFLORA (Bl.) DC. (X, "little ironweed")

Disturbed or open places; Napau Trail in steaming area; lava-tube opening at 450 feet. (s. coll. 282; F & M 374, 204, 145 (part))

XANTHIUM STRUMARIUM L. (X, "kikania" "cocklebur")

X. californicum Greene

At sea level at Halape. (F & M 342)

YOUNGIA JAPONICA (L.) DC. (X)

Crepis japonica L.

In sheltered disturbed places in moist or wet regions. (s. coll. 284; F & M 871)

ZINNIA ELEGANS Jacq. (X, "zinnia")

In gardens.

E- INVERTEBRATES OTHER THAN INSECTS

Some groups of insects, *e.g.*, Drosophilid fruit flies, are very well known for the Park, but insofar as the rest are concerned and the invertebrates in general, only the general information for the State or the Central Pacific can be acknowledged. The generally useful book on marine invertebrates is that by Edmondson (1946), "The Shore and Reef Fauna of Hawaii." It also covers the shelled molluscs and fishes in somewhat less detail than the other volumes mentioned. The bibliography of Edmondson's book includes the principal references to the earlier work on Hawaii, though there is essentially nothing specific on the Park. Perhaps the most useful reference for the marine shelled molluscs for anyone in Hawaii is the extensively illustrated little book by Tinker (1958) which has gone through several printings up through 1963.

F- INSECTS

While the Park has been the site of intensive studies of speciation in insects by Dr. Elmo Hardy's (University of Hawaii) group, there are no publications specifically on the Park's insect fauna. The different volumes of Zimmerman's (1948, etc.) treatise are generally useful for the insects in the Park which belong to those groups published on thus far (*e.g.* see Hardy, 1960). Unfortunately, for our purposes the locations given are too general as a rule for correlating insect distribution with the vegetational areas shown on the photo-overlays. These photo-overlays, the range of climates and the great variety of ground cover should make Hawaii Volcanoes National Park a most desirable area in which to study insect ecology. The benign gall infestation produced by *Trioza hawaiiensis* Crawford (Psyllidae) on the leaves of *Metrosideros* could easily be studied here.

G- VERTEBRATES OTHER THAN BIRDS

It is rather easy to cover the vertebrate fauna of the Park for so little has been done and there are so few vertebrates aside from the avifauna. Thus, leaving the birds until section H, below, the following is but a guide to the work done in the Park or published for the islands. The general works are most eminently W. A. Bryan's (1915) "Natural History of Hawaii" and the introductory volume of Elwood Zimmerman's (1948) "Insects of Hawaii." These do not treat the Park specifically, and actually very little study of the animals other than birds has been either done or published. A survey of the Halape-Kaoi Island area was promoted by the National Park Service in the late 1940's, but no record of the results of this has been found. The marine fishes are splendidly treated in the volume by Gosline & Brock (1960) and especial attention is called to the bibliography in this book on page 4 which includes a number of entries for papers treating the effects of the volcanic eruptions on the island of Hawaii on the fish populations. The chapter on Hawaiian fish ecology and biogeography is a most useful starting place for anyone interested in the fish fauna of the Park. The less expensive book by Tinker (1944) with its many illustrations is similarly useful especially for those who must rely more on the pictures than on the standard ichthyological descriptive methodologies.

The Park's fish fauna is not one depauperized by the island's fishermen as true nearer populated areas. Thus here is an opportunity for the naturalist to view and study fish populations at their best insofar as fishes of the non-coral reef shores are concerned.

Insofar as known there are no naturally occurring fresh water vertebrates in the Park and there are nearly no open or permanent bodies of fresh water in which they could persist. The study of Hawaiian amphibians and reptiles by Oliver & Shaw (1953) is indispensable for these organisms. This study describes the 23 species known to occur in the islands. Thus far nothing published has come to our attention specifically concerning the Park. The green turtle, Chelonia japonica (Thunberg), is commonly seen feeding in Sargassum patches in the sea below the cliffs of the shoreline. While sea snakes are rare finds in the State, none has been found in the Park. The giant neotropical toad, Bufo marinus L., may get into the Park. The small lizards, skinks of the family Scincidae and geckos of the family Gekkonidae, are abundant at least below the frost line. Three of the skinks and three, or possibly four, of the geckos are considered to be Polynesian in origin but only the marine reptiles are indigenous. None of the amphibians or terrestrial reptiles is endemic but the local populations have some minor distinguishing characters.

The domesticated and other animals that travel with man have done great damage in the Park in the past. Some notes on this subject are scattered in the text above. Other notes, including information on the bringing of domesticated animals to the islands, can be found in Degener's book (1930, e.g., p. 13) on the plants of the Park. Baldwin & Fagerlund (1942) published a study on the effects of former cattle populations and their grazing in the Park. See also Lamb, 1938. Perhaps two species of rats, a mouse, the dog and the cat are to be found within the Park borders regularly. Cattle were grazed in the Park formerly. No studies of them have been made there to date. Of the larger mammals, the pigs and goats, studies have been begun.

A 2-year study of the feral animal populations was undertaken by the Division of Fish and Game, State of Hawaii, beginning July 1, 1963. This

2-year study was intended to provide the information that would allow management of the pig, goat, sheep and cattle populations. Inquiries as to the results and on-going activities on this and related projects should be directed either to the Superintendent of Hawaii Volcanoes National Park or to the Director of Research of the state agency. It is understood that only the goat and pig would be studied within the Park as there are no populations of cattle or sheep there now.

H- BIRDS

Park birds are notably of two categories: common imports and the endemic family Drepaniidae. There is a great need for a thorough study of this unique avifauna of the Hawaii Volcanoes National Park from sea level to the higher slopes of Mauna Loa. Not only is the opportunity unusual in there being the climatic and vegetational information available, such as presented in this Atlas, but in there being available for study the interactions between these two bird groups and the special biology and ecology of the drepanids. Furthermore, there apparently does not exist a simple up-to-date check list of all the birds that now exist in this fascinating area. The preparation of any accurate and complete check list is dependent upon a considerable amount of field work by a competent field ornithologist and well-trained biologist.

Moreover, there does not exist any published thorough life history study on any bird species in the Park. Note that Baldwin's paper (1953) is considered to be primarily an ecological study directed in large measure toward the question of evolution of the Hawaiian honeycreepers. Munro's (1960) "Birds of Hawaii" and the attractive, well-illustrated booklet available at Park Headquarters (~~Baldwin~~ Dunmire, 1961) and the pamphlet by Schwartz & Schwartz (1949) on game birds are the most useful publications.

In preparing the preliminary check list of birds of the Park (Table V) largely six sources have been relied upon: Garrett Smathers (April 10, 1963); Garrett Smathers (September 5, 1963); Dunmire (1961); Baldwin (1953); Munro (1960) and Bryan (1958). Lacking at this time is specific information on recent introductions of game birds in or near the Park area by the State Fish & Game Department. Certain species have been included in the check list even though they are presumed by many to be extinct. It is not sure that all of these species are in fact extinct, but only intensive field work will provide the necessary information on their status.

In recent years it has been noticed that certain of the native birds are either extending their range or becoming more restricted in their range. Extensions of range are coordinated largely with the improved accessibility of certain areas in the Park and thus require further study before they can be accepted as real rather than as being merely improved observation. The nene, or Hawaiian goose, is a different sort of situation and is certainly a reliable case where there is a real increase in number. Restrictions of range are coordinate with increased frequency of records of competitors and are, unfortunately, perhaps on better grounds.

Dunmire's book (1961) is very good as far as it goes. The book was written for the tourist and general public rather than as a scientific study of the birds of the Park, and it includes the National Park on Maui. It is, however, a good beginning, excellent for all but those whose interest in the birds is strictly professional. It is felt that Dunmire would be the first to agree that a more detailed study should be prepared, especially one replete with information on the honeycreepers. The information on honeycreepers was intensified by the resumes (Smathers, April 10, 1963, and September 5, 1963) prepared as preliminary steps in this direction.

Table V. Preliminary check list of the birds of Hawaii Volcanoes National Park, 1965.

Acridotheres tristis (Mynah)*

Alauda arvensis (Skylark)*

Alectoris graeca (Chukar)*

Anas acuta (? Pintail Duck)

Anous tenuirostris (White-capped Noddy)

Arenaria interpres (Ruddy Turnstone)

Asio fammeus (Pueo or Short-eared Owl)

Branta sandvicensis (Nene)

Buteo solitarius (Hawaiian Hawk or Io)

Carpodacus mexicanus (House Finch)*

Chasiempis sandwichensis (Elepaio)

Ciridops anna (? Ula-ai-hawane)

Crocethia alba (Sanderling)

Drepanis pacifica (? Mamo)

Fregata minor (? Frigate bird)

Fulica americana (? Coot)

Gallinula chloropus (? Gallinule)

Garrulax canorum (="Trochalopterum") (Chinese Thrush)*

Geopelia striata (Barred Dove)*

Hemignathous wilsoni (Akiapolaau)

Heteroscelus incanum (Wandering Tattler)

Himatione sanguinea (Apapane)

Leiothrix lutea (Red-billed Leiothrix)*

Lophortyx californicus (California Quail)*

Loxops coccinea (Akepa)

Loxops maculata (Hawaii Creeper)

Loxops virens (Amakihi)

Meleagris gallopavo (Turkey)*

Mimus polyglottos (Mockingbird)*

Moho nobilis (? Moho, also called Hawaiian OO)

Munia nisaria (Ricebird)*

Nycticorax nycticorax (? Black-crowned Night Heron)

Passer domesticus (House Sparrow)*

Phaeornis obscurus (Hawaiian Thrus

Phaethon lepturus (White-tailed Tropic bird)

Phasianus colchicus torquatus (Ring-necked Pheasant)*

Phasianus versicolor (Japanese Blue Pheasant)*

Pluvialis dominica (American Golde Plover)

Psittacirostra psittacea (Ou)

Pterodroma phaeopygia (Dark-rumped

Richmondena cardinalis (American C

Spatula clypeata (? Shoveller)

Streptopelia chinensis (Spotted Do

Vestiaria coccinea (Iiwi)

Zosterops palpebrosus (White-eye)*

/ Those marked with an asterisk, "", are introduced species.

Smathers' literature resumes are solid contributions toward a better understanding of the birds in the Park. They form most of what is said below in respect to the nene and the honeycreepers.

Since the advent of the white man over a hundred birds have been introduced to Hawaii. These varieties have come from all over the world, and they have shown varying degrees of establishment. The introduced types have had an undesirable effect on native birds, especially the highly specialized Drepaniidae. Within the time mentioned above, three endemic forms have become extinct (or at least are thought to be extinct) and probably there are others; namely, the mamo (Drepanis pacifica), oo (Moho nobilis), which is not a drepanid, and moho (Pennula sandvicensis)—not a drepanid either.

The Hawaiian Islands offer an excellent opportunity to study an endemic avifauna. At the present time there are over 70 species of birds found nowhere else in the world. These include rare endemic forms such as the hawk, crow, goose, thrush, and flycatcher.

While they were mentioned, and in some instances given considerable attention by early travelers, naturalists, and ornithologists, the honeycreepers never received, except in a few studies, the attention they deserve and need.

Most ornithologists, conservationists, and naturalists agree that the Hawaiian honeycreepers (Drepaniidae) are on a decline. As to what biological or physical factors have contributed to the decline, scientists are not in complete accord. To one thing they do agree, more research studies must be done on Drepaniidae before additional species become extinct. Past and present investigations of this interesting family of birds have opened many new facets for future study. For example, a student interested in avifauna evolution will find that the drepanids offer a superb example of adaptive radiation.

It is not known how long the drepanids have been in the Hawaiian Islands. Their rate of evolution still remains unsolved. Evolutionists find it most difficult to show how divergent Drepaniidae is with its pre-drepanid prototype. Often, in trying to construct an evolving pattern, the student is conscious of many intermediate and unsuccessful groups that have "died-out", not leaving a trace. However, most authorities concur that Drepaniidae arose from the American nine-primaried passerines and possibly from a tanager-like ancestor (Thraupidae).

The most recent and important (directed research) studies and investigations of the drepanids have been made by Baldwin (1953), Amadon (1950), and Dunmire (1962). Basically, their contributions are in distribution, evolution, behavioral factors, and ecology of the honeycreepers. They have drawn upon the works of Perkins, Henshaw, Munro, and others in the correlation of their findings and observations. Their studies give us a greater knowledge of the honeycreeper and also upon the subject for further research in the origin, distribution, and ecology of Drepaniidae. The works are quite representative of basic and directed research. Also, their bibliographies are a good source for those interested in further inquiry into the subject. With this understanding, it is thought that a review and evaluation of their works should be representative of studies and investigations made of the honeycreepers. It is further concluded that these works could act as starting points for those interested in doing future studies of the Drepaniidae.

Baldwin (1953), knew the Drepaniidae problem very well. He lived and worked in Hawaii Volcanoes National Park for several years, and during this time he conducted many field studies of the Hawaiian forest avifauna. Baldwin's aim was to gain new knowledge of the honeycreepers' ecology which would contribute to a better understanding of their evolution as an insular group. He investigated their behavioral and reproductive cycles to ascertain how these factors enabled the birds to live together in their environment. Special attention was given to time events of annual cycles and seasonal march of environmental phenomena. In the use of seasonal data on climate, flowering cycles of plants, and occurrences of insects, he was able to compare adaptations possessed and ecologic niches occupied by several species. Baldwin's work and investigations were restricted to three kinds of drepanids:

1. Vestiaria coccinea - iiwi
2. Himatione sanguinea - apapane
3. Loxops virens - amakihi

These forms have a resemblance to each other in food habits. All depend upon nectar and insects; however, they exhibit differences in other environmental relations and behavior.

The environmental studies made by Baldwin (1953) were conducted on the island of Hawaii, and most of them in Hawaii Volcanoes National Park on the flanks of Kilauea and Mauna Loa volcanoes. A transect was developed from a minimum elevation of 2300 feet to the maximum elevation of 7500 feet. It was 20 miles long and consisted of a series of 12 stations located at intervals along its entire length.

Survey of the Environment

A description of the vegetation in respect to the avifauna is given here with notes on the plant formations and the dominant species. A table of physical characteristics of the field plots gives a quick reference to data collected on physiographic and climatic factors but, it is to be noted, the vegetational information is not always in agreement with the current study (see Chapter VII on vegetations). The avifauna are represented in the following vegetation types:

1. The dry Metrosideros—Sophora forest—occupies all of the transect lying between 2000 to 2300 feet, and parts up to 4000 feet. Changes in avifauna were found to correlate with development of vegetation. The young or developing vegetation offers a variety of food and nesting sites for insect-eaters, nectar-feeders, and seed-eaters (*Loxops virens*, *Himatione*, *Zosterops*, *Munia*, and *Streptopelia*).

2. The wet Metrosideros & tree-fern forest or mountain forest—appears in the transect from 2600 to 4000 feet. This formation shows a lower bird population than the transitional; however, the number of passerine species is important. This group was found to make up the greater part of the population present. At one station on the transect, near Napau Crater, the rare *Psittirostra psittacea* has been observed recently by Smathers.

From observations competition for food was found to vary among various forest species. A pattern of vertical distribution was maintained in their foraging activities, thus showing the following niches:

(a) *Vestiaria* and *Himatione* consume both nectar and insects and inhabit the same forest level (zone).

(b) *Loxops virens* ascneds into *Vèstiaria's* and *Himatione's* zone consuming insects and nectar, thus ecologically overlapping with them. But most of its foraging activities are in a lower zone.

(c) *Loxops maculata* occupies about the same vertical range as *Loxops virens* and also feeds upon about the same type of insects. However, *L. maculata* searches the twigs, larger branches, and trunks, whereas *L. virens* hunts for insects in the foliage and twigs.

(d) Chasiempis overlaps vertically with Loxops, but obtains its food by darting after moths and other insects in flight.

3. Acacia Parkland occupied points along the transect form 4200 to 6800 feet. Five species of drepanids were observed, and in one area where Acacia koa was associated with other trees a sixth species, Loxops coccinea, was present. Their distribution exhibits a pattern correlated with vegetational serals. The drepanid population was densest at the edge of a kipuka rather than in the interior. The greater variety and complexity of vegetation in a kipuka edge must contribute to this distribution.

4. Metrosideros-Styphelia sub-alpine shrub occupies the position from 7000 to 7500 feet. Himatione and Loxops virens, were found to be scattered throughout the association. Six avifauna species were observed and, in general, they resembled an early seral of the dry Metrosideros-Sophora association.

Avifauna and Weather along the Transect

Climatic phenomena in reference to the avifauna are manifested in the transect from low to high elevation, corresponded to physiographic factors and prevailing winds. See Chapters III and IV on, respectively, weather and climate for our current understanding of these phenomena within the Park. Weather stations on the lee side of Kilauea and Mauna Loa recorded less rainfall than those on the windward side. This correlation prevailed where the trade winds lost elevation on the drier leeward side.

A very interesting aspect of the weather data is presented by inspecting air temperatures along the transect. Air temperatures at the upper station (Kau transect) exhibited wide temperature extremes. At 7500 feet air temperature reached an equilibrium around 76 degrees F, but at 5500 feet it rose to 94 degrees F. While one may hypothesize that such an irregularity is attributed to the relatively still air trapped within protected groves of trees at 5500 feet, as compared to the more freely flowing air on the relatively open, shrubby lava fields at 7500 feet, this explanation remains to be established. Such a climatic manifestation would be of great significance in an approach to the study of ecotypes. It is also apparent that such wide ranges in temperature and precipitation appearing in such narrow microclimatic geographic limits merits a thorough investigation of meteorological conditions. The weather phenomena recorded to date will not permit this.

Flower and Nectareous Food for Birds

The periods of flowering of *Sophora* and *Metrosideros* determine the birds' locations throughout the year. Observations along the transect showed seasonal blooming. However, both *Sophora* and *Metrosideros* produce some blooms throughout the year at all elevations in their range. For the statistically minded, very interesting correlation curves can be developed from the phytogeographic data. One of the outstanding significances of the data was a definite altitudinal progression at the onset of flowering. For example, the duration of flowering periods apparently increases with rise in elevation; however, this situation is correlated inversely with the drop in air temperature. There was no correlation with rainfall found.

Though Perkins (1913) contended that *Lobelia* was a major source of nectar for the honeycreepers, Baldwin did not see one lobeloid visited by a *Vestiaria* or any other drepanid. Perkins thought that the lobeloid-drepanid's relationship was so ecologically bound that the pollination of the tubular flowers could only take place through the action of these birds.

The question may be, did drepanids change their habits of gathering nectar from the lobeloids to that of Metrosideros? Some botanists theorize that lobeloids preceded Metrosideros in Hawaii. When Metrosideros arrived at a later date and became the dominant forest tree, it offered a new and more available source of food, thus increasing the population of Drepaniidae.

Insects

The methods, periods of collection, and the quantitative aspects of the data might be seriously questioned by the entomologist. However, a tremendous amount of reliable data was assembled, and its broad application can be determined from the following:

1. In some instances large numbers of exotic insects are utilized by honeycreepers.
2. Insects are available (for food) in quantity throughout the year.
3. The drepanids mostly eat small, soft-bodied insects; such as, spiders, psocoids, psyllids, scales, leafhoppers, and lepidopterous larvae. Baldwin (1953) gives a list of the ecological characteristics of each species studied. This list shows the niche occupied by each species and how it differs with that of every other form. Though some of the niches overlap, they are ecologically segregated and compatible. All three drepanids studied eat nectar and insects and occupy the same habitat. Yet, their minor differences in morphology (bill structure, body size) and behavior (types of food taken, manner of feeding, etc.) result in different utilization of environment materials.

Physiological Cycles

Using tables, graphs, and other graphic media, Baldwin (1953) did an excellent job of reporting and evaluating his data, something that is to be greatly appreciated by successive students of Park birds.

Molt cycle:

1. Annual molt occurs between June and November.
2. Post-juvenile molt lasts longer than second and latter molts.

At this time, it is of significance to point out that the drepanid's slow fall-molt contrasts sharply with the rapid fall-molts in some northern passerine birds.

Skull development: Some authorities contend that the development of the skull is an indicator of age.

1. From collected specimens, it appears that the skull does not undergo double layering until 6 months after leaving the nest.
2. The majority of individuals develop double layering during post-juvenile-molt.

Baldwin believes the stimulus responsible for molt might be related to skull development. However, it appears reasonable to assume that any two such dynamic forces of development must be correlated to insure an equilibrium in glandular functions. Molt is a physiological activity, and it makes great demands upon the body's energy supply. Shouldn't there be some means of retarding one physiological activity while another is expedited? It appears that we need to know much more about the honey-creeper's physiological functions.

Reproductive Cycle: Sufficient information is given to establish the reproductive period. However, it does not cover all phases of the reproductive cycle. Baldwin's (1953) general observations were as follows:

1. Enlargement of testes of old adult males begins in October, younger members not until February.

2. Nesting occurs between January and July.

3. Post-breeding dispersal begins in late summer; the population spreads over the forest.

Populations and Their Movements

A very interesting picture of drepanid distribution was revealed by Baldwin's (1953) study.

1. Loxops virens and Himatione sanguinea were found throughout the transect.

2. Vestiaria was restricted to forests of the middle elevation and parkland above.

This distribution could indicate that Loxops and Himatione can tolerate a greater range of habitats than Vestiaria. Even though Vestiaria is found in other geographic areas of Hawaii, there must be present in the habitat certain biotic or physical factors. These limiting factors must be determined by additional investigations.

3. After post-breeding dispersal, Himatione and Vestiaria move in large numbers over the forests, following the flowering of trees.

4. Vestiaria chooses the flowers of both Sophora and Metrosideros. It showed a greater propensity for Sophora than Himatione did, and also a lesser response to Metrosideros.

5. Hiratione and Vestiaria (strong fliers) show a high dispersal rate: i.e., they show no sub-speciation from one island to another. However, some other bird species, probably the weak fliers with low dispersal rates, exhibit racial forms from island to island.

The climatic manifestations, combined with complexity of physiography and possible isolation through volcanic activity, could account for low dispersal of many types of Hawaiian plants and animals. It is reasonable to assume that isolated bird colonies could readily be established on mountain heights. Baldwin cites an interesting example of genetic isolation among the finch-billed species, Psittrostra bailleni, located on Mauna Kea. In Hawaii, however, it has never been established that mountain-top isolated colonies have been accompanied by genetic divergence to the sub-specific or specific level.

Environmental Processes and Their Selective Forces

The phenomena of climate throughout the transect were investigated by Baldwinto a limited degree, and its effect upon the bird life might best be represented now as:

1. Slight seasonal change of climate results in relative constancy of conditions in habitat, thus causing a minor need for seasonal bird movements.
2. Climatic gradients have produced markedly different habitats.
3. Climatic factors may limit the distribution of Vestiaria. However, since birds are mobile creatures, they may be largely affected through other habitat conditions more so than directly by climate.
4. Storms may strike at any time during the lengthy breeding period. At the time of this review (April 13, 1963) a great rainstorm is occurring and the total rainfall may break all records for the month of April. Its effect upon the Drepaniidae may be reflected by a decrease in next year's population density. Several Himatione and Vestiaria have been reported in the coastal areas of the Park—probably escaping the wrath of the storm.

Cataclysmic Factors

Either man or naturally caused cataclysmic factors can eliminate or drastically affect the habitat, the organism, or both. The Hawaiian birds have been subjected to the following:

1. Torrential storms, floods, volcanic activity, and forest fires.
2. Forest removal (lumbering), selective cutting of forests, grazing of cattle, goat- and sheep-hunting, and the introduction of exotic plants and animals, including foreign birds that have become abundant in the forests.

Evolution

The honeycreepers' ecology, which at present is not well understood, may provide some understanding of their evolution; *i.e.*, the functioning of natural selection and adaptive radiation. Essentially we can deduce:

1. Neighboring islands provided isolated areas for the establishment of different colonies of any species, which in time may produce hereditary differences.
2. The dispersal of genetically modified individuals back to the original colony or to a third colony could result in hybridization.
3. Should reproductive incompatibility develop, then a sympatric species could have been produced.

Baldwin (1953) poses the question, "Is all radiation adaptive?" In a manner he contends that too often the error of grouping non-adaptive traits with adaptive is found. It would seem reasonable to consider the two occurring together, and in time, through fixation, non-adaptive traits could represent permanent traits. Consider the following:

1. Wide divergence in plumage color does not show a relationship to food gathering or protection from predators.

2. Coloration could prove to be important for species or sex recognition. And yet, the outstanding divergence of color (Vestiaria and Loxops) may be difficult to explain by this hypothesis. This particular problem is but one among the many others connected with drepanid evolution.

3. Nectar and insect eating are traits that presumably existed in the immediate ancestry of the drepanids. This is substantiated by Himatione and Loxops virens now possessing these eating habits, and other birds in both sub-families having tubular tongues with fringed tips.

Amadon first (1950) became interested in the Drepaniidae while arranging and combining the specimens of this family in the Rothschild Collection for the American Museum of Natural History. Part of his military assignment was spent in Hawaii where he had the opportunity to study many of the drepanids in their natural environment. Part of this time was spent under the capable guidance of Dr. Paul Baldwin, then of Hawaii National Park (now= Hawaii Volcanoes National Park).

At one time the Drepaniidae were scattered (systematically) among several families. Different taxonomic entities were often placed among the finches, flower-peckers, and Austrailian honeyeaters. The present classification is:

Order: Passeriformes (perching birds)

Sub-order: Passeres

Family: Drepaniidae (Hawaiian honeycreepers)

The family Drepaniidae has been further divided into the sub-families Drepaniinae and Psittirostrinae.

With the use of tables, which are quite comprehensive, Amadon (1950) gives mean and coefficients of variations of certain structures. The males of Drepaniidae exceed females in size. However, the degree of sexual size dimorphism in different species is not constant.

Geographic size variation within species, if given sufficient measurements, would probably show that the members of every isolated population of the Drepaniidae differs at least slightly.

Even though statistical analysis tends to open many avenues for further investigations, the reliability of some phases of the statistics is questionable. Amadon is quick to point out this possibility. A very interesting phase of morphological investigation is presented since it was determined that the ratio of culmen to wing in Hemingnathus procerus varied from 0.61 to 0.75. The great size of the bill, relative to the bird's body, does not appear to be an adaptive response.

Molts of immatures and adults reveal the color of the better known adult members of Drepaniidae to be very much unlike that of the immatures. In the sub-family Psittirostrinae, there is usually less difference in the adult and immature plumage. In regard to molt of adults, it was found that they molted once each year. Molt starts with a drepanid once it is freed from the nest, if not before. The molt of these juveniles may be so protracted that birds in partially immature plumage breed. While this work is a good source for molting data of all honeycreepers, Baldwin's study (1953) is more contemporary for Vestiaria, Himatione, and Loxops.

Color, color patterns, and sexual dimorphism in color is of no great contrast in most drepanids. The known genera, both male and female, have brightly colored plumage. However, the colors may vary sharply with some members. For example, the female Loxops maculata flammea is brown, while the male is scarlet.

The phylogenetic trends in coloration investigated brought out the following interesting points:

1. *Himatione sanguinea* is the least specialized in color of the drepanid species.
2. Red coloration seems to be basic in the family since it also appears in the sub-family, Psittirostrinae (*Loxops maculata flammea* and three races of *Loxops coccinea*).
3. The orange wash that is occasionally present in male *Loxops virens* could possibly be a throwback to an ancestral type with orange plumage.
4. In Drepaniidae there is a phylogenetic trend toward an increase in black coloration. *Himatione* and *Vestiaria* exhibit black in their wings and tail, while in *Drepanis funerea* the entire plumage is black.

Song, Nesting, and Locomotion

The division of the Drepaniidae into two sub-families (Drepaniinae and Psittirostinae) correlates with a difference in songs and call notes. Ward (1964) provides the results of a recent study of apapane (*Himatione*) utterances.

The author attributes the truncated primanes of *Himatione* and *Vestiaria* as instruments of behavioral significance. These structural conditions produce a whirring sound while the bird is in flight and possibly is used in courtship or keeping the flock together.

Parasites, Diseases, Predation, Destruction of Forests, and Extinction

Amadon draws extensively upon the works of Baldwin and Perkins in this phase of his investigations. It is quite evident that introduced parasites and diseases are among the greatest dangers threatening the honeycreepers. The introduction of numerous game and other type birds has been a constant source of parasites and diseases. While the introduced species may physiologically tolerate these organisms (some may be endemic), the honeycreepers may be drastically affected. Here is certainly one phase of drepanid ecology that needs further study. In brief, the following parasites and diseases were found in the investigation:

Parasites:

Mallophaga (bird lice)—Perkins believes some to be endemic to the Drepaniidae.

Hippoboscidae (flies)—Non-endemic species found on *Vestiaria* and *Loxops virens*.

Cestode—Baldwin found tapeworms in *Loxops virens*, *Himatione*, and *Vestiaria*. It was not determined whether this parasite had been introduced.

Diseases:

Bumblefoot or Bird Pox—It is not known whether this disease was present in Hawaii before the introduction of foreign birds. Honeycreepers have been subject to the disease for a long time. The disease appears to prevail among birds in the rain forest, and outside this area most birds are free of it. Some reports tend to link the disease, a fungoid growth, with domestic chickens. However, this condition has never been linked with the extermination of Hawaiian birds.

Avian Malaria—Although malaria has not been demonstrated in the Drepaniidae, the honeycreepers are probably infected with it. In 1941 Baldwin found two species of bird malaria in introduced birds in the Park.

Predation: Several predators may be linked with the honeycreepers, but none appears to have been as effective as man. It appears that the Hawaiian hawk and short-eared owl have no great predatory effect on these birds. Since the drepanids are not ground-dwelling birds, it is highly questionable whether the mongoose or feral cats have attributed greatly to their decline.

The early Hawaiians often caught these birds and plucked their feathers for use in making feather capes and leis. The birds were later released unharmed. This benign conservational practice ended when firearms were introduced to expedite the feather traffic. Some authorities contend that Moho nobilis may have been wiped out on Hawaii by shooting.

Destruction of Forests: The wide removal of native forests in fostering agriculture has undoubtedly had an adverse effect on the honeycreepers. The introduction of pigs, sheep, goats, and cattle has, in some areas, had a devastating effect upon the population. Drepanids are quite sensitive to habitat changes, and in some woodland areas, where cattle have been introduced, the drepanids have disappeared.

Extinction: In regard to extinction, a list is given of the geographic locations of those honeycreepers that are now extinct. However, it is readily pointed out that the present studies (Amadon, 1950) of distribution and population density are not complete and need further attention. When one becomes conscious of the numerous unexplored areas, especially on Hawaii, where remnant species could find suitable habitats, it is not wholly unreasonable to assume that some species reported as extinct are still in existence. To bear this out Baldwin rediscovered Palmeria dolei on Maui.

Comparative Anatomy

Insufficient material and field work limited Amadon's (1950) study of anatomy from the phylogenetic standpoint. The most interesting observations were:

1. Drepanids are not related to old-world, nectar-eating birds but apparently their ancestors came from America.
2. The closest relatives of the Hawaiian honeycreepers are in the group of nine primaried song birds which are mostly American. The Parulidae (wood-warblers), Coerebidae (South American honeycreepers), and Thraupidae (tangers) intergrade and are no more than sub-families.

The tenth primary of the Drepaniidae is vestigal. This is one part of its structure connecting it with the American group of nine-primaried song birds.

Phylogeny of the Genera and the Family

By consulting the meager published information, in comparing the Drepaniidae's anatomy with closely related families and the analysis of their findings coordinated with his interpretation, Amadon (1950) concludes that primitive drepanids were perhaps most like some of the Coerebidae, but the latter may be only thin-billed Thraupidae and many taxonomists no longer recognize the family Coerbidae. Amadon further contends that the anatomical characters involved are so slight and inconsistent that thin-billed American groups of nine-primaried song birds, such as Parulidae or Icteridae, cannot be ruled out. To make his phylogenic explanation more explicit, he gives a good diagram of the phylogeny of the genera of Drepaniidae.

Realizing the problems that face taxonomists and to support his reduction of Drepaniidae and related families to sub-family status, Amadon admonishes comparative anatomists as follows: "Comparative anatomists who suggest combining all song birds into two or three families, without at the time providing an improved arrangement for the numerous sub-families and tribes that must be recognized in such families, accomplish very little."

Speciation

It is suggested that the differences in degree of sub-speciation may be the result of differences in power of dispersal and that such an explanation should be sought before invoking variation in mutation rates or other hypothetical explanations.

The author believes the diversification and speciation of some Hawaiian birds, such as the hawk (a strong flyer), nene goose, and drepanids like Psittirostra psittacea and Loxops coccinea can be the result of physiographic factors. All of the above are found on the island of Hawaii (some species are found only on this island) which provides numerous habitats. The other islands, with the exception of Maui, do not afford the suitable habitats for these animals. Topographic features (e.g., high volcanoes) allow competing sympatric species to occupy specialized or restricted ecological niches. This environmental condition may explain why five species of Psittirostra have survived on Hawaii, but no more than two on any of the other islands.

Geologists are not always in agreement as to the age of the Hawaiian Islands—especially the major eight. However, so far as speciation is concerned, the time factor presents no major problem. There is considerable evidence that speciation can progress quite rapidly under insular conditions. Though, while some data indicate adaptive radiation in the Drepaniidae has progressed quite rapidly, it is difficult to believe that the history of the honeycreepers did not begin in the early Pliocene or before.

The Hawaiian honeycreepers have often been referred to as the epitome of adaptive radiation. Since this radiation has occurred only recently, this family affords excellent material for the investigation of early phases of evolution.

In Hawaii the adaptive radiation has been expedited by:

1. Numerous empty ecological niches.
2. Lack of competition.
3. The availability of a variety of suitable environmental niches.
4. Lack of heavy predation or parasitism.

The occuping of available niches has produced a harmonic fauna. In many instances continental types have arisen; such as, creepers, woodpeckers, finches, and tanagers.

A very important study, reported by William W. Dunmire appeared in The Elepaio 22(9): 65-70. This 1962 publication of the Hawaii Audubon Society supplements in part some of Baldwin's investigations on the ecology of the Drepaniidae. Dunmire, a Park Naturalist at Hawaii Volcanoes National Park, started visiting in the fall of 1958 most of Baldwin's study plots. During the period of May 1959 through December 1961 he made formal censuses. His investigations show quite clearly that some very important changes have taken place in the Park in the past 12 years.

Dunmire's work is very easily reviewed, and the data are easily deciphered. Tables are arranged for the seven geographic areas studied, with the dominant vegetative associations listed. For each area Dunmire lists the number of birds seen and the approximate percentages.

Accompanying each table is a brief discussion and evaluation comparing Baldwin's findings with those of his own. For example, one of his tables is:

Kipuka Nene, elevation 3,000 feet
(Upland Scrub Forest—Transitional Dry Forest)
4 trips (6¼ hours: May 1/59; April, July '60 Nov. '61)

Species	Number	Percent
California quail	1	1*
Mynah	6	3
White-eye	93	40
Amakihi	13	6
Apapane	5	2
Cardinal	1	1*
House finch	107	46

*less than 1%

The population structure has been greatly modified in recent years by the explosive increase of exotic white-eyes (Zosterops) feeding in this kipuka... Whereas Baldwin recorded these birds on only some of his trips, today they are ubiquitous. The large number of house finches in the above table is accounted for by the recording of some huge flocks feeding in the grassy flats during one trip. But white-eyes were observed at a rate of at least 10 per hour on every trip, and they were found throughout the kipukas. Dunmire (1962) judged that there had been a decrease of amakihis since Baldwin's studies, and the elepaio, which were often seen here by him, have apparently left the area. It seems likely that direct competition from the white-eye, a bird with congeneric eating habits, has reduced the one species and eliminated the other from Kipuka Nene. Only 4% of the bird sightings were of native birds!

It is interesting to note that in the remaining six areas investigated the white-eye (Zosterops) has showed a sharp increase or retained a dominant position in the community. At some stations the ou and Hawaiian creeper were not found, though they had been recorded at these stations by Baldwin. The competition for food (insects) between the white-eye and Hawaiian creeper could help account for the latter's disappearance. However, not the ou since it is a fruit eater. Again, in Kipuka Puaulu, Dunmire (1962) points out the disappearance of three drepanids since Baldwin's observations; namely amakihi, Hawaiian creeper, and akiapolaau, and at the same time the great increase of white-eyes. Dunmire contends that this negative correlation is probably attributable to food competition.

Again, it is interesting to compare the foraging of the three species. The amakihi takes insects from the habitat pretty much in the same locations that white-eyes take theirs (tree trunks, limbs, twigs, etc.), thus their ecology overlaps and a high degree of competition could exist. However, the foraging activities of the Hawaiian creeper (Hemignathus wilsoni) does not seem at least in this writer's opinion, to conflict greatly with white-eye (Zosterous palpebrosus) gleaning methods. Hemignathus wilsoni gathers insects somewhat in a woodpecker action by beating on bark and wood. The ornithologist, George C. Munro, describes the method of food gathering of the Maui species (Hemignathus lucidus offinis) as follows: "It drives the lower mandible into the crevices of the bark . . . uses it as a lever. The piece which breaks off (bark) it takes with both mandibles and throws off, sweeping the long upper one into the crevices opened on the branch." Assuming that there are numerous micro-habitats for insects and their larvae in the bark and crevices, and the gleaning activities of Zosterops leaves these inhabitants untouched, it follows that the two birds' ecology does not seriously appear to overlap.

It is possible, as Dunmire has pointed out, that there may be other unassessed deleterious factors involved, other than the increased competition by more versatile exotic forms. It is on this little understood phase of the Drepaniidae that directed research is sorely needed.

The Hawaiian Goose, Nene

The decline of the nene (Hawaiian Goose), Branta sandwicensis, has caused considerable concern among conservationists. In the past, there have been periods when the nene nearly passed into extinction.

Through the concerted efforts of ornithologists, conservationists, and those other people having a keen interest in protecting and propagating the species, the nene has been able to survive. Today, the animal is by no means on safe ground, however, its future is much brighter than at anytime since the initial decline.

As of March 1963, the nene population on the island of Hawaii was listed as 114 birds. This total number represented 87 pen-reared Branta released into the wild, and an estimated wild population of 27 birds. Their present geographic distribution is from 5000 to 8000 feet on the eastern flank of Mauna Loa. The population tends to stay within this elevational limit the year around. In 1962, 35 pen-reared birds from England were released in Haleakala National Park in an effort to re-establish the nene on Maui.

The history of the nene, prior to white man's appearance in Hawaii, and since that time, is both interesting and pathetic. While a few naturalists, scientists, and organizations were very conscious of the declining Branta population—and many of these people made their views publicly—the majority of Hawaiians and government officials took little or no heed of the situation.

It is the major purpose of this report to list, review, and evaluate the work of these people. In doing so, a diligent effort has been made to compile all historic and contemporary information with the research information available.

Henshaw (1902) gives a fair description of the Branta habitat and some minor observations of ecological significance. His greatest contribution to nene conservation was pointing out population distributions that were being severly affected by man's presence. The lowland habitat was principally below 1200 feet, on barren lava flows near the sea, in the districts of Puna, Kona, Kau, and Kohala. These areas prior to the 19th century, and since then, contain most of the human habitations. He believed the nene migrated to the lower elevations in early fall for the nesting period, and he pointed out, that this nesting period conflicted with the contemporary hunting laws. Hunting was permitted from September 15th to February 1st.

Henshaw's general comments (1902) about predators, seasonal flights, and game laws, should have stimulated responsible people in undertaking measures to protect the nene. Mongooses, cats, and dogs were listed as deadly predators.

Miller (1937) produced an excellent study comparing the anatomy of the nene with that of the several other species named below. A good description is given of the Branta terrestrial habit in regard to the muscular and skeletal development. Contrasted with other species of Branta, the legs of Branta sandwicensis swing freely, the body lacks side to side motion and the toes freed by the reduction of webbing are flexible. All of these add to the animal's ability to climb, jump, and run through brush and among the broken rock, and grass tussocks.

The following species were used for comparison by Miller (1937). They are all primarily North American, breeding in far northern latitudes and, except for Philacte, migrating extensively:

1. Philacte canagica—probably most maritime of the geese.
2. Branta nigricans—with both terrestrial and marine habits.
3. Branta canadensis minima—primarily terrestrial, a strong flier and appearing to walk with greater ease than other races of Branta canadensis.
4. Anser albifrons albifrons—breeds in grassy sandy places in flat terrain close to water.
5. Chen hyperborea hyperborea—primarily terrestrial in habit.

In comparing muscles (bulk, weight, and linear measurements), muscle functions, skeletal and external characteristics, Branta sandwicensis and Branta canadensis were found to be positively correlated.

A very interesting phase of the study, and certainly one to bring about controversy, is concerned with comparing the anatomy of a juvenile (B. sandwicensis) with an adult. In the juvenile three large hind limb muscles show great extremes. Juveniles have a higher percentage of total leg muscle bulk, which are involved in power movements of running. Miller doesn't believe this is indicative of the phylogeny of the Hawaiian Goose, leading back to an even more perfectly land-dwelling type; but some anatomists and evolutionists might disagree.

Miller's work (1937) points out the need for further study in the evolution of the nene—emphasizing:

1. The web of B. sandwicensis is greatly reduced. No one has satisfactorily explained this evolutionery change. Have the toes become elongated or has the web been reduced because of

disuse? The reduction of web or extension of toes would have a decided advantage for the animal living on lava i.e. walking, climbing, and injuries to web.

2. Further evidence is needed for the assumption that Branta sandwicensis early diverged from the holartic genus Branta. We can't generalize by saying that Branta is a powerful flier; as could have been the ancestoral form arriving in Hawaii thousands of years ago.
3. We need to establish better the probable routes traveled by the ancestors, and the approximate time they arrived in the islands.
4. Some justification as to why the nene has forsaken water and flight to live on barren lava.
5. Can the evolutionary change in the Hawaiian Goose be traced to selection, amphimixis, geographic isolation, environment, or orthogensis?

Baldwin (1945) accomplishes two very important advancements in nene study: First—he gives a good description, with use of maps, of the nene's distribution prior to 1900 and after 1900. This information helps one to see the overall picture of geographic shifts in population density. He estimates the nene population in the 1700's to be about 25,000 and the population, at time of his study, to be 50 birds. Secondly—his work points out the sharp decline in the nene population and in some instances makes an effort to correlate it with periods of adverse elements.

Like Henshaw (1902) and others, Baldwin (1945) attributes the decline directly or indirectly to man as follows:

Direct

1. Hunting with firearms.

2. Sandalwood gathering in the uplands.

3. Ranching developments and activities.

Indirect

1. Introduced animals such as rats, goats, sheep, cattle, pigs (new stock), dogs, cats, mongooses, game birds, and such plants as the pasture weeds and grasses.

It is interesting to note, at this point, that Baldwin appears to condemn most or all pasture weeds. Sonchus oleraceous, an exotic plant, is relished highly by the nene fide (Henshaw), and at present, is considered an important food factor in Branta's ecology.

At the time of Smith's (1952) report, the world's population of nene was as follows: 24 captives, 33 (estimated) wild. He gives a brief introduction to the three projects currently underway to extend the life of the species. These were:

1. A nene farm started in 1949 by the Board of Commissioner of Agriculture and Forestry.

2. A similar venture (like the nene farm) by the Severn Wildfowl Trust at Slimbridge, England.

3. A nene flock maintained by Mr. Herbert Shipman at Keaau, Hawaii.

Each of these projects plans to rear nene in captivity, and to provide a source for building up the wild population. While this is a very important step to restoring the nene, we still need to understand the animal's ecology, so that wild populations can be protected and assisted in propagation.

An interesting report is made of the life history of the captive nene. Some observations do not concur with earlier studies, i.e., breeding and nesting season. He states they (nene) begin breeding in November.

He sets forth, in three parts, a sound and well organized plan for a nene conservation program:

1. An intensive ecological survey of the Hawaiian Goose found in the wild. This involves: direction of flight, time of flight, and flight distance; finding out what the nene are doing in places where sighted (foods, predation, behavior, etc.); and other environmental conditions (substrata, weather, etc.).
2. The production on nene under wire by methods, through which the production potential of the geese would be nearly realized, by protection and stimulation of maximum egg production.
3. The acquisition, management, and restocking of an area of nene habitat selected as a result of ecological survey.

The study by Elder & Woodside (1955) appears to be the first directed toward the nene's ecology. In a manner it fulfills an integral part of Smith's (1952) recommended conservation program. The study extended from September 1956 to September 1957, and was directed primarily to learn whether modern management could save the nene. The program of study was defined around the following objectives:

1. Learn present status of the species in the wild.
2. To discover essential facts in the biology of the wild population.
3. To prepare practical management suggestions.
4. To appraise the efforts being made by the Board and the Wildfowl Trust in England to rear nene in captivity.

By methodically interviewing ranchers, hunters, game enforcement officers, forest rangers, and others as to nene sightings, a flock's breeding ground was discovered. The location was established on the upper lands of the Keauhou Ranch, on the eastern slope of Mauna Loa at

6500 feet. Families were identified and studied. The short range goals of the research were achieved when the following were established:

1. The laying period was found to extend from October 20th to about December 1st. There was no evidence of renesting in the wild, i.e., after removal of eggs or young. This is just the opposite in captivity.
2. Approximately 2 young are produced per breeding pair.
3. Part or all of the nene family is vulnerable to ground-running predators for three months or more each year. During this time the adults are subject to molt, which renders them flightless for 4-6 weeks. Simultaneously the young are hatched and require from 10-12 weeks of growth before they reach the flying stage. It is interesting to note that in Hawaii Volcanoes National Park in an area adjacent to the breeding ground, the author found more wild pig signs than anywhere else in the island. Cats, dogs, pigs, and mongooses are feral in the district.
4. Flocking started after April and lasted into the middle of June.
5. The summer flight season (movement to summer ground) extended after the summer solstices June 21 through August (equivalent to wintering ground period for North American geese). The birds would feed and roost at the Shipman Ranch (Puu Oo) in the evening, and during the morning would fly toward the southeast (across the Saddle Road) to isolated lava flows for their daily activities.

This one year of research showed that only greater longevity and lower adult mortality rates could enable the nene to come back even slowly. The results from the study prompted the following management recommendations:

1. Controlled hunting is needed to reduce predators, especially of pigs, in the National Park. Poisoned meat baits can be used in the small isolated kipukas.
2. The breeding ground must be kept intact and relatively free of disturbance from September to April each year to protect nesting, flightless young, and molting parents. This will require posting these areas against trespassing and the elimination of predators.
3. The summer ground should be free of hunters and dogs from July to October.
4. Establishment of release areas adjacent to breeding grounds; so that pen reared stock can adapt themselves to natural conditions before full release.

Several observations were made, which will require further research possibly in genetics and incubation. Though females exhibit high fecundity, i.e., after removal of the first egg clutches to induce more laying some layed as many as 4 clutches per year. Despite this the number of young has not been great. Apparently the failure is centered about infertility and poor hatchability.

The Pohakuloa project, in the past 8 years, shows egg failure to be 39% due to infertility and 11% due to terminal days of development. These two factors are responsible for half of the failure of the nene to achieve its breeding potential in captivity.

The possibility of infertility may have arisen from imbreeding; since all captive stock in the world stemmed from a few original pairs in Mr. Shipman's flock. It is highly possible that the captives are becoming homozygous for a lethal gene. This genetic malady could be responsible for death at an early age. It is difficult to distinguish such a factor from infertility. However, there are other factors to consider such as improper humidity relations during incubation.

An important suggestion concerning policy was presented by the authors, and it is worthy of mentioning at this time, namely: the Hawaiian and English (Severn Wildfowl Trust) projects should have a sound policy as to the disposition of reared birds. Past records have shown that where this was lacking some flocks were dissipated as gifts to political friends and lost.

The fruition of the research was realized at the close of the study. In 1959 the 85th Congress passed act 891, which authorized the U.S. Fish and Wildlife Service to spend $15,000 a year for a period of 5 years to carry out a program of research and management to insure the preservation and re-establishment of the nene in its former known habitat. Plans were then made to extend the nene project an additional 5 years, with an annual allotment of $25,000 per annum to increase the scope of the project.

Since 1958 the federal program has been a tremendous aid in preserving and re-establishing the nene. The yearly progress reports of the Division of Fish and Game have become encouraging. Between 1959 and 1963, 87 pen-reared nene were released in the wild. Several of these birds have been observed pairing with wild mates. From July 1961 to June 1962, 92 predators were destroyed (73 pigs, 9 goats, 6 cats, 3 mongooses, 1 dog). The flight patterns for breeding and summer grounds have remained somewhat consistent. However, there are many problems still confronting the nene program. More research and a definite system of controls must be developed before the program can function at maximum efficiency.

Chapter VII- A Vegetational Background for Ecological Studies in the Park

A lava flow destroys all previous populations and leaves sterile unaltered still-molten, very hot magma from the interior of the earth as a new surface. The first change is the cooling of this surface. A series of changes taking many years, hundreds of years or perhaps hundreds of centuries, and leading toward a stable condition. This stable condition is referred to as the climax. Because there are many flows of different ages in different climates, Hawaii Volcanoes National Park is one of the best places in the world to study this phenomenon. Thus far only vegetational studies have been undertaken within the Park aside from the beginnings of studies on birds, insects, goats and pigs. The vegetatinnal aspects are discussed under the following headings.

A- HIGHER ELEVATIONS

B- KIPUKAS AND SOIL RELATIONS

C- VEGETATIONAL RESPONSES TO VOLCANIC ACTIVITY IN THE CHAIN-OF-CRATERS AREA

D- PUU PUA'I AND THE DEVASTATED AREA

E- THE WETTER LOWLAND VEGETATIONS

F- POPULATION DEVELOPMENT ON THE LOWLAND 1955-LAVA FLOWS

G- THE SEASIDE OR MARINE VEGATATIONS

Climax vegetations reflect the end result of the interaction between all factors concerned. This is such a broad statement that it is meaningl less without definition of the terms involved. As the terms are enumerated and defined the usefulness of the term "climax" becomes less or at least becomes questionable. In each of the above categories notes or discussions are presented to provide knowledge of the current status of research in the area on the mature (if not climax) vegetations and on the sere leading to it from the pioneer new lava flow condition.

A- HIGHER ELEVATIONS

Ever since the earlier American and British ecologists, such as Cooper (1913), Tansley (1920, 1929), Clements (1928) and Cowles (1929), made their pace-setting contributions in vegetation dynamics, the subject of vegetation succession and climax has received considerable interest in ecology and related sciences. According to Egler (1950), Clements has been recognized as the founder of the American School of "Dynamic Ecology." However, serious controversies have arisen particularly with regard to the climax concept. Whittaker (1953) called Clements' systematic treatment of all vegetation units in form of chronosequences a "terminological jungle," and Egler (1947) proposed abandonment of the term climax altogether.

Today there are three prevalent climax hypotheses in ecology: (1) Clements' (1928) monoclimax theory, (2) the polyclimax theory (Tansley, 1929; Domin, 1923; Du Rietz, 1930; Cain, 1947), and (3) Whittaker's (1953) climax pattern theory. The Park is an ideal site for carrying on experimental observational and experimental studies to test these different hypotheses.

Major difficulties in interpreting these central ecological concepts lie in:

1) the scarcity of study areas with known dates of substrata exposed at sequential time intervals, from which rates of vegatation change could be determined;
2) the common past tendency of overgeneralizing certain aspects of vegetation dynamics, which has resulted from preoccupation

with vegetation and consequential neglect of elaboration of associated environments and environmental changes.

It seems that the differences between the mono- and polyclimax theories cnn be resolved by information on the rates of vegetation change in primary succession. Whittaker (1953) recommended the use of certain features of stand structure in determining climax vegetation and advocated doing away with environmental features as indicators since they appear too hypothetical. This question could be further elucidated from correlating vegetation with topography and soil development in primary succession.

The Park offers an ideal setting for the study of vegetation dynamics for several reasons. Situated at the south end of the island chain is the largest and most recent island, Hawaii, which has still four active volcanoes that have produced a large number of recent substrata, whose dates have been accurately recorded since 1790 (Stearns, 1946). The largest of these volcanoes, Mauna Loa, has produced lava flows that radiate in all directions and extend from almost 14,000 feet elevation down to sea level. This lava flow pattern allows for comparing vegetation behavior under a wide range of air temperatures (up to 40°F) on the same substrate age. This rather unique aspect has recently been emphasized by Britten (1962). Furthermore, the northwest tradewinds produce a rather definite orographic rainfall pattern (Taliaferro, 1959), which allows for comparing vegetation behavior on the same age of parent materials in arid and humid climates. The major types of substrata are two types of lava flows (i.e., rough lava, called a'a[1/] and smooth lava, called pahoehoe) and two types of

[1/] These Hawaiian lava terms are now used in international geomorphological parlance.

ash (i.e., coarse, in form of cinders and pumice, and fine, in form of sand and dust). Since ash sprays and lava flows have often occurred at the same time (Wentworth, 1938), vegetation behavior can be compared within the same climates on different parent materials and topographies. The side-by-side occurrence of lava flows of different ages allows for comparisons of primary colonization and succession within the same macroclimatic zones. The varied aspects of secondary invasion and succession of introduced vegetation could form a number of separate studies, but these must be considered within the framework of primary colonization, succession and climax.

Most ecological work in Hawaii so far has been devoted to the classifying of broad vegetation zones (Hillebrand, 1888; Rock, 1913; Hosaka, 1937; Egler, 1939; Robyns & Lamb, 1939; Ripperton & Hosaka, 1942, and Krajina, 1963). Three important ecological studies were concerned with more local physiographic sections of Oahu (Hosaka, 1937; Egler, 1947; and Hatheway, 1952), with emphasis on description of current plant communities and some hints as to their chronosequence. A summary and general description of terrestrial ecosystems was presented by Fosberg (1961).

Studies directly concerned with aspects of vegetation dynamics on new volcanic material of the youngest island Hawaii were done by Forbes (1912), MacCaughey (1917), Robyns & Lamb (1939), Skottsberg (1941) and Doty (1956, 1957, 1961). Forbes confined his studies to the arid region on the lee side of Mauna Loa, where he made lists of plants on five dated lava flows in a few well described locations. He observed that, contrary to common assumption and his earlier belief, plant invasion appears to be more rapid on pahoehoe than on a'a lava. He ascribed this to the faster soil accumulation that appears in the many surface cracks on the smooth (pahoehoe) lava. He found the same plants on both types of lava, but concluded that rates of vegetation changes are faster on pahoehoe because of faster weathering there. He recognized a cryptogam stage, which is prolonged on a'a, there particularly by the presence of white crustose lichens. Next, he noted a fern stage that is accompanied by invasion of a tree, Metrosideros polymorpha (ohia). After this he observed the vegetation to gradually change into the type characteristic for the climatic zone. He also made some remarks about the moist, windward side of Mauna Loa, where he noted Metrosideros to persist long on a'a lava, while Acacia koa (koa) is found mostly on pahoehoe. However, where in certain situations Acacia koa occurs on a'a, he thought this to be rather old (much weathered) a'a. Thus, he believed Acacia koa to form the climax stage. His major conclusions with regard to plant invasion, succession and climax on lava flows on the leeward side are summarized in five points as follows:

"1. Appearance of lower cryptogams, eventually becoming conspicuous on the a'a.

"2. Appearance of Polypodium pellucidum (folded form), Sadleria cyatheoides and Metrosideros polymorpha, first on pahoehoe, and at a much later date on a'a.

"3. Gradual development of the typical floral aspects of the immediate vicinity, if in the central region of an ohia forest.

"4. Establishment of the final native vegetation, if in the central region of a koa forest.

"5. A later stage may be the encroachment of the naturalized flora, due to a change of conditions brought about by human agency."

MacCaughey (1917) also confined his study to the xerophytic regions. He described a few land form types in relation to vegetation, presented an account on the altitudinal ranges of several lava flow species and made observations on their xerophytic life form characteristics. He pointed out that rate of invasion depended on two factors: rainfall and adjacent vegetation and stated that his findings coincide generally with those of Forbes. But he found that lichens occur much sooner on a'a than on pahoehoe, while ferns and trees occur much sooner on the latter lava type. He also stated generalized ages for certain life form types, but did not show how the ages were determined. Robyns & Lamb (1939) presented a classification and general map of five major climax formations for Hawaii, following the concepts of Clements. They emphasized that climate governs the final form of vegetation, while the soil only accounts for developmental stages. They considered, among others, Aleurites moluccana (kukui) to represent a climax forest and believed the kipuka forests (which are vegetation islands surrounded by lava flows) to be at least one lava flow generation older than the vegetation on the surrounding flows. According to recent findings (Mueller-Dombois and Lamoureux, In Press), the kipuka forests referred to by Robyns & Lamb have probably originated on ash deposits, the upper layers of which may be as recent or younger than the surrounding flows. This points to an overgeneralization of the climate-soil relation concept as used by Robyns & Lamb. Also, cursory inspection of the distribution patterns of Aleurites forests on Oahu indicates that they cannot likely be considered a climatic climax formation, but a vegetation type conditioned mainly by slope seepage. According to Robyns & Lamb, weathering of a'a lava is faster (because of more surface area exposed) than of pahoehoe, an observation contrary to that of Forbes (1912) and MacCaughey (1917). Robyns & Lamb show vegetation lists from five different lava flows in the Kilauea region and concluded from these that the rate of invasion and vegetation density increases with moisture and that moisture is more important than age of lava. They also supported Forbes' findings in general, but said that less stress should be given to the first (cryptogam) and second (fern) stages as succession seems to start off directly with higher plants, while cryptogams occur consecutively. They list their observations of primary succession in the Kilauea region in three steps as follows:

"1. Invasion of the cracks in the new flow by ferns and flowering plants common to the adjacent area, and supported by cryptogams especially on the a'a lava.

"2. Gradual building up of heavier plant covering, filling in between the cracks, producing a shrub stage in which Dodonea viscosa, Styphelia tameiameia, and Metrosideros collina var. polymorpha predominate.

"3. Production of a plant community typical of the formation found on the adjacent area."

Robyns & Lamb also give a general account of secondary succession in the lower altitudes, where they observed, among other things, that Prosopis will probably form a climax, that Leucaena may replace Lantana, and that Aleurites may follow Psidium guayava.

In spite of some overgeneralizations, which may have been the result of too hurried observations, the paper of Robyns & Lamb gives a good overall picture of the vegetation on Hawaii, which is presented in an excellent framework. Also, the authors deserve much credit for attempting to present their findings in form of principles.

Skottsberg (1941) made a more detailed study by laying out six quadrats (the size of which was not stated) in 1926 on two dated lava flows. He listed the species in each quadrat, counted their individuals and gave excellent growth form descriptions. He re-examined the quadrats in 1938 and found that in one comparison plant invasion had progressed more rapidly on a'a lava (a finding in contrast to that of Forbes), but in another comparison pahoehoe was favored. He then drew attention to finer habitat variations on the two lava flow types and to the importance of seed source relations. Skottsberg also supported Forbes' earlier findings, that a definite cryptogam stage can be distinguished followed by a fern stage.

While Skottsberg's study definitely pointed the way to further studies with regard to (a) a more adequate habitat classification, and (b) a recognition of seed source characteristics, his results remain rather inconclusive, since they are based only on six quadrats and a few general observations, which apparently did not provide him with enough results to formulate principles. Doty (personal communication) spent days trying to relocate Skottsberg's quadrats without success.

Doty (1956, 1957, 1961) studied plant invasion on the 1955 flow right after it had cooled to air temperature. Much of his information is included below in reference to population establishment on the lowland areas. This lava flow originated at about 1000 feet elevation and ran into the sea presenting an opportunity for studying vegetation dynamics above and below sea level. He observed little difference in populations on different habitats except in their rate of invasion, which was on terrestrial habitats related to water availability and in marine habitats to stability of substratum. On the terrestrial habitats he observed a sequence of first algae, then mosses, and then ferns that arrived together with higher plants and fungi, and he noted lichens to arrive as the last group among the pioneers. In these latter observations his findings coincide with those of Robyns & Lamb (1937).

Doty's study is being continued. In addition two new studies have been initiated subsequently. Mr. G. A. Smathers (formerly Park Naturalist, Hawaii National Park) placed a number of meter square quadrats on the 1959 lava flow of Kilauea Iki and the slope of a cinder cone that was formed from the same eruption. His narrative account provides the basis for the information included below in reference to population establishment on the Kilauea Iki devastated area. Another group of quadrats was laid out by Drs. C. H. Lamoureux and Dieter Mueller-Dombois (Department of Botany, University of Hawaii) on the October 1963 and 1965 flows (Figs. 5 & 7) at the bottom of Napau Crater. No results are as yet available from these recently begun studies.

The literature survey shows that vegetation dynamics studies on Hawaii have been attempted mainly with two questions in mind:

1. What kinds of plants are the invaders on new lava material, and what are their followers?
2. Which type of lava is invaded first: rough (a'a) or smooth (pahoehoe)?

Except for observations applicable only to restricted localities, results with regard to both questions are as yet inconclusive. The first question will soon be elucidated further with the new quadrat studies under way on the 1959 and 1963 lava materials, which will add results from different climatic zones in addition to Doty's study (see next section) on the 1955 flow. Taking advantage of dated lava flows, however, means more than a study of invasion. On most dated flows the invasional stages have not been observed, yet they present a great ecological asset because of the possibility of comparing successional stages and studying their rates in permanent quadrats.

The second question can be answered adequately only after a thorough study of habitats resulting in a habitat classification that is tied in with plant distribution and growth. It would be disirable also to do a survey of vegetation islands and to attempt a classification of seed sources. Moreover, it would be of interest to study invasion and succession not only on a'a and pahoehoe lava flows, but also on ash deposits, such as cinder cones, ash dunes and ash blanket-deposits, which represent other characteristic land form types on Hawaii.

Studies of vegetation on volcanic materials in other parts of the world have centered around the following major themes:

1. Damage to existing vegetation and its recovery after volcanic activity.
2. New colonizers.
3. Invasion rates with respect to different materials.
4. Stages in succession to climax.

Partial destruction of existing vegetation from deposits of the same volcanic materials was found to have a selective effect on species and size within species. Eggler (1948) observed a better recovery of oaks than of other tree species, and found medium-sized pines to be favored over small- and large-sized ones under deposits of ash on the slopes of El Paricutin, Mexico. Such effects may have contributed to differences in current species composition of vegetation islands on Mauna Loa. Griggs (1933) drew attention to the importance of distinguishing between hold-over plants and new colonizers on Katmai, Alaska. Upon complete destruction of existing plant communities seed sources for new colonization may become a limiting factor (Rigg, 1914; Eggler, 1963) and new substrates may lack organic nitrogen entirely (Griggs, 1933; Tezuka, 1961) or the level of organic nitrogen may be very low (Eggler, 1963). From these studies it becomes apparent that the type of colonizers may be in part a function of the destruction effects.

Griggs (1933) found the first colonizers on the deep ash deposits on Katmai to be liverworts of Jungermanniaceae, which apparently can make growth on substrates almost devoid of organic nitrogen. Mosses and algae invaded only after nitrogen levels had increased. A local increase of nitrogen levels on new materials was observed beneath mosses (Eggler, 1963; Tagawa, 1964). In some tropical habitats the first colonizers have been found to be algae (Treub, 1888; Booth, 1941; Doty, 1961). However, there are obviously great differences with regard to species, population density and habitat. Treub observed thick carpets of blue-green algae on the new substrates of Krakatau. Similarly, Booth observed complete coverings of Myxophyceae extending over hundreds of acres on badly eroded, new soil in the south-central states. Doty (1961) observed an algal population of Scytonema on Hawaii at low elevations above the salt spray range. Apparently, algae do not play such an important role in other tropical habitats. Hasselo and Swarbrick (1960) studying a section of the 1959 lava flow on Cameroons Mountain found creeping herbs that were rooted in undisturbed neighboring soil to be the first colonizers. While they noted no definite algal stage, they found algae to cover about 20% of the surface. These authors also drew attention to seasonal variations, which were particularly shown by mosses and herbaceous plants.

The volcano, Sakurajima, overlooking the city of Kagoshima, Japan, has erupted with a frequency about like that of Mauna Loa and Kilauea and scientific studies of the vegetation have been carried on since the last major eruption in 1914. One of the main vents, Manami-dake, has been almost continously active in the sense the Halemaumau is active, at least since 1956 and Tagawa (1964) has reviewed and continued detailed studies of the vegetational events to date. Tagawa found early development characterized by bryophytes and lichens and he drew particular attention to the invasional difference between bryophytes and lichens and higher plants; the cryptogams having a more universal means of distribution and the higher plants being more directionally distributed from seed source centers. Tezuka (1961) pointed out that mosses and lichens were not important on Oshima and that their role as invaders has been exaggerated by Clements. He also could not recognize the so called "herbage" stage. However, a distinct herbaceous stage was recognized by Tagawa (1964) on Sakurajima.

Similarly as on Hawaii (by Forbes & Skottsberg) a fern stage was recognized by Keay (1959) on Cameroons Mountain, which was well established 14 years after deposition of the 1922 lava flow in a very wet region. Shrubs became established 29 years after eruption, while ferns persisted. Keay reported 12 species of Ficus as pioneer trees.

Different rates of invasion with regard to differences in substrates were observed by Eggler (1963) on El Paricutin. Plants were able to start on lava but not on unmodified ash. Mosses started in lava cracks where run-off water accumulated. Invasion rates were related to accumulation of aeolian ash that had sifted into cracks rather than to either a'a or pahoehoe lava. He also observed faster colonization of mosses where soil water was locally augmented from condensation near steam vents. Eggler (1941) noted, however, slower vegetation succession on a'a in southern Idaho, as did Forbes (1912) on Hawaii. Tagawa (1964) also found more mosses and lichens on rough lava (a'a) than on smooth on Sakurajima.

Studies that go beyond the questions of invasion and the following stage in primary succession are those by Eggler (1941), Tezuka (1961) and Tagawa (1964). In all three of these it was remarkable that the climax communities were not comprised of the largest number of species, as has commonly been assumed (Rock, 1913; Robyns & Lamb, 1938 et al.). Eggler contributed this trend to the changing habitats that were more complex during early stages of lava weathering (i.e., narrow and broad crevices, shallow and deep soil pockets, etc.), while a more uniform habitat resulted after the entire flow surface had weathered to a certain depth. Tagawa (1964) gave development rates in years for each seral stage and estimated that it takes 700 years for development of the climax vegetation type on Sakurajima. He found that invasion begins slowly, then changes increase in rate to finally slow down again. Tezuka (1961) correlated vegetation with soil development and found the vegetation climax to occur much sooner than the soil climax, also a finding contrary to common assumption (e.g., Billings, 1941). However, while the study of the environmental framework clearly supports Eggler's conclusions, Tagawa's and Tezuka's papers are not too clear in this respect.

B- KIPUKAS AND SOIL RELATIONS

By D. Mueller-Dombois & C. H. Lamoureux

Preparations have been made in particular detail for continued study of Kipukas Puaulu and Ki. Thus the soils have been studied, buried charcoal dated and the plants carefully listed with considerable effort being made to understand the historical records. Changes and disturbances of different kinds were considered from the point of view of cause and effect relationships. For the most part the results of this more intensive consideration are detailed elsewhere in the appropriate sections of this Atlas and most of the following text is being published separately (Mueller-Dombois & Lamoureux, In Press). Detailed lists of the plants are included here as Appendix A, a systematically arranged check list because of its length.

Kipuka, the Hawaiian word for "opening," has come into scientific usage as a term used to designate older areas on the slopes of volcanic mountains that have been surrounded by more recent lava flows. They are common landscape features on the slopes of Mauna Loa and Kilauea volcanoes on the island of Hawaii, where they can be readily recognized as islands of denser vegetation amongst the vast, sparsely vegetated areas. They range in size from a few square meters to hundreds of acres.

Kipukas are of special interest for several reasons. As vegetation islands they provide seed source centers for the invasion of vegetation on new volcanic material. As vegetation islands they represent somewhat simplified ecosystems, analogous to bogs or lakes, that are very suitable for studying internal ecological relationships. The isolation of small populations in kipukas provides unique opportunities for evolutionary studies.

So far, very little ecological work has been done with Hawaiian kipukas. Need for such work has arisen in Hawaii Volcanoes National Park, where the Park Service is confronted with the task of interpreting certain kipuka features to the Park visitors. Kipuka Puaulu, popularly known as "Bird Park," has been made accessible to the public for some time and the nearby Kipuka Ki is soon to be opened. For this reason the present study was begun in these two kipukas.

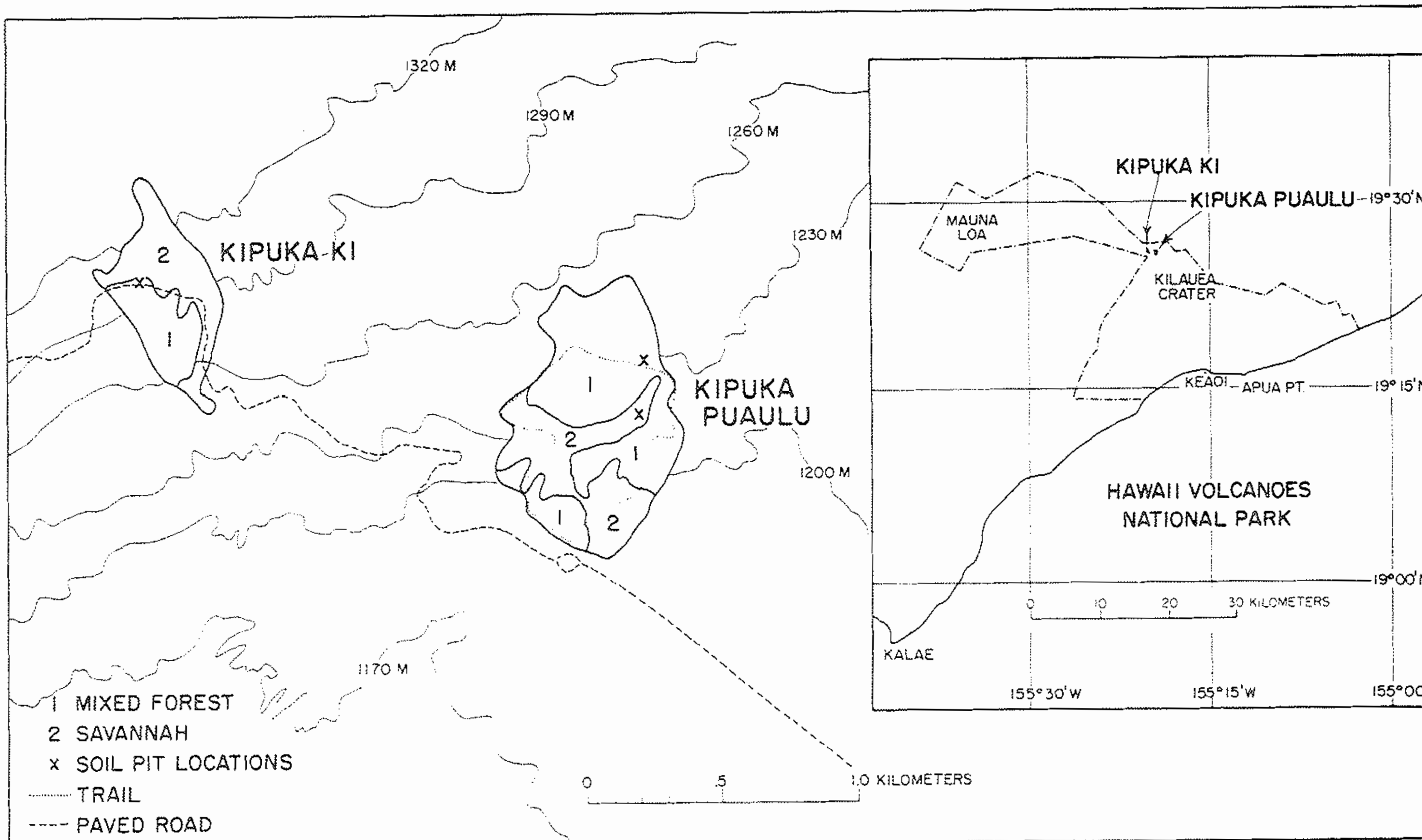
Rock described the flora of both kipukas in an undated manuscript (probably written around 1910) and reported a few general ecological observations. He remarked on the unique and complex composition of arborescent species from which he judged both kipukas to be "of great age." However, as an approximation he cited Professor T. Jaggar's (Geologist at the Hawaii Volcano Observatory at that time) estimate which placed the origin within the Christian era (i.e., less than 2000 years). Rock recorded 40 arborescent native species forming a complex forest type in Kipuka Puaulu. Only half this number of tree species were found in Kipuka Ki. He also noted the presence of two vegetation types in Kipuka Puaulu, a complex forest type containing many tree species and a *Metrosideros*-dominated type. He believed that soil differences were responsible for the presence of these two types of forest. A general description of the kipuka soils is given in the Soil Survey report for the Territory of Hawaii (Cline *et al*., 1955), where the soils were classified as Latosolic Brown Forest soils derived from two layers of volcanic ash.

The primary objectives of this study were to determine the floras of both kipukas, to describe the vegetation types present in each, and to determine what soil-vegetation relationships exist in these places.

Description of area

Both kipukas (Fig. 21) occur at an elevation of about 1200 m on the southeast slope of Mauna Loa approximately 3 km northwest of Kilauea Crater. (Aerial photo 8-0078 is better than those indexed in Fig. 6 for this area). The central elevation of Kipuka Ki is about 60 m higher than that of Kipuka Puaulu. Both are surrounded and separated by recent beds of rough prehistoric a'a lava. Their boundaries are about 800 m apart. Kipuka Puaulu is about 40 hectares and Kipuka Ki about 12 hectares in size. The climate is characterized by a rather uniform mean annual temperature of 16 deg. C,

Fig. 21. The location and vegetations of the Bird Park, Kipuka Puaulu, and of Kipuka Ki in reference to elevation and the Park boundaries. One thousand meters is 3270 feet.



which is 7 deg. cooler than that experienced at sea level. The mean variation between the warmest month (August) and the coolest (February) is only 3.5 deg. C. Occasional freezing temperatures can be expected during February nights. Approximate annual rainfall is 150 cm, varying monthly from about 2.5 cm in June to 20 cm in January. According to Krajina's (1963) zonal classification, they are both in the lower Metrosideros zone, whose climate is described as humid marine tropical (or subtropical) with cloudiness common. The kipukas are somewhat more sheltered from the windward rains than much of this zone, and Rock (1913) described them as being occupied by dry-mixed forest.

Both kipukas are situated on moderate south slopes and have an irregularly undulating topography with a few short, steep slopes, several level areas, a few larger, somewhat inclined areas and scattered small, pocket-like depressions.

Two distinct vegetation formations (Fig. 21) were found in Kipuka Puaulu, a closed to semi-open mixed forest type and a savannah type with a dense grass cover and scattered trees of Metrosideros and Acacia koa. Kipuka Ki is dominated by a moderately stocked mixed forest vegetation type, which in places is also semi-open, but lacks the very dense, or closed forest stand segments found in Kipuka Puaulu. A savannah also reaches marginally into Kipuka Ki occupying here mainly however a transition zone in which occasional lava rocks protrude to the surface, indicating a relatively recent lava flow which entered the kipuka and which has since been covered by a thin layer of ash. Characteristically, no rocks are found near the surface in either kipuka. Within the forest formation of both kipukas several vegetational associations can be recognized. One of the more obvious associations, common to both kipukas, is characterized by a ground cover of *Microlepia setosa*, a lush fern up to 1 m tall. The tree layer is dominated by *Acacia koa* and *Sapindus saponaria*. This plant association occurs on level to moderately sloping ground.

SOILS

For the purpose of comparing the soils between the two kipukas, soil pits were dug in each kipuka in the *Microlepia* association near a tall *Acacia koa* tree in a level place. A level place near a tall koa tree was also chosen for a soil pit in the savannah for comparing the soils between the forest and savannah formation within Kipuka Puaulu. The reason for choosing a level place was that the soils here were presumably not influenced by lateral seepage.

The pits were each dug to a depth of 2 m. The soil horizons were described (Fig. 22) as to depth, material, and color, and samples were collected for laboratory analysis. The soil samples included three sets, one for microbiological analyses (now being conducted), one for current soil moisture analysis and one for other soil tests. In addition, the three soil profiles were prepared as soil monoliths after the method of Smith and Moodie (1947) for further mega- and microscopic inspection and as permament records.

Subsequent soil tests carried out included determination of moisture equivalents (by the centrifuge method), permanent wilting percentages (by the sunflower method), organic carbon (by the Walkley-Black wet-combustion method) and pH (by electric pH meter).

The soils give convincing evidence that they have been derived from volcanic ash and not from old, disintegrated lava as has been assumed by the authors of the earlier nature trail guides for Kipuka Puaulu. Ash

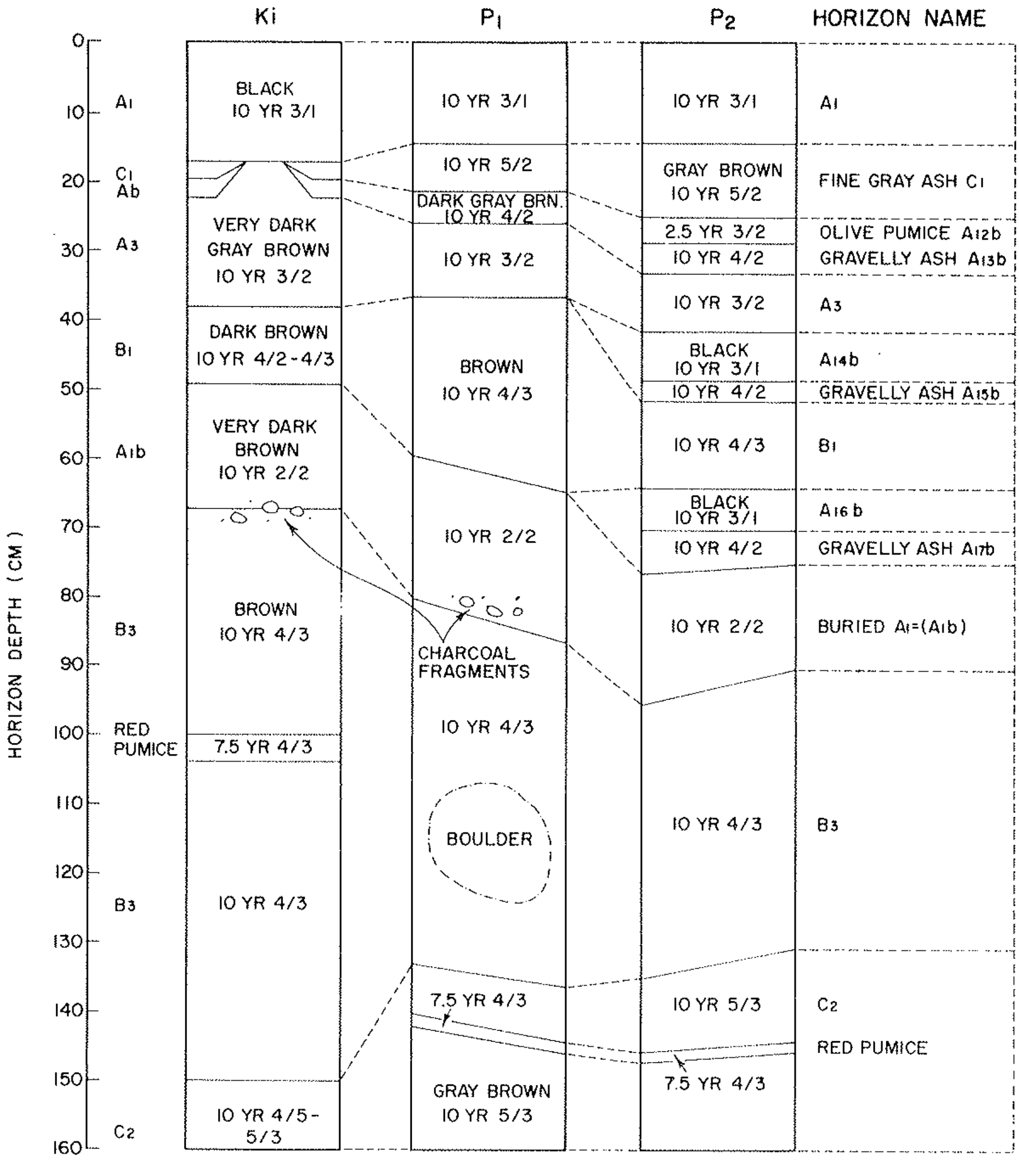


Fig. 22. Comparison of horizons of kipuka soils (Ki = Forest soil of Kipuka Ki; P1 = Forest soil of Kipuka Puaulu; P2 = Savannah soil of Kipuka Puaulu). Color symbols from Munsell charts refer to dry soil. The nomenclature of the horizons is that of the 1962 Supplement to Agriculture Handbook No. 18 of the Soil Survey Manual. See Table I, below; for the meaning of the symbols and nature of the soils.

strata were found to a depth of 2 m to which all soil pits were dug and there was no sign of parent material change at this depth. Rock (undated) indicated that the soil in Kipuka Puaulu was nearly 6 m deep. The maximum soil depth in Kipuka Ki is not known. Refer to Chapter V on soils and, especially, Fig. 19, to relate the kipuka soils to the others in the Park.

Ash was deposited not at one time but in several stages, probably extending over many hundreds of years. Corresponding ash layers that appear to have originated from the same eruptions can be found in all soils. Noteworthy are two thin red pumice layers that occur in each soil. One occurs in the lower profile at the 100 cm depth in the soil of Kipuka Ki, at 140 cm in the forest soil of Kipuka Puaulu and at 145 cm in the savannah soil (Fig. 22). A second red pumice layer is found in all soils nearer the surface, at 60 cm in Kipuka Ki, at 70 cm in the forest soil of Kipuka Puaulu and at 85 cm in the savannah soil.

Ash deposits were of at least five different materials; a fine, dusty gray ash with scattered pebbles up to 5 mm in diameter, a gravelly ash with basaltic and variously vesicular pebbles up to 1 cm in diameter, a black vitreous ash, a yellow-olive pumice and the red pumice mentioned above.

The fine, dusty gray ash occurs at a depth of 15 to 20 cm from the surface in all profiles. It is most pronounced in the savannah soil and least in the soil of Kipuka Ki. This layer looks like the leached layer of a podzolic soil. However, there are three arguments against this interpretation of it. First, the layer is brightest under savannah, which has the least acid surface layer (Table I). Second, it was horizontally continuous only in Kipuka Puaulu, whereas it occurred in local pockets in Kipuka Ki. Third, Wentworth (1938) in his study of ash formations around

Table I. Some parameters of the Kipuka soils.

Horizon	Current moisture content (%)1/			Available water (%)2/			Organic carbon (%)3/			pH4/		
	Ki	P1	P2	Ki	P1	P2	Ki	P1	P2	Ki	P1	P2
A1	67	56	106	23	23	30	11.1	10.4	14.3	5.2	4.8	5.7
Fine gray ash C1	21	27	30	13	13	10	4.2	3.3	1.1	5.7	5.5	5.4
Olive pumice A12b			55			34			15.7			6.4
	23	16		--	--		9.6	12.6		5.9	5.8	
Gravelly ash A13b			17			7			15.4			5.9
A3	24	44	28	18	13	10	9.9	10.5	7.2	6.2	5.6	6.4
A14b			58			--			12.0			5.7
gravelly ash A15b			19			5			3.0			6.5
B1	29	44	44	15	16	15	7.7	7.8	5.7	5.9	5.6	5.7
A16b			48			--			13.5			6.1
gravelly ash A17b			10			3			7.8			6.3
Buried A1(=A1b)	40	75	60	23	20	20	12.7	12.1	10.1	5.7	5.7	5.7
B3	47	42	37	9	10	5	9.0	6.9	5.4	6.0	5.7	5.9
Red pumice	53	31	16	--	--	--	3.8	3.6	1.8	5.8	5.7	7.0
C2	90	36	21	11	12	5	9.0	7.6	1.9	6.0	5.7	6.0

1/ Moisture content at date of sampling, November 23, 1963
2/ Available water = Moisture equivalent (%) - Permanent wilting percentage
3/ Walkley —Black values
4/ Measured electrometrically

Ki = Kipuka Ki, Forest soil
P1 = Kipuka Puaulu, Forest soil
P2 = Kipuka Puaulu, Savannah soil

Kilauea Crater described a "gray-lavender, fine sand-size ash" near the surface in several places which seems to fit this layer.

The gravelly ash is described by Wentworth as "basalt in glass" and is well shown in the savannah soil, where it recurs as a thin layer (usually ± 5 cm thick) at depths of 30, 50 and 70 cm.

Black vitreous ash appears as a 20 cm deep layer in all three soils from 50-70 cm depth in Kipuka Ki, from 60-80 cm in the forest soil of Kipuka Puaulu and from 75-95 cm in the savannah soil. It recurs at three places above this layer (at 65 cm, at 45 cm and at 25 cm) in the savannah soil. These black layers are not only black from ash but also, perhaps more dominantly so, from an extremely high incorporation of organic carbon (between 10.1 and 15.7%, Table I).

A yellow-olive pumice layer (called "reticulite" by Wentworth) is found in the savannah soil incorporated into the black layer at 25 cm depth. Some of this pumice occurs also in both forest soils beneath the fine gray ash layer (C1), but here it is less abundant and less well stratified (Fig. 22).

The lower ash deposits, from the thick black layer (A1b) down, in both soils of Kipuka Puaulu are not stratified horizontally, whereas the upper ones are more or less horizontally stratified (see Fig. 22, P1 and P2). Angles of departure were between 20-30°. This fact indicates that there have been some relief changes throughout the build-up of the soil to its present surface-level. This suggests something about the origin of Kipuka Puaulu, which may apply to Kipuka Ki as well. It appears probable that lateral translocation of ash has occurred after deposition as a result of wind or water erosion, particularly during the early stages when the kipuka was only sparsely vegetated.

A small kipuka of about 1 hectare in the Kau Desert south of Kilauea Crater, which is just "in-the-making" shows that it has originated as a small dune ecosystem. Gray-black sandy ash was deposited here in a thin layer on a large flat area of smooth pahoehoe lava. Wind has swept up much of this ash and re-deposited it as a dune at a place where the smooth lava was intercepted by a rough a'a flow. The ash-dune now represents an island supporting a pioneer vegetation. This process is accumulative since the vegetation, once established, catches more eolian deposits and in turn contributes organic matter, soon forming a moisture- and nutrient-improved habitat that also differs in elevation from its surroundings. It is quite conceivable that such elevated dune ecosystems can be surrounded by subsequent lava flows. Such an occurrence, on a much larger scale, could account for the origin of the kipukas discussed here, although additional evidence to support this hypothesis must be obtained. Also, many, if not most, of the Hawaiian kipukas such as Kipuka Nene have undoubtedly developed merely by the disintegration <u>in situ</u> of older lavas, and their subsequent surrounding by newer flows.

The upper ash deposits in the kipuka soils are more or less horizontal with respect to the present soil surface, a form of deposition which Powers (1948) calls "blanket deposits." The "blanket deposits" in the savannah soil show that there have been at least 9 ash deposits in Kipuka Puaulu since establishment of the thick black horizon (A1b). These may not all have been from different explosions, but Powers has discovered ash from at least 26 eruptions in the area that are later than the big Kilauea ash explosion of 1790. The latest recorded near Kipuka Puaulu was from the 1924 eruption. This shows that the soil is not of one (old) age, but of several ages from older to younger and the surface soil may even be much younger than the surrounding rough a'a flow, rather than older as indicated by Rock. The surrounding flow is prehistoric, thus at least pre-1778.

Fragments of charcoal were found in both kipukas in the forest soils. They occurred at the 70 cm depth in Kipuka Ki and at 80 cm in Kipuka Puaulu. This indicates two facts. First, that there was fire in both kipukas at an earlier date of their development and second, that both had woody vegetation growing on them at that time. Although charcoal was not found in the savannah soil, fire may explain its origin.

It is interesting that the savannah soil looks quite different from the forest soils, which in spite of being from two separate kipukas are similar in appearance. Both forest soils are deeply melanized, dark brown in color and are rather uniformly enriched with organic carbon (Table I). The savannah soil shows more clearly the parent material, because of less uniform melanization. Here organic carbon content fluctuates greatly between soil horizons. These two patterns, that is, the more uniform color and organic carbon distribution in the forest soils and the greater variation in color and organic carbon distribution in the savannah soil are undoubtedly associated with past rooting zones. One may assume that a mixed, well-stocked forest occupies soil volume more uniformly than a dominantly grass-covered savannah. The grass and ground vegetation roots may have been more restricted to the black horizon zones. Such a concentration in rooting depth was also found presently at the soil surface of the savannah soil. This pattern supports the assumption that the savannah originated after the fire that has occurred in the past. It is probable that the fire occurred when the 20 cm thick, black layer, the buried A1 horizon (A1b), was at the surface supporting actively growing vegetation, as the charcoal was found right at its lower boundary in both forest soils (Fig. 22). Therefore, the savannah may be quite old. The carbon-14 date of the 70 cm deep charcoal in Kipuka Ki came to 2170 ± 200 years; i.e., 220 years B.C.[2/]

Analysis of potentially available water, organic carbon and pH show no significant differences between the savannah and forest soils in Kipuka Puaulu so that neither soil water or nutrient differences can be assumed responsible for causing the difference in vegetation. Moreover, there is no unique topographic pattern associated with either type so that the savannah origin is not attributable to environmental differences related to topography.

FLORA

Between November 1963 and March 1965 botanical surveys were made of both kipukas. Voucher specimens have been deposited in the herbarium of the Department of Botany, University of Hawaii, and duplicate specimens in the herbarium of Hawaii Volcanoes National Park. The plants found are listed in Appendix A, which also includes records from Rock (undated, 1913), and Fagerlund & Mitchell (1944), as well as specimens in the herbaria of Hawaii Volcanoes National Park and the Bernice P. Bishop Museum, Honolulu, Hawaii.

Table II summarizes the information provided in the check list in Appendix A. It can be seen that Kipuka Puaulu now contains, and has contained, significantly more species of vascular plants than has Kipuka Ki. Table III provides an analysis of the numbers of species common to both kipukas and of those found only in Kipuka Puaulu or Kipuka Ki. This indicates that while each kipuka contains species which the other does not, Kipuka Puaulu has significantly more unique species than does Kipuka Ki.

2/ Sample GX0394, Geochron Laboratories, Inc.

Table II. Numbers of species, varieties, and forms of vascular plants recorded from Kipuka Puaulu and Kipuka Ki. Figures outside the parentheses include all spp. ever recorded. Figures within parentheses include all spp. growing naturally in 1963-65.

	All data	Kipuka Puaulu	Kipuka Ki
Total number of spp.	158 (104)	145 (92)	73 (63)
Native spp.	86 (52)	81 (48)	36 (30)
Native trees	42 (21)	42 (21)	15 (11)
Introduced spp.	72 (52)	64 (44)	37 (33)

Table III. Distribution of species, varieties, and forms of vascular plants between Kipuka Puaulu and Kipuka Ki. Figures outside parentheses include all spp. ever recorded. Figures within parentheses include all spp. growing naturally in 1963-65.

	Common to both kipukas	Kipuka Puaulu only	Kipuka Ki only
Total number of spp.	60 (51)	85 (41)	13 (12)
Native spp.	31 (26)	50 (22)	5 (4)
Native trees	15 (11)	27 (10)	- (-)
Introduced spp.	29 (25)	35 (19)	8 (8)

The observations recorded in Tables II and III and Appendix A thus agree with Rock's (1913) original observation that there are more species in Kipuka Puaulu. The number of native trees now growing in Kipuka Puaulu (21) is almost twice as large as that in Kipuka Ki (11). However, Rock reported in 1913 that there were at least 40 native tree species growing in Kipuka Puaulu. Even allowing for differences of taxonomic opinion, the decrease in number of tree species over the last 50 years appears quite remarkable. In his book "Indigenous Trees of the Hawaiian Islands," Rock (1913) shows 19 photographs of tree species in Kipuka Puaulu. Fifteen of these show bits of landscapes and ground vegetation, which at that time appeared badly abused by cattle grazing. Many areas appear barren or show trampled ground vegetation and several pictures show broken-down trees. From the photographic record one could assume that the present savannah formation is caused entirely by cattle grazing. However, two photographs show what appear to be sections of the present savannah formation. One of these shows a dense cover of Pteridium, which today is also well established in the savannah. As fire has definitely occurred in both kipukas, it is believed that fire may have created openings in the forest that were aggravated and maintained by subsequent cattle grazing. It seems probable that cattle were guided in their grazing habits by this fire-conditioned vegetation pattern, as a denser ground vegetation would be found in the open, coupled with fewer obstacles to the movement of cattle. Increased cloud interception and fog drip in the forest (Ekern, 1964) may also have contributed to maintaining the pattern. This is indicated by the greater current moisture content in the lower profile of the forest soil (Table I) and the location (Krajina, 1963) of the kipukas in a zone of common cloud occurrence.

There are several possible explanations for the larger number of both native and introduced species in Kipuka Puaulu.

1. The larger number of native species in Kipuka Puaulu may be related to:

(a) Larger area: both kipukas are so much larger than the "minimal" area—size of forest stand communities cited in the literature (Ellenberg, 1956, gives 500 m^2; Cain & Castro, 1959, 20,000 m^2 for tropical rain forest) that one may think that size is not a factor. However, such minimal area calculations are based on the more common species. From the records it is quite clear that the now extinct species were extremely rare. The smaller size of Kipuka Ki can therefore be used as one explanation for its smaller number of indigenous species.

(b) Greater age: Rock (1913) believed that Kipuka Ki was more recent in origin than Puaulu, because of the common assumption that an older area would have more species. His idea cannot be disproved from current evidence, but one observation points into the opposite direction. The amount of organic carbon did not decrease in the lower profile of Kipuka Ki, whereas it did so in both soils of Kipuka Puaulu (Table I). This may indicate vegetative activity at an earlier date in Kipuka Ki as compared to Puaulu.

(c) Greater diversification in habitats in Kipuka Puaulu is not expected from observations made so far. Both kipukas have similar topographic variations and deep, rich soils. Also, the distribution of tree species is not as likely affected by small-scale environmental variations as are herbaceous plants.

(d) Different disturbance—history: little definite information is avilable on differences in disturbance—history. We only know that three important disturbance-factors operated in both kipukas: fire, cattle grazing and pig damage. Current pig damage appears to be less in Kipuka Ki. Past cattle grazing also was probably less devastating here. It is possible, however, that fire eliminated a few trees either directly, or indirectly by competition of more aggressive plants that followed the fire in both kipukas. In this connection the chance of the smaller, isolated kipuka to restock with rare species would be less than that of the larger one which also may have provided a greater chance to survival of rare tree species simply because of its larger size.

(e) Different rainfall and productivity: it was interesting to find that the current moisture distribution downward in the soils differed between the kipukas. The current soil water content increased considerably in the bottom part of the profile in Kipuka Ki and was higher than in the soils of Kipuka Puaulu, whereas the upper part of the profile was drier than that of the soils in Kipuka Puaulu. This indicates a different rain shower pattern between the kipukas. This may be a random pattern however, which then would have no bearing on the total amount received. Except for the lower profile parts (B3 and C2), there was little difference in the amount of organic carbon of both forest soils, indicating a similar productivity in both kipukas. Thus, the differences in number of species cannot be related to differences in productivity.

2. The larger number of introduced weed species in Kipuka Puaulu may be caused by (a) its greater exposure to man and cattle and (b) its larger sun-exposed area, which favors the establishment of shade-intolerant weeds. It is interesting that the fewer weed species in Kipuka Ki occupy more ground. Some of them have formed dominant communities.

VEGETATION

Several self-evident plant communities occur under forest cover. They are represented by native and introduced plants as follows:

Native:

1. *Microlepia* association
2. *Nephrolepis* association
3. *Peperomia patches*
4. *Pipturus* shrub strata
5. *Coprosma* thickets

Introduced:

6. *Commelina* association
7. *Rubus penetrans* association
8. *Solanum* association
9. *Dactylis* patches
10. *Commelina-Nephrolepis mixed community*

Nephrolepis communities and *Dactylis* patches are common also in open areas. *Coprosma* thickets are characteristic only for Kipuka Puaulu. The *Rubus penetrans* and *Solanum* associations are characteristic for Kipuka Ki. Only one small *Solanum* patch was observed in Kipuaa Puaulu. The rest occur in both kipukas. *Peperomia* patches seem to be established on ground that has been rather recently scarified by pigs forming here a pioneer community in shaded habitats. *Coprosma* thickets are likewise associated with pig scarification, which is particularly pronounced under the larger *Sapindus* trees where the pigs seem to search for their fruits.

SUMMARY AND CONCLUSIONS

The following facts seem important:

1. The soil of both kipukas is from several ash deposits. The lower, sloping ones in Kipuka Puaulu differ from the upper ones which are horizontally stratified.

2. Charcoal was found in both kipukas under forest in association

with a buried, black surface horizon, at the 70 cm depth in Kipuka Ki and at 80 cm in Puaulu.

3. The carbon-14 dating of the 70 cm deep charcoal in Kipuka Ki indicates a fire at about 220 years B.C.

4. The forest soils of both kipukas were uniformly melanized showing considerable megascopic similarity and differed markedly from the savannah soil which showed melanization restricted to narrow layers and which exposed a clear parent material stratification.

5. The soil parameters tested indicated no significant differences between the forest and savannah soil of Kipuka Puaulu in terms of soil water, organic carbon and pH.

6. The forest soils of the kipukas differed only in the current soil moisture distribution and the organic carbon content of the lower (B3 and C2) horizons.

The work so far is only an introduction to the plant ecology of Hawaiian kipukas and points to the need for the following further research:

1. Analysis of photographs. It would seem profitable to examine all photographs Rock made of Kipuka Puaulu and possibly relocate some spots for rephotographing. This could reveal certain interesting successional changes over the last 50 years.

2. Current observation indicates reoccupation of the savannah by forest. This appears to be accomplished by sucker growth of *Acacia koa*. Invasion of trees by seed seems practically impossible. It would be interesting to study the rate of re-invasion, now, when there is no longer interference by cattle.

3. Studies of cloud interception. Differences in soil water supply as a result of fog drip should be investigated to determine the role this

environmental factor plays in decreasing the rate of re-invasion of forest into the savannah.

4. Measuring pig damage. Current observation indicates that pigs seems to affect the forest vegetation in two ways: (a) by scarifying the surface they eliminate ground vegetation and provide ideal seed beds for germination of , *e.g.*, tree seed which is left. Many formerly pig-scarified areas seem to come back in thickets of tree seedlings of *Sapindus* and *Coprosma*. (b) During periods of food scarcity or over-population pigs seem to gnaw away the bark of trees particularly *Coprosma*, thus damaging them severely, *e.g.*, by providing entrance avenues to pathogens. Their food habits should be studied in connection with population counts to explain their influence on vegetation patterns.

5. Quadrat studies of vegetation patterns. These should be done in particular with *Peperomia* as a probable native pioneer on pig scarified ground; with *Commelina* and *Nephrolepis* mixed associations to determine whether *Commelina* takes over the habitats occupied by the native fern, *Nephrolepis*; further, with the two weed communities formed by *Rubus penetrans* and *Solanum pseudocapsicum* to determine their effect on the native *Microlepia* association.

6. An ecological survey of all kipukas and their surroundings should be made in an attempt to assess their development in succession and their influence on the vegetation of the surrounding more recent volcanic material.

Appendix A. Systematically arranged check list of the vascular plant species of Kipuka Puaulu and Kipuka Ki as of May 1965. * = Native Hawaiian species; # = Native tree; + = Growing, apparently naturally, in kipuka in 1963-65; a = Growing in kipuka in 1963-65 only as individuals recently planted by National Park Service; b = Specimens, collected between 1930 and 1960, in herbaria at Hawaii Volcanoes National Park or B. P. Bishop Museum, but species not found growing in kipuka in 1963-65; c = Reported by Fagerlund & Mitchell (1944), but no specimens available; d = Reported by Rock (undated, 1913), but no more recent specimens available.

		Kipuka Puaulu	Kipuka Ki
AMARANTHACEAE			
* #	Charpentiera obovata Gaud.	+	a
APOCYNACEAE			
*	Alyxia olivaeformis Gaud.	+	
* #	Ochrosia sandwicensis A. Gray	a	
ARALIACEAE			
	Brassaia actinophylla F. Muell.	b	
* #	Cheirodendron trigynum (Gaud.) Heller	+	
ASPIDIACEAE			
*	Athyrium sandwichianum Presl.	+	
	Cyclosorus dentatus (Forsk.) Ching	+	
	Cyclosorus parasiticus (L.) Farwell		+
*	Cyrtomium caryotideum (Wall.) Presl.	+	
*	Dryopteris glabra (Brack.) Kuntze	b	
*	Dryopteris hawaiiensis (Hillebr.) Christ	+	+
*	Dryopteris latifrons (Brack.) Kuntze	+	
*	Dryopteris paleacea (Swartz) Christensen	+	+
*	Elaphoglossum conforme (Swartz) Schott		b
ASPLENIACEAE			
*	Asplenium adiantum-nigrum L.	+	
*	Asplenium cf. caudatum Forst. f.	+	+
*	Asplenium macraei Hook. et Grev.	c	b
BLECHINACEAE			
*	Sadleria cyatheoides Kaulf.	+	+

Appendix A. (continued)	Kipuka Puaulu	Kipuka Ki
CELASTRACEAE		
* # *Perrottetia sandwicensis* A. Gray	+	
COMMELINACEAE		
Commelina diffusa Burm.	+	+
COMPOSITAE		
Achillea millefolium L.	b	
Bidens pilosa L.	+	+
Cirsium lanceolatum (L.) Hill.	+	
Erigeron albidus (Willd.) A. Gray	b	
Erigeron canadensis L.	b	
Hypochaeris radicata L.	+	+
Senecio sylvaticus L.		c
Sonchus asper L.	+	+
Sonchus oleraceus L.	c	
CONVOLVULACEAE		
* *Ipomoea indica* (Burm.) Merr.	+	+
CRUCIFERAE		
Lepidium virginicum L.	b	
Sisymbrium officinale (L.) Scop.		b
CYPERACEAE		
* *Carex macloviana* D'Urv. var. *subfusca* (Boott) Kükenth.	+	+
* *Carex wahuensis* C. A. Meyer var. *rubiginosa* R. W. Krauss	+	
* *Cyperus brevifolius* (Rottb.) Hassk.	+	+
* *Cyperus hillebrandii* Boeck.	b	
* *Cyperus polystachyus* Rottb.		+
DAVALLIACEAE		
* *Nephrolepis exaltata* (L.) Schott	+	+
EPACRIDACEAE		
* *Styphelia tameiameiae* (Cham.) F. Muell.	+	+

Appendix A. (continued)	Kipuka Puaulu	Kipuka Ki
EUPHORBIACEAE		
Aleurites moluccana (L.) Willd.	a	
FLACOURTIACEAE		
* # *Xylosma hawaiiensis* Seem. var. *hillebrandii* (Wawra) Sleumer	b	
GENTIANACEAE		
Centaurium umbellatum Gilib.	b	
GERANIACEAE		
Geranium carolinianum L. var. *australe* (Benth.) Fosb.	+	+
GRAMINEAE		
Agrostis retrofracta Willd.		+
Anthoxanthum odoratum L.	+	+
Briza minor L.	b	
Bromus commutatus Schrad.	c	
Bromus rigidus Roth	c	+
Bromus secalinus L.	b	
Bromus unioloides (Willd.) H.B.K.	+	+
Cynodon dactylon (L.) Pers.	+	+
Dactylis glomerata L.	+	+
Digitaria pruriens (Trin.) Buese	d	
Festuca dertonensis (All.) Asch et Graebn.	b	
Holcus lanatus L.	+	
* *Panicum tenuifolium* Hook. et Arn.	b	
Paspalum conjugatum Berg.	+	
Paspalum dilitatum Poir.	+	+
Paspalum urvillei Steud.		+
Poa annua L.	+	
Poa pratensis L.		+
Setaria geniculata (Lam.) Beauv.	+	
Sporobolus africanus (Poir.) Robyns et Tournay	+	
Stenotaphrum secundatum (Walt.) Kuntze	b	
Unidentified grass	+	+
HYPERICACEAE		
Hypericum mutilum L.	+	

Appendix A. (continued)

		Kipuka Puaulu	Kipuka Ki
IRIDACEAE			
	Tritonia crocosmaeflora Lemoine	+	
LABIATAE			
	Mentha sp.	+	
LAURACEAE			
	Persea americana Mill.	+	
LEGUMINOSAE			
* #	Acacia koa A. Gray	+	+
	Desmodium unicinatum (Jacq.) DC.	+	+
* #	Sophora chrysophylla (Salisb.) Seem.	+	+
LILIACEAE			
	Cordyline terminalis (L.) Kunth	+	
*	Smilax sandwicensis Kunth	d	
LOBELIACEAE			
* #	Clermontia hawaiiensis (Hillebr.) Rock	d	
* #	Clermontia sp.	a	
LORANTHACEAE			
*	Korthalsella complanta (Van Tiegh.) Engl.	+	
LYTHRACEAE			
	Cuphea carthaginensis (Jacq.) Macbride	b	
	Lythrum maritimum H. B. K.	+	+
MALVACEAE			
* #	Hibiscadelphus gittardianus Rock	a	a
* #	Hibiscadelphus hualalaiensis Rock	a	
* #	Kokia rockii Lewt.	a	
	Modiola caroliniana (L.) G. Don	+	+

Appendix A. (continued)

		Kipuka Puaulu	Kipuka Ki
MENISPERMACEAE			
*	Cocculus ferrandianus Gaud.	+	
MORACEAE			
	Ficus carica L.	b	
MYOPORACEAE			
* #	Myoporum sandwicense A. Gray var. fauriei (Lév.) Kraenzl.	+	+
MYRSINACEAE			
*	Embelia pacifica Hillebr.	+	
* #	Myrsine lessertiana A. DC.	+	+
MYRTACEAE			
* #	Metrosideros polymorpha Gaud.	+	+
	Psidium cattleianum Sabine	+	
	Psidium guajava L.		+
NYCTAGINACEAE			
* #	Heimerliodendron brunonianum (Endl.) Skottsb.	+	a
OLEACEAE			
* #	Osmanthus sandwicensis (A. Gray) Knobl.	+	+
ONAGRACEAE			
	Oenothera stricta Ledeb.		+
OXALIDACEAE			
	Oxalis corniculata L.	+	+
PAPAVERACEAE			
*	Argemone glauca L. ex Pope	b	
PASSIFLORACEAE			
	Passiflora ligularis Juss.	+	

Appendix A. (continued)

	Kipuka Puaulu	Kipuka Ki
PHYTOLACCACEAE		
* *Phytolacca sandwicensis* Endl.		+
PIPERACEAE		
* *Peperomia cookiana* C. DC.	+	+
* *Peperomia hypoleuca* Miq.		+
* *Peperomia leptostachya* Hook. et Arn.	b	
* *Peperomia reflexa* Dietr. var. *reflexa*	c	
* *Peperomia reflexa* Dietr. var. *parvifolia* C. DC.	+	+
PITTOSPORACEAE		
* # *Pittosporum hosmeri* Rock var. *longifolium* Rock	a	
* # *Pittosporum hosmeri* Rock var. *saint-johnii* Sherff	a	
PLANTAGINACEAE		
Plantago lanceolata L.	+	+
POLYGONACEAE		
Rumex acetosella L.	+	+
POLYPODIACEAE		
* *Pleopeltis thunbergiana* Kaulf.	+	+
PRIMULACEAE		
Anagallis arvensis L.	c	+
PSILOTACEAE		
* *Psilotum nudum* (L.) Griseb.	+	
PTERIDACEAE		
* *Cibotium glaucum* (Smith) Hook. et Arn.	+	+

Appendix A. (continued)

PTERIDACEAE (continued)		Kipuka Puaulu	Kipuka Ki
*	Cibotium chamissoi Kaulf.	d	
*	Coniogramme pilosa (Brack.) Hieron.		+
*	Microlepia setosa (Smith) Alston	+	+
*	Pellaea ternifolia (Cav.) Link	b	
*	Pteridium aquilinum (L.) Kuhn	+	+
*	Pteris cretica L.	+	+
*	Pteris excelsa Gaud.	+	
RANUNCULACEAE			
	Ranunculus muricatus L.	c	b
RHAMNACEAE			
* #	Alphitonia ponderosa Hillebr.	a	
ROSACEAE			
	Fragaria vesca L. forma alba (Ehrh.) Rydb.	+	+
	Prunus persica (L.) Batsch	+	c
*	Rubus hawaiiensis A. Gray	+	
*	Rubus macraei A. Gray	d	
	Rubus penetrans L. H. Bailey	+	+
	Rubus rosaefolius Smith	+	+
RUBIACEAE			
* #	Coprosma cymosa Hillebr.	c	
* #	Coprosma rhyncocarpa A. Gray	+	+
* #	Gouldia terminalis (Hook. et Arn.) Hillebr. var. antiqua Fosb. forma antiqua	c	
* #	Gouldia terminalis (Hook. et Arn.) Hillebr. var. antiqua Fosb. forma acuta Fosb.	+	

Appendix A. (continued)

RUBIACEAE (continued)	Kipuka Puaulu	Kipuka Ki
* # Gouldia terminalis (Hook. et Arn.) Hillebr. var. konaensis Fosb. forma konaensis	b	
* # Psychotria hawaiiensis (A. Gray) Fosb. var. hillebrandii (Rock) Fosb.	+	+
RUTACEAE		
* # Fagara dipetala (Mann) Engl. var. geminicarpa (Rock) St. John	+	
* # Fagara mauiense (Mann) Engl. var. anceps (Rock) St. John	b	
* # Fagara mauiense (Mann) Engl. var. anceps (Rock) St. John forma petiolulatum (Rock) St. John	b	
* # Fagara sp.	d	
* # Pelea hawaiiensis Wawra var. gaudichaudii (St. John) Stone	+	
* # Pelea puauluensis St. John	+	
* # Pelea zahlbruckneri Rock	+	
* # Pelea sp.	d	
* # Pelea sp.	d	
* # Pelea sp.	d	
SAPINDACEAE		
* # Dodonaea viscosa (L.) Jacq. var. spathulata (Sm.) Benth.	+	+
* # Sapindus saponaria L.	+	+
SCROPHULARIACEAE		
Linaria canadensis (L.) Dumont	b	
Veronica plebeia R. Br.	+	+
Veronica serpyllifolia L.	+	

Appendix A. (continued)

	Kipuka Puaulu	Kipuka Ki
SOLANACEAE		
* # Nothocestrum breviflorum A. Gray	b	b
* # Nothocestrum longifolium A. Gray	d	
Physalis peruviana L.	+	+
Solanum pseudocapsicum L.	+	+
THYMELAEACEAE		
* Wikstroemia phillyreaefolia A. Gray	b	
TROPHAEOLACEAE		
Tropaeolum majus L.	+	
UMBELLIFERAE		
Hydrocotyle sibthorpioides Lam. var. oedipoda Deg. et Greenwell	+	
URTICACEAE		
* # Pipturus hawaiiensis Lév.	+	+
* # Urera sandvicensis Wedd.	+	
VERBENACEAE		
Verbena litoralis H. B. K.	+	+
ZINGIBERACEAE		
Hedychium coronarium Koenig	+	

C- VEGETATIONAL RESPONSES TO VOLCANIC ACTIVITY IN THE CHAIN-OF-CRATERS AREA

By F. R. Fosberg & C. H. Lamoureux

Because of the March 1965 lava flow, it seems wise to provide the following four categories of notes collected during the course of obtaining the material for this Atlas. While provided by the authors as information to be used, these notes were not submitted as a manuscript for publication. However, their prospective value to future Park students has led the editor to include them. They concern four places (Fig. 8) along the Chain-of-Craters Road. Excellent places for observation; they are named here, the Aloi hot spot, the Puhimau study area, the Puhimau hot spot and the Napau Crater area.

1- Vegetation of the Aloi hot spot.

A brief reconnaissance was made of the Aloi "hot spot" (Fig. 8; Aerial Photo 8-0068) crossed by the Chain-of-Craters Road, adjacent to Aloi Crater in November 1963 and March 1964 with other studies being made later (e.g., in March 1965). This area has enlarged since the first examination in 1963, but at that time few notes were taken so no adequate comparison can be made. In March 1964 F. R. Fosberg took descriptive notes and made a list of the plants seen, even though time was not available for a detailed study. A more thorough investigation with a map showing the steam vents, soil temperatures and vegetation is recommended as soon as funds and personnel are available.

In March 1964 there was an area of perhaps several acres where the ground was partly bare and partly covered by sparse vegetation with some clumps being denser. This was surrounded by a zone of yet more dense vegetation, much of which was dead, some of it apparently quite "cooked" though not yet decomposed. In this area were some steam vents and especially some elongate, rather fresh looking cracks from which steam issued at temperatures measured between 81 and 86 deg. C. There was a slight sulfurous odor to the steam in this area, but nowhere was it strong enough either to be very uncomfortable nor was any sulfur being deposited.

Several years ago (at least as recently as November 1956 (St. John, 1957)) Ophioglossum nudicaule L. f. var. minus Clausen was found in some of these vents. No plants of this were seen during the 1963 visit though they were looked for.

The central, essentially bare area had in places little but a thin film of a blue-green alga, Stigonema, with scattered plants of Fimbristylis and Cyperus. These bare areas may have been around vents but were just as likely to have been found a little way from any obvious steam. In slightly more vegetated areas, Digitaria, Sacciolepis, and Paspalum were scattered but common. Andropogon was locally common but much of it was dead. Around many of the vents, Euphorbia thymifolia was very abundant but not around the hottest. Arundina was locally common and Nephrolepis hirsutula even more so. The latter seemed to form spots where there was evidence of past vegetation, e.g., peaty areas supporting stubs of old dead vegetation and small clumps of dwarfed Gleichenia. Near some of the vents were patches of Sphenomeris, always very dwarfed. Pteris was found, though rarely, in similar situations. Waltheria indica was generally common in the more vegetated spots. Locally, Lycopodium cernuum was found though rather small and mostly vegetative. Small shrubs of Metrosideros were occasional in this area, mostly dead or nearly so and much more common and in somewhat better shape in the peripheral area. Small plants of Psilotum nudum were seen generally scattered, only a few stems at a time, and these all seemed to be dead or dying. Not a single, healthy individual of this species was seen. A few plants were seen of Ageratum, Cuphea, Conyza, Elaphoglossum, Euphorbia hirta, Vernonia, Sadleria, with no obvious pattern of occurrence, and one seedling of what probably is Gnaphalium purpureum.

On parts of the bare areas, Cladonia cf. rangiferina was quite abundant. In places this was on ground that was moist and steamy and the lichen was then very soft and almost jelly-like at the base though apparently dry above. Very locally, another Cladonia cf. cristatella was found. Stereocaulon vulcani was locally very common on bare soil, but in many places when touched it crumbled, apparently dead from the heat. Cushions of Rhacomitrium were locally abundant, in some places dying or dead from the heat.

Toward the periphery, vegetation generally becomes more abundant, especially Gleichenia and Nephrolepis, which together form large patches. Locally, however, these were dead or dying. Metrosideros bushes were more common and in better condition though still often dead above and sprouting or with dead tips. Small Psidium cattleyanum 1-1.5 m tall, also partly dead, was locally common. Psidium guajava was very rare. Styphelia tameiameiae, frequently partly dead, was locally common. Waltheria and, less so, Stachytarpheta were found locally. Clumps of Machaerina became common toward the periphery of the area. In open spots, most of the herbs listed above were found at least occasionally.

The species found in this hot spot (Table IV) are an interesting lot, the ecology of which should be studied further. They fall into two natural groups as indicated in that Table. Surrounding the actively steaming area is a zone of Gleichenia with scattered small Metrosideros. Time has not

Table IV. Lists of the species recorded in the Aloi hot spot area, March 16, 1964. List "A" is of those seen in the more open actively steaming area. List "B" is of those seen in the peripheral area dominated by living or dead vegetation. The following abbreviations indicate relative abundance: a = abundant; la = locally abundant; c = common; lc = locally common; o = occasional; r = rare.

List A

la	*Euphorbia thymifolia*
la	*Sphenomeris chinensis*
la	*Andropogon virginicum*
la	*Cladonia* cf. *rangiferina*
la	*Rhacomitrium lanuginosum*
la	*Stigonema* sp.
c	*Waltheria indica*
c	*Fimbristylis dichotoma*
c	*Cyperus polystachyos*
c	*Sacciolepis contracta*
c	*Psilotum nudum*
c	*Metrosideros collina*
c	*Arundina bambusifolia*
lc	*Paspalum orbiculare*
lc	*Digitaria chinensis*
lc	*Nephrolepis hirsutula*
lc	*Ageratum conyzoides*
lc	*Pityrogramma calomelanos*
lc	*Gleichenia linearis* var. *tomentosa*
o	*Veronia cinerea*
o	*Euphorbia hirta*
o	*Cuphea carthaginensis*
o	*Lycopodium cernuum*
r	*Sadleria cyatheoides*
r	*Elaphoglossum reticulatum*
r	*Conyza canadensis* var. *pusilla*
r	*Pteris cretica*
r	*Gnaphalium purpureum* (?)

List B

a	*Gleichenia linearis* var. *toment*
a	*Nephrolepis hirsutula*
la	*Andropogon virginicum*
c	*Metrosideros collina*
c	*Waltheria indica*
c	*Arundina bambusifolia*
lc	*Psidium cattleyanum*
o	*Styphelia tameiameiae*
o	*Stachytarpheta dichotoma*
o	*Lycopodium cernuum*
o	*Gleichenia linearis* var. *linear*
o	*Machaerina angustifolia*
o	*Spathoglottis plicata*

been available for the exploration of this area further.

2- Tagged Metrosideros trees at the Puhimau study area.

Ten individual *Metrosideros* trees were tagged in November 1963 between the crater and the Chain-of-Craters Road (Figs. 8 & 23; Aerial photo 8-0104) and notes taken on them to start an investigation on the rate of progress of a "disease" which seems to have caused the death of a large number of trees in the Puhimau Crater area. These trees, re-located on March 16, 1964, were re-examined to note their condition in comparison to that four months earlier. The following observations made on ten of these are expressed in terms of comparison with the condition noted and recorded in November.

Tree #1. (Tag missing, the following notes apply only to a tree most likely to have been #1.) Looks about as described in November, but one large lower branch completely dead. Most twigs have 3-5 cm of new growth, but leaves on this tend to be small, somewhat pale and reddish.

Tree #2. Essentially the same as in November, but many twigs show as much as five or even eight cm of rather pale green new growth.

Tree #3. This tree has declined. Certainly far less than one-fifth of the twigs are still leafy. The leaves are much more brownish-red than green. A few small, new sprouts several cm long show pale yellowish green leaves.

Tree #4. About the same as in November, but almost all twigs have put forth a few cm of new growth. Galls on the leaves are very numerous, even some on the new growth.

Tree #5. Essentially as in November but looks generally somewhat less healthy. The leaves tend to be splotched, the older ones turning red. Young growth appears on many twigs, but tends to be red, distorted, dwarfed and galled.

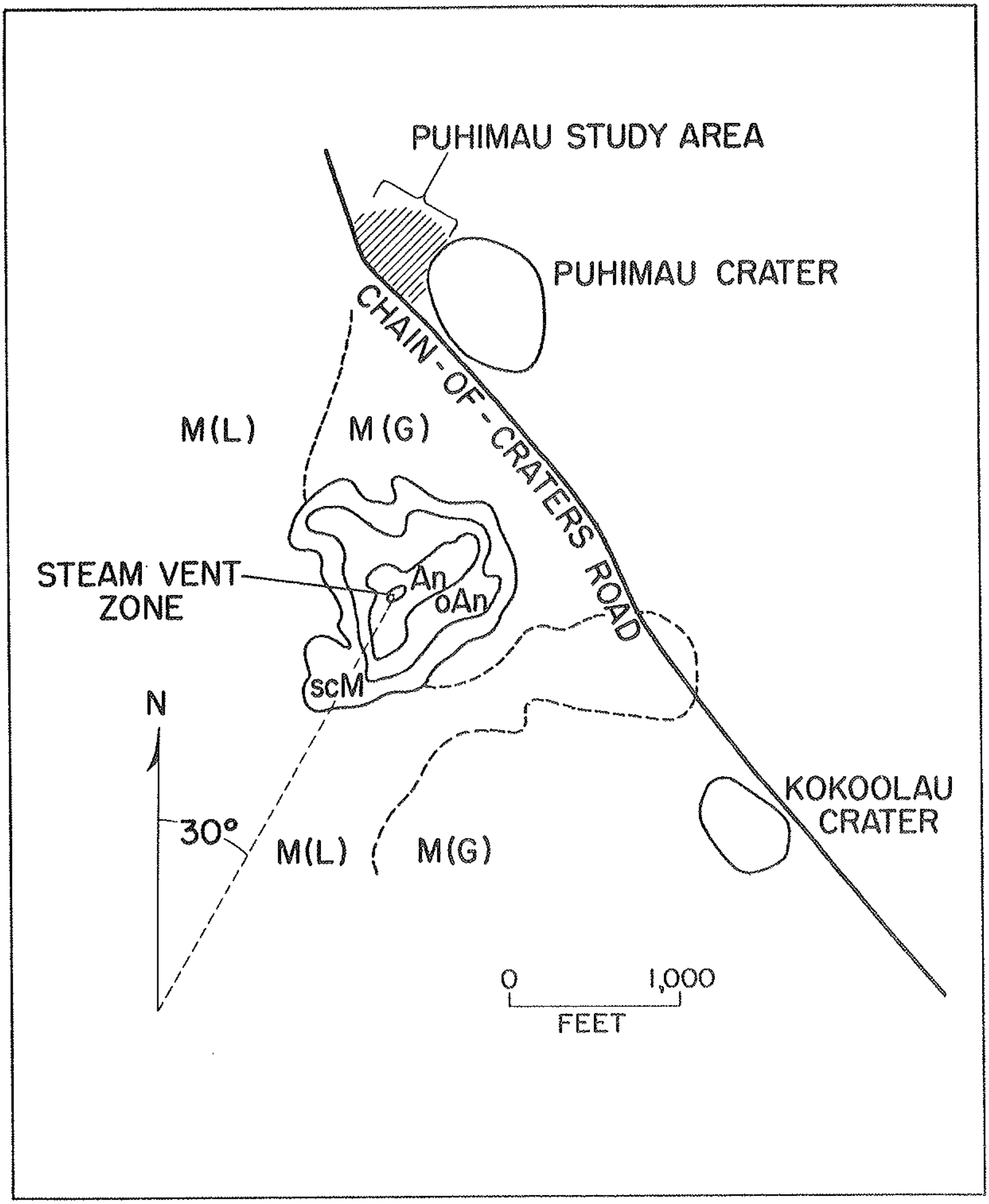


Fig. 23. Map of the hot spot south of Puhimau Crater to illustrate the major more or less concentric vegetational areas and the transect sampled by various people bearing 210° from the center of the steam vent zone. The map symbols for vegetation are those of the vegetation mapping described in Chapter VIII. "An" meaning a rather closed stand of Andropogon virginicus; "oAn," an open stand of the same Andropogon; "scM," scrub cover of Metrosideros colina; "M(L)," Metrosideros with the lichen, Cladonia, as a ground cover, and "M(G)," Metrosideros with the ground cover largely Gleichenia.

Tree #6. About as in November, but perhaps more leaves reddish or brownish. A few cm of young growth on many twigs, large buds on some others with large galls abundant even on the new growth.

Tree #7. Essentially as in November, but most branches have put out new growth, some as much as 10 cm. The new growth on some twigs tends to be pale and reddish.

Tree #8. A considerable number of leaves have turned brown or reddish, especially on lower and middle branches. Some twigs have young growth up to 5-6 cm long, mostly healthy, but some twigs are a bit pale. Many branches have well-grown flower buds, several inflorescences are just starting to flower.

Tree #9. All leaves are now dead, some of them still persisting on the tree. The bark when cut appears dead and dry inside.

Tree #10. This is still rather healthy-looking, generally fruiting but only one or two inflorescences still in flower. There is abundant new growth. This is rather pale, but on upper branches seems healthy. The extreme upper twigs of the tree seem not very healthy as the leaves are rather small and there is not much young growth. The tallest basal shoot (about 3 m) has its young growth acutely dwarfed and infested with galls; the leaves of this shoot are a bit brownish, not as healthy-looking as in the tree itself. Another similar basal shoot is reddish-yellow-green, has little new growth and looks unhealthy. A third, smaller shoot has a rather reddish appearance, but has some reddish young growth; the leaves of the lower branches of this shoot are turning red on the lower parts of twigs.

A brief check by cutting into the bark of a number of the non-tagged trees in the area shows that the inner bark of most is red and juicy, but in a few it is pinkish and tends to be rather less juicy.

Across the road from Puhimau Crater, two rough transects were walked, perpendicular to road, and 100 trees checked in each, over 5 m tall. In one there were 32, in the other 28, badly diseased or dead trees. Just above Kokoolau Crater, two transects were walked, south of road, counting 100 trees in each, over 4 m tall, in open to semi-open Metrosideros forest up to 20 m tall. In one of 23 trees, 10 were dead, the rest partially dead, or had obviously-dead parts. The other transect showed 15 affected trees, 5 of them dead.

This condition seemed to prevail generally along the Chain-of-Craters Road, worse in some places than others. Nowhere, however, was it so extreme as here, northwest of Puhimau Crater.

More such transects should be walked in various parts of the Metrosideros area of the Park. Some transects should be permanently marked and re-examined. The method of doing rough transects is to walk with a counter in hand, clicking it for all trees over minimum height within easy counting distance, about 10 m on either side, estimating height of dead, broken trees, from diameters, and noting down the trees that are dead or have conspicuous dead parts. Dead twigs are ignored.

3- Puhimau hot spot.

Along the Chain-of-Craters Road, just south of Puhimau Crater (Figs. 8 & 23; Aerial Photos 8-0104 & 8-0106) a circular area in the vegetation shows as light spots on conventional black and white photographs and as a dark spot on infra-red photographs. This latter darkening indicates surface temperatures over 48 deg. C. A preliminary study of this area was begun by a rough mapping of the vegetation (Fig. 23) and soil sampling for various factors. This latter was along a profile extending outward from the center of the hottest area on a heading of 210 degrees.

The soil sampling included work toward distributional studies of the microorganisms of which the algal work completed (Table II in Chapter VI, above) indicates interesting and correlated variations.

In the steam vent zone and open Andropogon (oAn on Fig. 23) area temperatures of 48 to 89^{0} C were measured. Much of the soil is white as though it were ash from a fire. The closed Andropogon area (An) is warm at the surface, the temperatures measuring 46-47^{O} C. The scrub Metrosideros area has normal surface temperatures, but it is presumed those of the tree root zone are high. Actually some aerial photographs show a large outer contour to this spot not shown in the present figure.

4- Napua Crater area.

The Napau sulfur-affected area (Figs. 5 & 8; Aerial Photos 8-0026 & 8-0028) just west of the crater, the crater floor itself, and kipukas on the crater floor were briefly examined in November, 1963, and re-examined on March 15, 1964, though because of unfavorable weather perhaps certain aspects were not studied as carefully, even as the limited time available would otherwise have permitted. The crater floor and kipuka areas were completely covered (Fig. 5) by lava earlier during March, 1965, one year later. The following notes are included to assist future students of the area.

About 300 m below the side trail around the rim of Makaopuh Crater on the Napua trail, a spot was noticed where the air seemed appreciably warmer than elsewhere. A trace of steam could be seen and a small area of the generally luxuriant Gleichenia tangle was dead or apparently so. This was only a few meters across.

Along the trail a few dead shoots of Lycopodium cernuum were noticed here and there, but most plants of this species seemed healthy. Shortly before reaching the pulu factory, the numbers of these seemed to be greater. It is not suggested that these have died since November, 1963, but that, since at that time this species was seen to be affected by sulfur fumes, more attention was paid to it in the upper parts of the trail. Whether or not the dead shoots in the area between Makaopuhi and the pulu factory were, in March 1964, due to the sulfur is hard to guess. Sulfur fumes undoubtedly reached here, but the bulk of the Lycopodium population was certainly not visibly affected. There was only a small proportion of dead or unhealthy-looking plants. No other unusual effects were evident.

Toward Napau Crater from the pulu factory, the number of dead Lycopodium shoots increased rapidly along the trail and by the time the somewhat smaller and more open Metrosideros forest was reached, almost all the mature shoots were either dead or only had the main rachis green. However, numerous green, actively growing shoots were growing up from the prostrate stolons below.

In the neighborhood of the pulu factory, some Cibotium ferns showed dead lower leaves though the newer leaves were healthy. Dead fronds were not noticed here in November, 1963, but may have been present.

In the more open area on the 1840-flow, starting somewhat east of the pulu factory, not much of an abnormal appearance could be seen except for the dead Lycopodium shoots mentioned above. The Metrosideros trees had largely recovered from the partial defoliation observed in November though they still were a bit sparse. Along the trail somewhat below the beginning of the sparse, 1840-flow area, there were many dead fronds on the Gleichenia, but vigorous, newer, immature to mature ones were abundant. Here, also, Machaerina angustifolia and the much rarer M. meyenii, showed many dead or partly dead leaves, but also many, young healthy ones. Some plants of firmer species were flowering. Just below here above the steeper stretch of trail, the sparseness of the Metrosideros became more striking, seemingly more so than as remembered from November. Here also, about 50% of the fronds of the Gleichenia were dead, the rest green.

On the zone of steeper slope, the vegetation was much less dominated by Metrosideros. Here was a somewhat open mixture of Androgogon with a few other grasses, Machaerina, Cyperus and other sedges, Gleichenia, Arundina, Polypodium pellucidum, and some scattered dwarfed Metrosideros. The Arundina seemed normal, but here the recovery of Lycopodium cernuum from the severe damage noted in November was much retarded. The Andropogon and Cyperus polystachyos had both the leaves and inflorescences dead above. Sacciolepis contracta showed no bad effects. Below this slope on the relatively level, but still open ground, the Gleichenia, at least, and perhaps also the Lycopodium showed more recovery or less damage than on the slope.

Beyond the fork in the trail on the right branch, the forest was much taller and greener for a short distance, and nothing showed much damage. Only the Lycopodium and Gleichenia showed some dead parts. The Metrosideros trees here had begun to show many leafless branches and some trees were completely leafless. These had dead bark, also. In an area to the left of the trail, there were many dead trees and but few healthy ones. After this and further toward Napua Crater, there was a stretch of trail through forest that looked almost normal. Then an area of tall Metrosideros forest with a conspicuous understory of Cibotium extended to the edge of Napau Crater. The Metrosideros showed little evidence of the defoliation evident in November, 1963. The Cibotium which had no living fronds then, now all had 2 or 3 fully developed green fronds. In this area Coprosma, Gouldia, Cheirodendron, Alyxia, and Pelea showed no evidence of any damage and Vaccinium calycinum very little except that all leaves seem to be rather young. Broussaisia was putting out vigorous, young shoots from otherwise leafless shrubs.

Away from the crater the Lycopodium cernuum was still producing some new shoots, but near the crater none at all. The most persistent and striking effects seemed to be on the epiphytes, bryophytes, and ferns. All bryophytes in this forested area were dead (with the possible exception of terrestrial forms covered by an unusual amount of dead fallen leaves) as were Polypodium tamariscinum, Grammitis tenera, Elaphoglossum hirtum, Hymenophyllum spp., Psilotum, and Selaginella cf. menziesii. Elaphoglossum reticulatum, however, had completely recovered and showed no effects whatever. Its leaves were bright green, firm, and leathery, and its rhizome hard and alive. Some distance to the right toward the gulch leading to the crater floor, abundant new shoots of Selaginella had appeared both on the ground and epiphytically. Whether these represented recovery or new sporelings was not determined.

At the crater's edge, the Styphelia and Coprosma ernodeoides had produced new, vigorous, leafy shoots. Isachne distichophylla had resumed active growth from its stem tips. Vaccinium and Gouldia were healthy, and the Metrosideros looked almost normal. On the trail, Youngia japonica had appeared in abundance. There was considerable Cyperus polystachyos and C. brevifolius that seem almost normal. Hypericum was very common as was a broad-leafed sterile unidentified grass. Sacciolepis and Paspalum orbiculare were common and healthy. The Youngia was common locally in the woods away from the trail in spots that were not too densely covered by dead leaves.

In the gulch leading down to the crater floor, the damage, as before, seemed to be generally less conspicuous than on the flat above. Some bryophytes were still living, but most of the epiphytic bryophytes as well as epiphytic ferns were thoroughly dead. Cibotium fronds here were partly brown but not dead. Selaginella, also, was somewhat brown but not dead. Peperomia and Thelypteris seemed to have recovered very well.

On the new (1963-) lava crater floor no plants had appeared (except a tiny seedling found deep in a crack by Lamoureux). In a small kipuka in this 1963-lava pool devoid of any living plants in November, seedlings of a number of species had appeared. With one or two exceptions, the seedlings have appeared on scorched, peaty soil lying on the surface of the old lava rather than on the 1963-lava itself. Their number, names, and sizes are listed:

1 Andropogon virginicus (3cm).

1 Conyza bonariensis? (small rosette).

1 Cyperus cf. polystachyos.

Many Dubautia scabra (to 1 cm).

9 Erechtites valerianifolia (very small to 50 cm tall, one budding).

1 Gnaphalium sandwicense (10 cm).

Many Isachne distichophylla (mostly small, one 10 cm).

Many Machaerina angustifolia (small to 4 cm).

4 Pipturus albidus (red veined) (to 4 cm).

1 Pluchea odorata (small rosette).

8 Rubus rosaefolius (several cm).

1 Senecio sylvatica (15 cm).

1 Unidentified plant with firm, opposite, obtuse leaves to 15 mm long.

A tiny satellite kipuka, very near the large one which had apparently no living plants in November, also showed some growth. One Metrosideros shrub out of two was putting forth a few tiny sprouts at the base. There were three Erechtites valerianifolia seedlings, one budding, 25 cm tall; one Pluchea odorata 10 cm; a few very tiny Hypericum; and many Machaerina augustifolia up to 6 cm. In sheltered places and crevices on old lava fern gametophytes and tiny sporelings were abundant. A few small patches bore tiny moss plants.

The larger kipuka looked perhaps a bit drier than in November, but most plants were showing some recovery except Lycopodium. No L. phyllanthum was seen, and not a single living sprout or stem of the more abundant L. cernuum was seen. Machaerina angustifolia was alive but not flowering. Dubautia scabra was flowering abundantly and Vaccinium reticulatum somewhat less so. Styphelia was sending out some new sprouts. Gleichenia showed both dead and green fronds.

On the scorched peripheral area on the north side of the kipuka, seedlings of Erechtites valerianifolia, E. hieracifolia, Pluchea odorata, and Pipturus albidus, as well as many tiny unrecognized seedlings and sporelings had become established.

Almost no steam was issuing from the new lava surface on the crater floor except along a line stretching east-west across the crater to the north of the above mentioned kipuka. On the flat just west of the crater, to the north of the trail in line with the line of steaming vents on the crater floor below, was a hot, abundantly steaming area which, judging by its vegetation, had not been hot or at least not so hot for very long. The steam from many of the vents was uncomfortably hot. The area was covered by Gleichenia linearis and Andropogon virginicus in a dense mass, with clumps of Machaerina angustifolia and a sparse stand of dwarf Metrosideros as well as scattered other plants including Lycopodium cernuum. The Metrosideros, Andropogon, and Gleichenia were mostly dead, the Machaerina mostly still alive. In the hottest areas the Lycopodium was completely dead, but where there was any green vegetation, the mature Lycopodium shoots were dead but green, new sprouts were growing from the basal stolons. The gas from the numerous fumaroles smelled sulfureous but not strongly so. This suggested that sulfur fumes below a critical concentration may not have a serious effect on Lycopodium. The dead shoots may probably date from the time of the October eruption when stronger sulfur fumes covered the area.

There were numerous fumaroles in the area, some producing jets of uncomfortably hot steam, and in much of the area where the fumaroles were hottest and most numerous, the vegetation was entirely dead, but mostly not yet disintegrated. Immediately around some of the fumaroles, open areas were beginning to appear and the dead Gleichenia was becoming rather low. It seems probable that in the near future, an open area similar to that near Aloi Crater (the "hot area" described above) may develop here.

This area should be accurately mapped and described in the very near future and periodic checks made on the development or retrogression of the vegetation. In fact, it would be of interest to map and describe the Aloi area and any other new warm or hot spots that appear, as well as any areas where fumaroles occur or develop. Both physiognomic and floristic comparisons should then be made at fairly short intervals. Photos should also be taken regularly from fixed points. These variably-hot sites are unique study areas provided in Hawaii Volcanoes National Park.

D- PUU PUA'I AND THE DEVASTATED AREA

The 1959 November-December eruption in the wall of Kilauea Iki (Fig. 10) produced a new lava surface flooring this crater, produced the cinder cone Puu Pua'i and, beyond it, produced as a shadow to this cinder cone a field of windblown ash. The article by Zahl (1959) and its accompanying photo record illustrates the initial events of this eruption. In the area all organisms were destroyed or damaged.

Thus, this section is in three parts describing 1) the eruption, 2) recovery of the devastated area and 3) succession where the previous population was completely destroyed. There are on file various sets of notes on these events by Smathers (18-month summation, 1963b), Wentworth (Initial report, 1960) and Wentworth and Haugens (Early recovery, 1960). Very conveniently, similar old areas remained undamaged nearby and these serve very well as control areas. This study has been continued by the University of Hawaii team and its notes are on file in the Park as well.

1- THE ERUPTION AND THE ORIGINAL POPULATION

(From C. K. Wentworth's "Initial Report")

Kilauea Iki is an ancient pit crater, near Kilauea on the east rift zone. Its sides are steep in places but nearly everywhere well wooded. The major shape of the crater with somewhat sloping sides gives a rough estimate of its age as several hundred and, probably, several thousand years. There were very small flows down its west side and into the bottom in 1832 and 1868. The less weathered surfaces of the latter flow in the bottom were covered with a scattering of ohia trees but were less wooded than the sides.

The adjacent edge of the floor of Kilauea is nearly bare of trees but has a sparse scattering of shrubs and trees that have commenced slowly to grow on the surface; that side to the north was covered by lava flows in 1919. The greater part of Kilauea is essentially devoid of trees. Otherwise, the area surrounding Kilauea Iki is forested, heavily at the east but dwindling a mile or so west and southwest of the crater.

The 1959 eruption caused various kinds of damage to adjacent vegetation, from complete killing by burial under the pooled lava in the Kilauea depression or the cinders of the three hundred foot cone, Puu Pua'i (Fig. 10), to only temporary effects of fume or retardation or augmentation in relation to lesser cinder cover over a wide area. If the natural forest under the existing climate is considered, the story of the ultimate reforestation which will be restored to the top and lee sides of this new cone, Puu Pua'i, may be written a hundred years hence.

The vegetation and trees in the lower 300 feet of the former pit were wholly consumed. Around the margin of the lake, where lava reached only during surges, a few tree molds were left. As lava rose in successive episodes, trees at the margin, already dried by the heat of the encroaching lake, caught fire and added their flares to the lurid scene. Many of the fires burned a strip up the sides of the crater and threatened surrounding country. Whether any considerable number of tree molds are preserved under the deeper parts of the fill of lava in the lake is not known; their preservation was threatened by the vigorous remelting of the lava which later enveloped them, but it seems certain that some have been preserved.

Burial and killing of vegetation over the base area of the cone Puu Pau'i where the thickness of the cinder is over 25 feet is certain. There seems little evidence that any trees survived a surrounding cover of so much as 10 feet. Beyond the periphery of the completely bare area of the cone, there begins a belt of fallen and completely defoliated trunks of the former forest. A few yards wide it merges outward with a belt of tree molds, followed by another narrow belt where the trees are still standing but scorched and defoliated. Outside this belt the trees have been severely excorciated by falling pumice and clots of lava, but these are recovering as their trunks are heavily furred by a new growth of leaves on the trunks. For months the tops of these trees were covered with the stripped and dead, smaller branches.

In the central area of deep burial, there was no survival of trees or roots or seedlings. Here is an area which we may suppose will be reforested, perhaps with seed from the surrounding undamaged country.

Some trees and shrubs were temporarily buried and widely defoliated by mechanical impact from falling debris. Though annual weeds, ferns and such were destroyed or covered at the time of eruption, many of the trees and larger plants at the margin survived and regrew from their buried bases. Ferns were particularly responsive in recovery and showed new fronds in a few days. The climate is such that vegetative growth takes place at all seasons. It appears that growth of fern buds toward the surface in cinder can certainly take place from depths of three or four feet. Refoliation of the trunks of small trees that had been excoriated was a conspicuous process in the weeks that followed the eruption.

In several areas where there was a heavy fall of slung clots of lava, which molded somewhat together, but was of lava insufficiently molten to flow as a whole. The heat of three of four feet of this was sufficient to burn off the trunks of the trees and form numerous tree molds. These are from less than an inch in diameter to over a foot and show the usual features of the shape and branching of the trunks. There are, no doubt, many of them under the coverings of cinders where the lava clot layer lies below the cinder layer. In many cases the fallen trunks lie close to the mold and show a tapered burnt end with the final tip unburnt but broken.

In an area adjacent to the impressions molded in lava, where the layer of cinders is but a few inches thick over the lava molds, the cinders have slumped into the underlying lava mold forming another type of tree mold, funnel-like in form.

In areas where observation could be made the fallout of cinders and even cobble-size blobs was at the rate of several feet of depth per hour but mostly for quite short periods. This environment at that time, was untenable for humans except by inadvertance and rough on trees and the few buildings in the area, particularly those at the old summer camp. Trees were stripped of their leaves, bark and smaller branches, and many are now either buried or remain denuded today. Farther from the source of the lava fountains, trees were heavily scarred but the trunks retained enough vitality so that subsequent recovery took place in the form of numerous small leaves and then quickly a rather lush foliation from the trunk, including flower buds which went on into a conspicuous blossoming of the red lehua. The furry refoliation of the lower ohia trunks, with increasing flowering of certain trees, and the bare, killed slender twigs at the top gave a very bizarre appearance to many of the trees.

In the heavy fallout areas, flung blobs of soft lava landed in the forks of trees. Some fell at once, others clung long enough to scorch the tree but fell after the cooling due to crumbling. A few remained draped in trees which still stand and can be seen today. A number of larger trees intercepted enough clots and cinder that when they fell they formed a mound on the near side of the tree.

Some of the small fires that burned up the inner sides of the crater burned several months after the close of the eruption. Some even occasioned enough alarm that the National Park fire department was called out, but there was no spreading.

At times during the eruption, the winds were aberrant enough, or calm enough, that fumes from the eruption sat low and people living in certain districts noticed fume damage to certain plants. It does not seem that this was severe enough or of long enough duration to cause definable economic damage. Other eruptions, at certain times, have affected plants enough or persisted long enough to occasion crop loss or have an appreciable effect on humans, especially those in delicate health. At times the fumes have been restrained under an inversion layer in the atmosphere, and thence at a given level have drifted against the mountains to make their effect, but not in this case.

2- RECOVERY OF THE DEVASTATED AREA

By Garrett Smathers

Where the ash fall was light and the plants were merely denuded or superficially buried, the woodier tended to recover. To be able to follow the recovery, a belt transect, which forms part of the major axis of the cinder and pumice fallout area, was laid out (Fig. 10) to determine floristic conditions and composition resulting from the devastation. Data from this will help in analyzing vegetative recovery corresponding to the climatic, physiographic, biotic, and edaphic factors involved. This major transect extends from a point near the summit of Puu Pua'i for a distance of 4800 feet, 200 degrees west of south, to a high point in the Kau Desert. It has been laid off in 15 meter sections, each marked with a wooden stake about four inches above ground. Four weather stations were located (Fig. 10), three at 2600 foot intervals along this line and a fourth in the crater of Kilauea Iki, itself.

These stations will provide data on meteorological phenomena occurring in the transitional zone between the leeward and windward climates. The transect has not been mapped; thus we do not know the floristic composition, distribution, devastation and vegetational recovery throughout its length.

Photo stations were established and near them bisects were made to ascertain methods of recovery; also photos were made of recovery in shelters such as tree molds, cracks, lee side of trees, tree holes (both dead and living trees), and similar habitats. Other vegetative manifestations such as aerial roots on Metrosideros, some over a meter long, have been photographed.

Four 5-by 5-meter quadrats were established on the southeast side of the cinder fallout area, about 500 feet from its periphery. These, when suitably mapped and checked every six to eight months, should reveal interesting aspects of early succession upon pumice, cinders and spatter substrata. These quadrats urgently need mapping and tests should be run on the pumice, cinders, and spatter for chemical, biotic, and moisture content. The primitive edaphic conditions prevailing now can tell us a lot about pioneer colonizers and their developing associations.

The pumice and cinder field (the area of pyroclastic material fallout) for the plant ecologist is unique because of its geologic composition and geographical position (bisected by a rain shadow). Here both leeward and windward climates are manifested at an elevation of approximately 4000 feet.

In 1960, the photo stations established throughout the area allowed some means of recording vegetative recovery and succession. While these photographs have been very useful in depicting recovery of trees and shrubs (especially their foliage), they are inadequate in recording pioneer colonizers and association. Also they do not permit a quantitative analysis of the life forms present, seral composition, or of populations appearing on tree boles and in tree molds.

The most remarkable aspect of the devastation, plant recovery and succession is that being exhibited by ohia, Metrosideros. Nearly 100% of these mesophytes were killed within 2500 feet downwind (southwest) from the main vent by heat, excoriation, pumice and spatter deposition. Starting at about 75 inches of deposition (downwind), the first survivors appeared and became more numerous toward the southwest as pumice deposition decreased. In the area of complete devastation, Metrosideros seedlings were found growing in the protection of tree molds and at the leeward base of dead trees. Outside the area of complete devastation, sprouts from trunks of covered trees have pushed through the pumice.

Field inspection of each photo station quadrant shows a high number of exotic plants present. At Station #1 of line #1 the lists prepared show over 75% of the pioneer colonizers to be exotic plants. It is difficult to establish which species or taxon first appeared. While the early establishment of photo stations was most desirable, much valuable information was lost by not placing quadrats in each photo quadrant. However, part of the developing sere may be seen at Station #1, line #1 (along the boardwalk). Here Buddleja asiatica, Nephrolepis cordifolia and Rubus rosaefolius, dominated among the initial colonizers. These are (in 1963) being replaced by Setaria geniculata, Paspalum conjugatum, Cyperus rotundus and Holcus lanatus. Following this association endemic and indigenous species appear such as Cibotium chamissoi, Astelia menzessiana, and recovering Metrosideros collina, var. polymorpha.

The pumice and cinder field is revealing many interesting phases of vegetative recovery and succession. More attention has been given to this area than the crater floor. Spatter pumice and cinders, either by physical nature or location, are helping to create numerous habitats, along with tree molds and lee side of dead trees. Remarkable "migration" of some species, though there may be some question as to ecesis, has been made to spatter areas and to those places of low cinder deposition. Most plants appearing on the former substratum have developed from dispersed disseminules. While on the latter buried rooting systems have pushed stems through several inches of cinders and pumice and formed low-lying shrubs. The distribution appears go be correlated with precipitation and the physical nature of the substratum.

Most of the pioneer colonizers (from seed) are exotic types, and along the boardwalk they appear in great quantity. Most represent the families Compositae, Rosaceae, and Gramineae. Analyses of photo quadrants tends to show some of the exotic plants being replaced by endemic and indigenous species.

Ohia (Metrosideros collina var. polymorpha) exhibits some very interesting aspects of recovery and reestablishment. Most noticeable are that branches and branchlets appear on the lee side of devastated trees, while their windward side remains bare. On a few trees all of the conductive tissue was destroyed on the windward side by flying pumice and cinders, thus leaving narrow strips of conductive tissue on the lee side. The majority of recovering trees were not greatly excoriated on their windward side. But their buds were killed there or reduced in number by the blasting by hot cinders, severe desiccation by superheated air, or a combination of these and other physical factors perhaps such as acid or gases.

Ohia trees, approximately 2400 feet (downwind) from the main vent, were stripped of their branches but buds remained alive in the bark. These have given rise to numerous foliated branches that give the trees a fuzzy appearance.

Manifestations of the devastation wrought, especially on live branches on the lee side of trees, tell a story of prevailing trade winds carrying lava from the fountain southwestward.

In areas where burial was 100 inches or more it appears all conductive tissue was destroyed above ground by heat and excoriation. In all probability the rooting system remained alive for an extended period, but died later because of lack of food since there were no leaves.

This hypothesis is supported by one large tree that produced a few leaves on its lee side one year after the eruption. During the following year all the leaves disappeared and since then none has reappeared. It is reasonable to assume that these few leaves were unable to manufacture the amount of food needed.

Some young ohias were completely destroyed above ground; however, the rooting systems apparently were not injured. In several areas the underground parts have pushed stems through four to ten inches of pumice and produced shrubs two to three feet high.

It was reported that within one to two years after the eruption the recovering trees produced a profuse bloom of lehua blossoms. Apparently this indicates more energy available for flower development. Horticulturists often produce a profusion of blooms on shrubs by pruning twigs and branches, a process carried out by the eruption in this case. It is interesting to note that these numerous blooms produced a copious supply of seeds that became dispersed presumably throughout the devastated area.

Most of the seeds that have germinated seem to be in sheltered places and at present appear to have become established.

Another interesting adaptive ability of Metrosideros, after devastation, was the development of aerial roots. Several of these reddish woody appendages have been seen to have taken root. Most of them hang one to two feet from the trunks or limbs and, in allover appearance, resemble witches'-broom formations. By observing trees within and outside the devastated area, it is evident Metrosideros is more likely to develop these appendages after some type of injury. Those trees surviving the devastation exhibit more aerial roots than those outside the fallout area. It is difficult not to believe that these aerial roots are not performing the vital functions of absorption normal to aerial roots. However, Rock (1917) believes their presence is due to "a law of heredity, the reverting to, or the producing of certain characters peculiar to the ancestor." He bases this on observing Metrosideros possessing aerial root in both mesic and xeric habitats.

The dead as well as the live ohia is important to the ecesis of many taxa. Their leeward sides provide suitable habitats for cryptogams and flowering plants. Their presence produces numerous microclimate conditions conducive to germination of seeds and spores, as well as guarding against desiccation and dislodgement by the prevailing trade winds. These microclimatic conditions are also manifest beneath and along side fallen branches and trunks.

At present the sheltered areas are occupied by blackberry (Rubus penetrans), butterfly weed (Buddleja asiatica), hino-hana (Erechtites valerianifolia), pamakani (Eupatorium riparium), sedge, kaluha (Cyperus brevifolius), sword fern (Nephrolepis exaltata), kupaoa (Railliardia scabra), and several mosses and lichens. While their ecesis may be questioned, the ability of these forms to live but a short period will definitely influence the substratum. All but two of the above mentioned are exotics. Certainly these foreign species have their place in the allover plant succession.

On the moist windward side of one dead ohia, near the boardwalk and within 1500 feet of the vent, a colony of snails was located. They tend to put in their appearance during long periods of rain or when suitable moisture is available. Spiders are found on many trees but more often in tree molds.

Absence of fungi throughout the area may indicate high quantities of acid gases at one time. Some fungi are quite susceptible to sulfur poisoning. However, on a dead Acacia koa, about 1200 feet downwind from the main vent, a Basidomycete, Schizophyllum commune, was growing. This fungus is common in temperate regions of the United States.

Phanerophytes are the most obvious of all plant forms appearing since the eruption. The majority of these woody forms are developing from old rooting systems not destroyed by the eruptive events. Their recovery is dramatic especially when the 1- and 3-year differences are compared in photographs. Bisects made approximately 5000 feet from the main vent show that Styphelia tameiameiae, Dodonea viscosa, Vaccinium reticulatum, and Railliardia laxiflora have pushed their stems through four to six inches of pumice. Today, some of these shrubs are over 10 decimeters high.

Most herbaceous plants have developed from seeds. Dissemules dispersed to the lee of trees or into mats of ground runners (Coprosma ernodioides and Commelina diffusa) have found conditions favorable for establishment and in most places it appears that such migrations have been successful.

Some of the leeward spots are colonized by therophytes such as Sonchus oleraceous and Erechtites valerianifolia. Perennials such as Tritonia crocosmaeflora and several grasses have survived from root stocks buried under three to four inches of pumice. It is again interesting to note that most all types of live forms exhibiting recovery from old rooting systems, bulbs, etc., are phanerophytes, hemicryptophytes or ceophytes. Most of the pioneer colonizers fall among the therophytes and chamaephytes.

Some Rubus plants, on spatter substratum, have developed very dark green leaves which probably indicates a copious supply of nitrogen. This is a weak assumption since most vegetation on young volcanic soil looks "nitrogen poor." Is it possible that the dark green condition is attributable to a dense population of bacteria and a related availability of nitrogen? The great sterility of spatter substratum, produced by extremely high temperatures at the time of ash fall, may have favored high bacterial densities prior to the entry of controlling predators. However, no bacterial counts have been made of the spatter to support this hypothesis.

3- SUCCESSION ON NEW SURFACES

By Garrett Smathers

Two principal categories of surface were formed by the 1959-60 Kilauea Iki eruption. These are the consolidated lava surface flooring of Kilauea Iki and the ash or cinder forming Puu Pua'i and the soil cover nearby. For comparative purposes, studies of both the new floors of Kilauea Iki and the nearby similar crater Keanakekoi have been undertaken.

On the floor of Kilauea Iki Crater four transects and 10 quadrats have been established to record and keep check on plant succession. Primarily the quadrats have been located in such a manner as to give proper perspective of recovery determined by physiographic and climatic influences. However, other habitat determining factors, such as substratum and biotic effects, have not been overlooked.

Each quadrat is one meter square, and it has been mapped for every square decimeter. Care was taken to locate the quadrats in respect to cracks and crevices, microphysiographic features that provide a variety of exposures and shelters. Under these conditions some knowledge should be obtained to help correlate early plant forms with insolation, evaporation, air and substratum temperatures. It is now hoped that the remapping of each quadrat every six to eight months will be continued.

To expedite location of quadrats, they were placed on transects related to the present position of the U.S.G.S. rain gauge. The four corners of each quadrat were marked with a spot of yellow paint about two inches in diameter. A map of the crater floor was prepared, and on it the transects and quadrats have been located.

Keanakakoi Crater floor was selected as the control area for seral comparisons. The flora on the floor of this crater now exhibits a composition and in distribution what may appear at a later state in succession on the new floor of Kilauea Iki. It is most interesting to notice the cracks and periphery of this crater floor already lined with ohia and other woody plants. This population is similar to that destroyed by the lava now covering the floor of Kilauea Iki.

The most interesting aspect of the new Kilauea Iki Crater floor is its physiographic significance. As a type of land form this crater, like many others, may play a very important part in the distribution and development of some Hawaiian floral elements. The opportunity for isolation of a taxon and center of dispersal of its disseminules makes these habitats important. Kilauea Iki evidences numerous microclimates, and in no way do they represent to any great extent the local climate. The yet-continuing downward sinking of the floor creates new and various habitats in new cracks and crevices. Many of these have come to shelter mosses and ferns. The sword fern (Nephrolepis cordata) is now found on northern exposed cracks where favorable microhabitat conditions apparently prevail. These latter conditions vary tremendously with the degree of isolation. Several mosses have been collected. In one crack with a northeast exposure, on the northeast side of the crater floor, a spermatophyte (Lythrum maritimum) germinated and survived for a season. Its success is partially attributed to dust and bits of organic materials, dead parts of plants, etc., that were blown by the wind into the crater and later became lodged in vesicles and recesses of the lava cracks.

Ferns and mosses are exhibiting an indicator manifestation. In some places observed, only on the reddish ferric oxide rich part of the lava strata do these early colonizers appear in great numbers.

Since most of the cryptogams are found on northwest to southeast exposed cracks, insolation must be the primary determining climatic factor. However, on the islands or large blocks of lava rising above the crater floor and the crater periphery, these pioneers may be found on all quadrats. A variety of shelter is produced by the numerous cracks, crevices and shelves.

Yet, this is not the complete story because the temperature of air and the surface, the chemical content of the different lava strata, the biotic and moisture content of dust filled vesicles, and other important factors have not been explored. One would think that primary succession characteristics of a xerosere would be exhibited. But such is not the case in every lithosere. One would expect lichens to be the first colonizers followed closely by mosses and other cryptogams. In all quadrats these forms have appeared first or simultaneously with mosses. However, very few lichens have been observed. Probably the vesicles in the lava account for this advanced seral; i.e., they are analogous to lichens in collecting and holding moisture, dust, and disseminules. Winds blow in all directions on the crater floor, thus insuring even distribution of any disseminules that find their way into the crater. While there is no supporting data present, these winds can be very dry, thus causing great desiccation and killing or damaging most plant life present.

Unlike the steam cracks elsewhere throughout Kilauea's summit area, those on the floor of Kilauea Iki fail to provide suitable habitats for plants. It is suspected that the vapors are still too acid to allow even the most physiologically tolerant cryptogams to invade or take hold. The deposition of sulfur and acid salts at these openings lends support to this hypothesis.

The U.S.G.S. has maintained a rain gauge on the crater floor (Number 1 of Fig. 10) since April of 1960. While the data collected (Chapter III, Table VI) may be reliable for some purposes, its use for biological work is highly questionable. It is imperative that maintenance of this gauge must become part of the project. Knowing the annual precipitation of this area is the heart of the research. Without this information vegetative recovery and soil development cannot be correlated with climatic phenomena.

The floor of Kilauea Iki Crater possesses a hostile climate, and only hardy cryptogams have been able to colonize to any extent. It is an area of high air and surface temperatures, extreme evaporation, and very strong light intensities. In many respects it is like a desert climate, though subject to greater fluctuations. The ferns and mosses exhibit a distribution that correlates with their physiological tolerance to the harsh climatic conditions.

In all probability, as previously pointed out, recovery will not entirely follow the xeric to mesic succession pattern because of the small amounts of organic and inorganic debris collecting in cracks and crevices. These shelters can retain their moisture over an extended period and could become suitable habitats for higher plant life, such as ohia (Metrosideros) and other woody and herbaceous plants. Once established these pioneers will further modify habitat conditions and act as centers of dispersal for disseminules. The floor of Keanakakoi Crater, in part, reveals such a sequence. There Metrosideros and other woody plants have lined the cracks and crevices forming a mosaic of vegetation upon the crater floor.

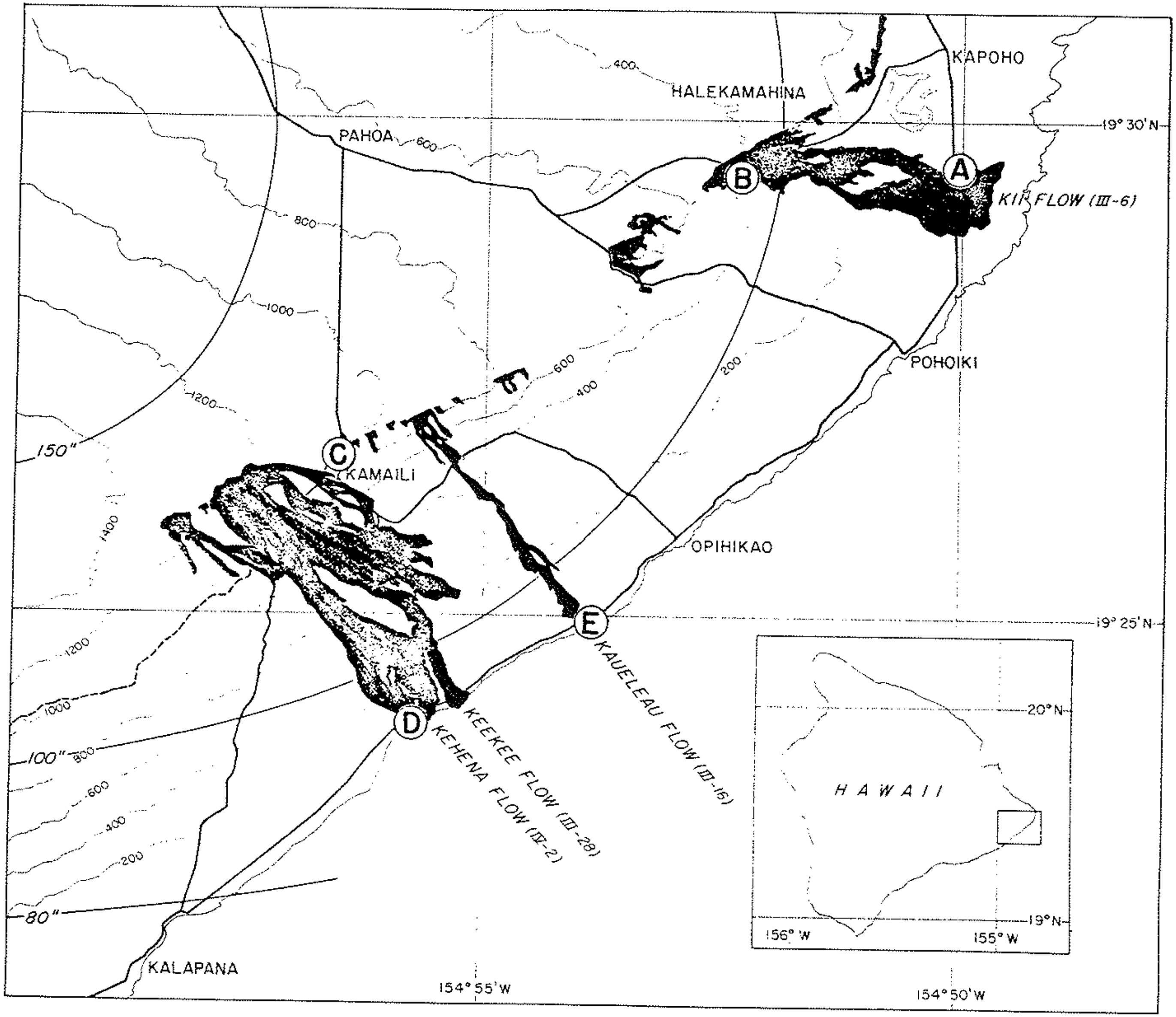
Plant succession on the floor of Kilauea Iki Crater is occurring in the shelter of cracks and crevices. Though this area receives about 73 inches of rain annually, plant distribution is characterized by other climatic factors such as high insolation and the latter in time effecting microhabitat conditions such as moisture and heat. The dark color of the lava substratum also adds to the degree of insolation.

E- THE WETTER LOWLAND VEGETATIONS

Expecting a flow in the Park to extend to the lower elevations sometime in the future, this information from just outside the Park (Fig. 24) is included here for reference to give the reader some orientation as to the nature of the floras that would be removed, covered or passed through by such lava flows. Two are described here cursorily. They are the near-shore forest and that at the 900 foot elevation studied in reference to the 1955 flows. The 1955 flows cover prehistoric lavas that are, nearby, rather uniformly populated, at least qualitatively, regardless of age. That is to say, while it is obvious in many places that one is at the edge of a younger flow where it has passed over an older flow, at such a place there is no marked vegetational change. For the present purposes, which are noting the first steps leading toward the climaxes (*i.e.*, in the sense of their being stable communities) in these different regions, two pairs of adjacent prehistoric and 1955 flows, considered to be uniform in respect to climate, were studied. The prehistoric vegetations are taken up first and then (in the next section F) the 1955 surfaces.

1- *The prehistoric lowland forested surfaces* alongside the Kii lava flow ("A" in Fig. 24) about 100 meters upwind from the related study sites on 1955 lava is predominated by *Metrosideros collina* (ohia) running about 6 meters tall and averaging one for every 2.5 square meters of forest floor. The elevation is about 90 meters. The frequency distribution of diameters is given in Figure 25. Elsewhere in the islands this species is not often found at such low elevations. Here it commonly extends to the coastline or about to the 15-meter (50-foot) elevation contour. Perhaps every tenth tree

Fig. 24. Map of the 1955 'a flow just to the east of the Park and on which population events ..ave been followed at the sites labeled A-D. The times indicated at the seaward ends of the major flows are the day the flow stopped moving at its seaward end.



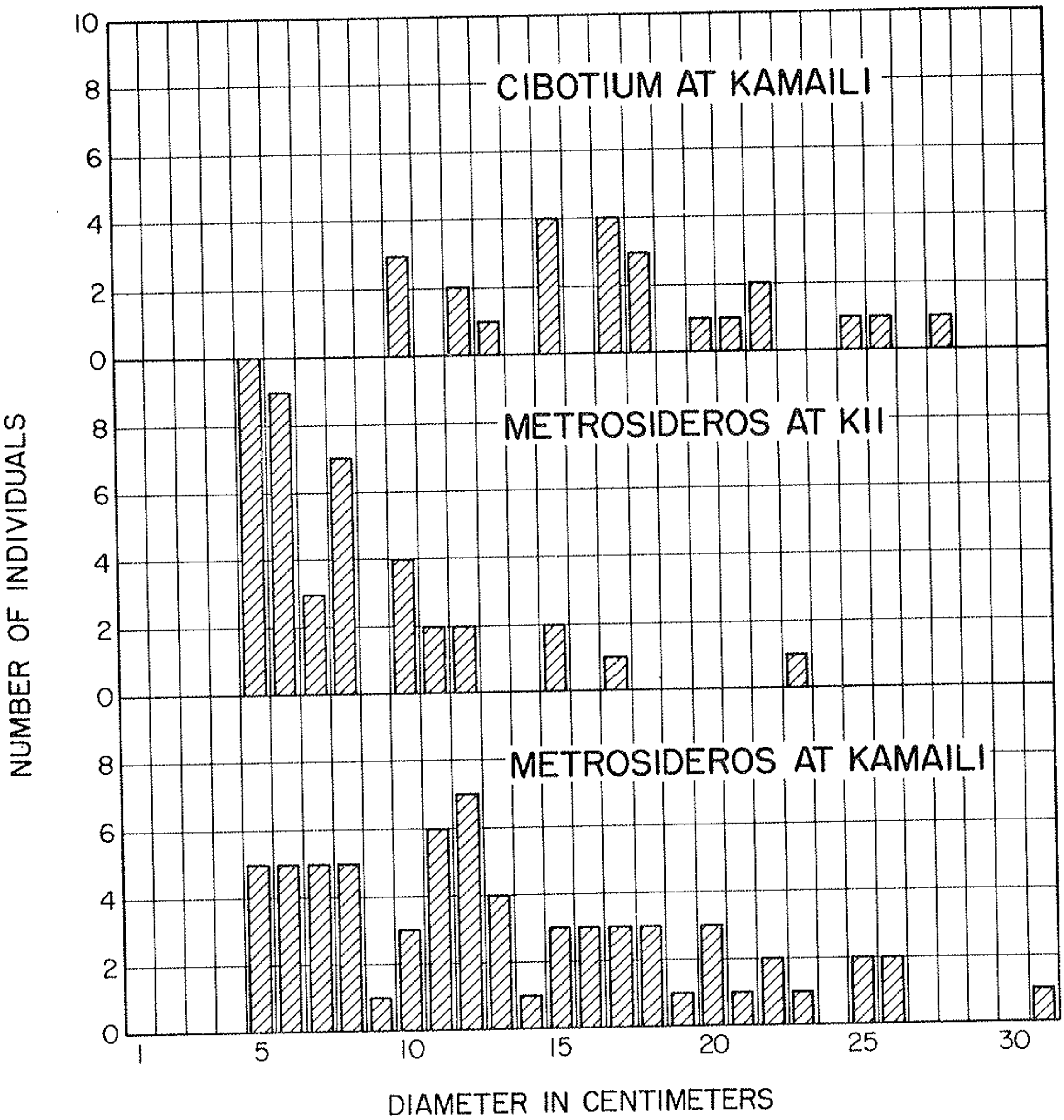


Fig. 25. Histogram to show frequency distribution of trees of different diameters in "control" areas for the Kamaili and Kii study sites on the 1955 lava flows.

is Rhus chinensis var. sandvicensis or Diospyros ferrea, but any other tree is unusual. Every 60 meters or so one can expect to see a spindly seedling of Morinda citrifolia with very broad leaves and perhaps fruiting. A very few guavas, Psidium guajava, and also strawberry guava, Psidium cattleianum, have appeared in the area and near the road mangoes, Mangifera indica. Overhead the forest is perhaps 50 per cent open.

Plants that are secondary in size in the form of shrubs or bushes are not particularly common, and when present are usually small forms of the above species, with the exception that there are but few small plants of ohia. One of the most common shrubs is a species of Wikstroemia and small forms of the above endemic Rhus. There is a small acacia, Cassia leschenaultiana, that is woody but of herb size. An occasional woody bushy plant of Lantana camara can be found.

There are a number of vines which are for the most part herbaceous. Running into the tops of the trees is Cassytha filiformis and climbing on this or on other vegetation are occasional plants of Passiflora foetida and Cocculus ferrandianus.

The herbs with the lichens and mosses cover some ninety per cent of the forest floor on some older pahoehoe areas, but perhaps only 15 per cent of the forest floor in the youngest prehistoric a'a areas. The fern Nephrolepis exaltata is predominant among the herbs. The grass (Paspalum), Stachytarpheta cayennensis, Psilotum nudum, which is often on trees as is Nephrolepis, and the orchid, Spathoglottis plicata, make up about ninety per cent of the remaining herbaceous cover. Here and there other plants, e.g., Peperomia leptostachya or Fimbristylis pycnoephala, are common. They are usually localized in areas a meter or two across or restricted to a ledge or fold in the lava, otherwise they are but occasional isolated plants, as were the scant half dozen thalli seen of the fern, Sadleria cyatheoides.

The tops of the lava chunks otherwise barren of vegetation are for the most part covered with Campylopus exasperatus[3]. On the rather vertical sides of rocks not covered by higher forms of vegetation such lichens as Cladonia didyma are common. Below these uppermost surfaces occur a number of bryophytes, e.g., Rhacopilum cuspidigerum, Brachiolejeunea sandvicensis and Frullania meyeniana. The latter two occur on trees as well but usually only near the ground. On occasion Weisia viridula and Bryum megalostegium had developed in small heavily shaded upward-facing rock concavities at least three decimeters below the normal ground level. These concavities had in them, beneath the small moss patches, a few millimeters of simple soil. Other bryophytes and lichens are abundant above the ground on the trees. Stereocaulon does not seem to be present.

2- The prehistoric higher-level forested surface studied at Kamaili ("C" in Fig. 24) is not greatly different from that at Kii, other than in degree. The elevation is about 290 meters. The same Metrosideros collina is the dominant tree, quite to the exclusion of others. The individuals are a little more closely spaced (one per 1.5 m^2) than on the older of the two prehistoric flows at Kii. Also at Kamaili they are larger (Fig. 25), often 20 to 35 cm in diameter, breast high, and 12 to 18 meters tall. In a stand nearby occasional specimens were estimated to be 30 meters tall. The forest is nearly closed over above.

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[3] We wish to express our appreciation to Dr. H. A. Miller, who repeatedly assisted us by identifying the bryophytes, and Dr. I. MacKenzie Lamb, who identified the species of Stereocaulon.

At the bush level the space is occupied mostly by Cibotium chamissoi Kaulf., there being about one for each 4 m^2 of forest floor. Though this is a low elevation for this species, it was assumed to be this species for there were stiff blackened prickles on the leaf bases rather than the soft hair, the pulu of C. splendens (Gaud.) Krajina, the common lowland species. It is a low elevation for Metrosideros, too. The trunks of the tree ferns were often 1.25 meters tall with the fronds reaching up another 1.5 meters. Figure 25 shows the distribution of trunk diameters. Guava, Psidium guajava, was the next most frequent small tree or large bush. There were some woody plants of other species up to a meter tall, but these merge into the herbaceous cover on the ground. Of the herbaceous plants on the ground Stachytarpheta cayennensis, Oplismenus hirtellus, a Cyperus sp., probably one of the many forms of the common Cyperus compressus, and the weedy orchid, Spathoglottis plicata, were the prevailing cover along with several grasses and other herbs, including Erechtites valisneriafolia, that were not conspicuous.

The above-mentioned Cyperus was much less conspicuous here than was Fimbristylis at the lowest elevations at Kii. Nephrolepis exaltata and Psilotum nudum were absent and there were none of the rock lichen or moss genera so common at lower elevations to be seen. However, Table V, other genera of mosses and lichens were abundant. No bare rock shows. There was no decomposed rock soil cover but the surface was thoroughly covered with not only the flowering plants but as well by an abundance of the bryophytes (Table V) and a number of small ferns, such as Polypodium lineare.

It is to be noted that where roads have been built through this type of forest the roadsides are usually lined with a dense stand of Nephrolepis exaltata though it may be quite absent in the woods away from this edge

Table V. List of bryophytes found in order of their abundance in the forest at 950 feet elevation adjacent to the Kamaili study area.

Rhizogonium spiniforme

Leucobryum gracile

Acroporium fusco-flavum

Bazzania didericiana

Cephalozia sandvicensis

Bazzania brighami

Frullania apiculata

Odontoschisma of. sandvicensis

Brachiolejeunea sandvicensis

Anastrophyllum esenbeckii

Radula cordata

effect. In some places what is taken to be the Cyperus mentioned above dominates the scene rather than the Nephrolepis.

F- POPULATION DEVELOPMENT ON THE LOWLAND 1955-LAVA FLOWS

After preliminary warnings the 1955 eruption began at 08:00 on February 28 (Macdonald & Eaton, 1955) some 5 kilometers (Fig. 19) directly north of Opihikao. The village of Kapoho was evacuated as the eruption extending via cracks opening successively seaward and down the rift zone began exuding lava toward it. As Macdonald describes the event in his detailed account (1959) "efforts to remove all reasonably moveable property" were made. While the village, ultimately, was not destroyed until the 1961 eruption, an immense amount of material was extruded, at times at such rates as 450,000 cubic meters per hour. In all, perhaps 108×10^6 cubic meters of material were extruded.

At various intervals during the following month in different places this molten rock flowed down toward the shore, (Fig. 24) reaching it independently in three places (Kaueleau, Keekee and Kehena); two of these coalesced later in part. A fourth flow (Kii) did not quite reach the sea. The extent of these is illustrated in Figure 24 as well as the dates when they are accepted as having become stable surfaces.

About one month after the flows had cooled, a study of several areas was initiated ("A" through "E" of Fig. 24) and continued for ten years through March, 1965. At first, studies of these areas were made at about 2-month intervals. With each visit both quantitative and qualitative observations were made or attempted. Macdonald & Katsura have published studies revealing the rather similar chemical compositions of these flows, and in 1959 Macdonald noted that the entry into and cooling of the lavas in sea water did not alter their chemical nature measurably. Thus, essentially, a set of chemically uniform surfaces of the same age formed the study sites.

The observations inland away from the shoreline were largely to provide a record of what happens up to the four year old stages studied by Skottsberg (1941). Three elevations (Fig. 24) were investigated on dry land initially: "C" 290 meters at Kamaili near Iilewa; "B" about 108 meters at Halekamahina near Kapoho; and "A" at about 90 meters on the Kii flow. These sites have rainfalls (Figs. 11 & 12) estimated, respectively, at 3750 mm, 2500 mm and 2000 mm per year. The temperatures are less well known but the near-ground free air temperatures probably do not vary often as much as 6 degrees from 25 degrees C in vegetated areas. Other factors influencing the biological events observed on these very young 1955 flows are described below.

The area at Kamaili near Iilewa ("C" in Fig. 24) is on the lava of vent area "R" of Macdonald (See his Figs. 12, etc., 1959). Macdonald's illustrations, (See his plates 10-15, 1959) are from a remarkable series of photographs he made before the crack which opened began issuing lava. These illustrations show not only the cucumber plants but the native forests both of which were destroyed as the lava outflow continued. During days after rains there was a great deal of steam in the air during the first two years of this study. This area has _Metrosideros_ forest within about a hundred meters of three sides. This forest was described, above, as the "higher forest." The other two areas have no such moistening influences nearby. For example, the Halekamahina area ("B" in Fig. 24) is 300 meters from the surrounding sugar cane fields, and the Kii area ("A" in Fig. 24) is about 100 meters in the upwind direction, from the _Metrosideros_ forest described, above, as the "lowland forest." In other directions the Kamaili study area is separated by 100 meters and the other two by at least 4-tenths of a kilometer of the same lava flow from the forests and fields, the normal sources of populants.

At the lowest elevation ("A" in Fig. 24) nothing was observed until March, very nearly one year after the flow had ceased moving. At this time along the 99-foot (30.4 meter) base of the Kii area, at least 6 mossy spots were found. In every case the moss area was sharply restricted to one rock even though adjacent rocks were in contact. This moss though immature was just becoming fertile. It appeared to be Campylopus densifolius. One of the mossy areas was irregularly about 3 decimeters square. In none of these areas was any spermatophyte seen.

These observations raise three issues. It seems unlikely or even incredible that a microscopic base for colonies 15 to 25 cm across would grow or that such colonies could grow macroscopically to this size in the time between studies; thus, one is led to expect that such colonies arise from a number of disseminules rather than one. The different moss colonies are often ten meters apart. A rock bearing mosses often may bear ten plants per five square centimeters. If these arose from separate disseminules, then by chance, the rocks between those bearing macroscopic mosses must also have caught disseminules. Each plant appears to be an independent, erect individual having no relation to others that could be distinguished with the magnification afforded by the 20x lenses of a dissecting microscope. This leads to the second question and that is, how does it happen that some chunks of surface clinker and not others have moss colonies on them? The chemical differences (Macdonald, 1955; Macdonald & Katsura, 1964) between such clinkers are insignificant insofar as analyzed. The water-holding properties do not seem to differ significantly. A third enigma here is that there is no increase in the frequency of moss colonies with nearness to the forest on the windward side of the flow. In fact, the frequency of colonies fall off when investigated at different times during the first three years of the study. Only one Campylopus, the different species Campylopus exasperatus, was found in the edge of the forest, where this species and four other bryophytes cover a major portion of the old lava and near-ground tree surfaces.

Around steam vents, now inactive, the undersides of some lava cinders were densely green with a coating of an unicellular green alga, which for convenience we call here Chlorococcum humicola. In order to determine whether there was an increase with time in the amount of greenness on the undersides of rocks near the inactive steam vents, a special search was made on July 27, 1956, and September, 1960. There seemed to be no increase in density of these populations; in fact, there were no visible populations below the surface elsewhere on the flow such as those of algae described by Newhouse (1954; 46) and Doty (1954; 17) from atoll island surfaces where moisture conditions must be equally severe. These early green algal populations were on sky-facing surfaces, and they became progressively less conspicuous as the years passed and were no longer visible in 1960.

Some fourteen to sixteen months (July, 1956) from the time of cooling, two widely separated "1.5 by 1.5 meter" boulders were found from the overhanging under surfaces of which were growing ferns. These few sterile fronds were apparently of the common Nephrolepis exaltata. The largest were perhaps 7.5 cm tall but by far the most were about 2 to 3 cm tall. There were many dead dried fronds of these smaller sizes. By November 10, 1956, a few of these Nephrolepis thalli were fertile.

From one of the overhanging surfaces just described there were collected at the same time moss thalli and small bits of greyish-green hard gel. The gel appeared to be a mixture of fungus filaments with Palmogloea protuberans. Moss thalli were wide-spread and identified as juvenile Campylopus. Still there were no evidences of spermatophytes appearing on the study area or other 1955 flow surfaces at this elevation.

An increase in the conspicuousness of algal and moss colonies on the individual rocks was recorded up to November, 1956. The occurrence of these colonies was so irregular, easy to overlook, and infrequent that any count in the study area seemed ridiculous. While the moss colonies were more conspicuous, they seemed to be so through increased density rather than height of thalli or color change. Except near disturbed areas and right at the edges of the flows, a moss colony could perhaps be found in any ten to twenty meters traversed. In December, 1959, only one moss colony could be found. This colony was but a trace of the largest observed several times before, and the thalli were but little more developed, if at all. Many colonies were found in September, 1960. The thalli were of the same size as before, but perhaps the colonies were smaller in diameter. In March, 1965, fewer thalli were present and it is presumed the variation during the past few years is fluctuation rather than periodic or seral change.

The Halekamahina study area at the middle elevation ("B" in Fig. 24), near Kapoho, was first visited in August, 1955, some three months after the lava surface had cooled. At this time there were in evidence a very few dicotyledonous seedlings, estimated at 0.75 per square meter. These were in the folds of blister surfaces and absent on the superficial surfaces of the very rough a'a and loose cinders.

Unfortunately, between the time of the laying out of the transect and the second visit in December, 1955, a road was built right alongside the previously remote study area. Only one small dicotyledonous seedling was seen on the whole study area and nothing else, *e.g.*, there were no mosses, ferns or algae to be seen. However, along the opposite side of the new road there were 4 similar seedlings in one particular square meter area. None of these seedlings was sufficiently large to be identified, most of them being 0.5 to 1.0 cm in their greatest dimension. By March, and in July, 1956, no seedlings could be found anywhere here. While no algae or mosses were to be seen on the undisturbed surfaces or on down-facing surfaces, in crevices there were areas where many small fern thalli could be counted. These ferns in July had become larger but many had become noticeably pale in color.

In November of 1956 ferns had become abundant as small sporophytic thalli on almost all of the red partially-shaded cracked surfaces below the general flow level. Nothing was to be seen growing either on the cinder beds or on the undisturbed blister area, with the exception of ten tiny dicotyledonous seedlings in a deep crack in one blister surface. Some few mosses, a Cyperus, and a few dicotyledonous seedlings were seen on disturbed blister material near the road.

Yearly into 1965 *Nephrolepis* has been progressively less evident. Since December, 1958, such as the following have grown on the site: *Plumeria*, *Musa*, *Vanda*, *Aleurites*, *Drymaria*, *Emilia*, *Pipturus*, *Nicotiana*, *Canavalia*, *Leucaena*, *Pueraria* and *Cyperus compressus*. Various plantings have been made since then in this disturbed area, and thus attempting to observe natural events in this area was discontinued.

The casual observation was made at the Kamaili site that after sitting on the sun-warmed dry rocks, one would find cameras and notebooks and pants wet on the underside. Furthermore, the undersurfaces of cave rooves were usually dripping water[4/] though perhaps only 6 to 15 cm thick and warm and dry on the upper surface. This seems to indicate the rock porosity is such that the rain water is both caught in abundance and runs through without most of it being held by capillarity. Several large gas vents were formed near this middle elevation study area at Halekamahina when the flows were active. These produced steam each time there was rain during the first year or two of the observation period. As time went on steaming was less frequent and finally steam was to be seen only after periods of very heavy rain.

Apparently the heat in a new lava bed, at least, at first prevents the water from percolating through and becoming lost to the pioneer colonizers. One would expect that ordinarily the water is driven to the surface so slowly that when the sun is out and the humidity low, e.g., only 60 to 75 per cent, the vapor is not noticeable and most of the vapor condenses in the rock, and the water not held by capillarity percolates back down again to the hot lava. At first even a light rain with its accompanying high humidity brings clouds of water vapor to the observer's attention. With time the effect is less and the depth to rock as hot as 100° C greater.

While the hot rock may repeatedly redistill the water and this may promote the more rapid transfer of heat toward the surface, clouds of water vapor arising from the surface come to notice only when the humidity is high and there has been enough rain either to fill much of the rock to field capacity above the hot layer leaving little space in which the vapors

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[4/] Such drippings collected in leaves and shells were a major source of drinking water for the Polynesians in this district.

can expand, cool and condense or enough rain to provide more steam than there is space for it in the rock.[5/] Water especially from light showers must be merely recycled repeatedly, but when the flow cools throughout to temperatures below 100°C., then the rainwater in excess of field capacity would percolate through to the fresh water lens or any existing water table below, and perhaps be lost to the pioneer plants on the surface.

Thus, while at first there is water enough for plants on the relatively barren surface and pioneer colonizers are abundant, with time the surface is exposed to increasing dryness and to such an extent that quite possibly such plants as the Erechtites, which was an early colonizer and shed seeds, could not persist or reproduce, especially during the rainless periods of two or three days to be expected (Fig. 8) about once a month. Such edaphic changes in water or chemical availability may act as screening mechanisms determining ecesis and, thus, separating mere pioneer colonizers from those pioneers that succeed themselves and form a pioneer community.

In the immediate vicinity of vents near Halekamahina, but not at all affecting the middle elevation study area ("B" of Fig. 24) at Halekamahina, the air and less so the rock surfaces were, thus, very humid, and it was here a pioneer community was first manifest on the 1955 flow. On the outer slopes of these vents ferns developed in the folds of some blisters to the stage where the primary sporophyte leaves were fully developed August 15,

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[5/] Another factor would be the steam driving the air out of the surface layers of the cooling flow and the re-entry of the air as the water vapor decreased, an aeration process that would be repeated to differing degrees with each greater or lesser wet period.

1955, four and a half months after volcanic activity had ceased. No mosses or other plants were in evidence there at that time. In July, 1956, this same fern, Nephrolepis exaltata, was an incomplete sward 30 cm tall and abundantly fertile. There were also present many patches of the moss Campylopus introflexus (Hedw.) Bridel. Since this time there have always been Nephrolepis thalli reproducing and in various stages of growth. Thus, we feel a community of ferns in simple form was established 14 months after the flow.

Further development has been along two lines actually followed in greater detail at the other two terrestrial elevations studied and, respectively, described above and below. These two lines are 1) toward more complete cover by the pioneer community to where there is in places a sward of fern except on the protruding rocks, and 2) the production of a more complicated community a) species-wise, b) with zonation or storying, but c) without the physical and perhaps close physiological interrelationships between the components to be found in a stable mature population such as found on the prehistoric flows.

The highest area elevationally, at Kamaili near Iilewa ("C" in Fig. 24), was first studied closely 9 months after the cessation of activities. At this time (December, 1955) a study area was laid out covering some of the same area as shown in Macdonald's (1959) Plate 15. In the restricted part of this Kamaili area selected for rather close observation, there were at this time 124 ferns and 21 dicotyledonous seedlings in 10 square meters. One seedling of Spathoglottis plicata Blume with three leaves was seen. No mosses or algae were seen in this study area, but in lava blister folds nearby and downhill on a random walk of perhaps a hundred meters, three dark green dense tufts of moss, Campylopus boswelli, with an undeterminable very juvenile leafy liverwort were seen and collected.

By February, 1956, the fern Nephrolepis exaltata was much larger but none of the thalli was fertile. There were only 3 flowering plants of Erechtites valisneriafolia left in the study area. Here and there, mostly in the crack-like folds of lava blisters, there were small low dense moss mats of the very common Campylopus densifolius Angstrom and a few algal spots.

In March, 1956, no new flowering plants or fern thalli were found, however, one fertile frond of Nephrolepis exaltata was collected. Mosses were much more in evidence and seemed to be entirely Campylopus densifolius, the same species appearing later on the lowest and driest study area. The only specimen of Erechtites valisneriafolia remaining was small but blooming. Other plants were flowering on the edge of the lava near the forest. The more conspicuous of these were Coleus blumei, Commelina diffusa Buym., Pluchea odorata and larger specimens of the same Erechtites. On the study area the one small felt-like algal patch found, turned out to be the nearly ubiquitous Scytonema hofmannii.

A visit here in May, 1956, revealed the disappearance of the last of the flowering plants from the study area, though they were covering over the edges of the flow nearby. There were fewer clusters of ferns. The individuals were larger and were producing sporangia. There was more moss and an abundance of what we took to be the same Scytonema hofmannii. At the time of this visit the rock surfaces even on that particularly dull and cloudy day were dry and warm to the hand. The Scytonema felt was, however, cool and sufficiently wet that water ran out of it when it was pressed with a finger.

In July of 1956 there were ten small seedlings taken to be of the same

Erechtites valisneriafolia in shaded (Temp. 26° C) blister folds. The same fern plants were larger than before and producing many prostrate rhizomes, some 20 cm long, as Holttum (1960) emphasizes as characteristic of Nephrolepis hirsutula and other Nephrolepis species. The Scytonema hofmannii on the broken blister edges had become differentiated in some places either into dark more gelatinous areas or into browner areas. The browner, as opposed to the dark, areas covered were of apparently more actively growing filaments with more hyaline sheaths.[6/] The sunny surface of the browner Scytonema was about 28.3° C, two degrees cooler than the non-algal covered surfaces adjacent. Campylopus exasperatus Bridel had spread and the thalli were much taller. Where water drips through the rooves of open blisters onto their floors gelatinous algal scums, largely mixtures of Scytonema hofmannii and Stichococcus subtilis, were found as well as green whefts of unidentifiable moss protonemata. There were also isolated branched strands of the moss Rhacopilum cuspidigerum (Schwaegr.) Mitt. on the floors of these small "blister caves."

In November, 1956, the Erechtites was all dead and, indeed, only a single dead stalk about 30 cm tall was to be found in the study area. The floor of the blister cave had a number of brown and blackish patches not unlike crusts of paint. These were taken to be the same Scytonema hofmannii

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[6/] The browner drier material had some fungi in the sheaths. Dr. Francis Drouet tells us this was not noticeable in the former collection from the same place. That this difference noted after 14 months might be incipient lichenization or, in view of their disappearance by November (see below in text), a suffering from fungus disease are appealing hypotheses.

collected before on the broken edges of the roof above. These broken edges were now populated by only the black form of colony first noted in July, 1956. Nephrolepis had become conspicuous, protruding above the general surface of the flow and lining the folds in the surface. However, few were over 10 cm tall and none of those in the small intensive study area was fertile. In a small kipuka about two meters across and 3 meters long near the study site, Colsus blumei Benth., Stachytarpheta cayennensis (L. Rich.) Vahl, Commelina diffusa Burm. and Pipturus brighamii Skotts. were blooming. In March, 1965, Pluchea odorata was blooming in this kipuka and there was no Coleus and little Commelina, as though the site were drier.

In the spring of 1962, seven years after the lava first covered this site, a restudy was made. At this time it was interesting to note the shifts away from the pioneer communities and the establishment of what we take to be the full development of the pioneer communities on the surface of the flow. The latter seems to be indicated by the appearance in some places of mature yellowish brown tufts of Campylopus exasperatus appearing as tufts dominating areas but a few centimeters across in the general field of grey Stereocaulon vulcani[3 & 7/] covering the flow surface. Secondary invaders were beginning to appear. Insofar as they were flowering plants they were the non-native orchids Arundina bambusifolia Lindl. and Spathoglottis plicata, or the native Metrosideros colina.

Metrosideros presents an interesting picture for while on the study area there were only small plants, perhaps 6 to 9 cm tall, unbranched and

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[7/] Stereocaulon vulcani (Bory) Ach. is accepted as synonymous with S. flavireagens Guilnik.

with one plant visible per 9 square meters on the average, near the study area where there had been more disturbance of the lava a number of plants 20 to 30 cm tall were to be found. These larger plants almost all show dead shoots and some "runners" as well as "adventitious" shoots from the base; as though the tops had died back during unfavorable weather and the plants had shot up from a crown again during more favorable conditions. Indeed, most of the Metrosideros on the even drier regions along the shore in this area that seem young are, in essence, several irregular trunks arising from the ground level as though they had arisen from separate shoots engendered by a common base. We, thus, presume the small unbranched seedlings will die-back and sprout up from the base on the study site and give rise to such bushy trees as described.

This pioneer form should not be the unbranched tall form of tree that occupies the mature forest in the immediate vicinity of the Kamaili study area. Therefore, we assume that the original forest at the study area, removed by the lava flow or in the land clearing process, was of trees that had grown in soil formed from prehistoric lava and that they were not merely old trees formed under different climatic conditions, probably as secondary growth.

Interestingly enough on the study area and nearby the Nephrolepis similarly shows dead stalks as though it had died back from time to time. These stalks often 18 cm tall may, however, in the case of this fern represent merely the remains of fronds which were fertile and from which the pinnules were eventually shed. The living fronds in 1962 were often only about 12 cm tall and, thus, shorter than the dead stalks. Whether this indicates seasonality or a decline in the fern population, we cannot tell at this time.

While the first community to become established was algal and of Scytonema hofmannii, blackened areas of Stigonema eventually became conspicuous. Sometimes low dense coatings on the pahoehoe are formed among the podetia of the predominant surface organism, Sterocaulon vulcani, and formed so extensively that for areas a decimeter or so in extent, 30 to 50 per cent of the rock surface is black. This, it would seem, would be a replacement of the primary blue-green pioneer colonizer, Scytonema, by a secondary and morphologically more complex colonizer, Stigonema.

The hypothetical explanation that currently seems to fit these observations from all three areas is that there is seral development of a rather classical nature, with the addition that there are conspicuous early populants which may be ephemeral accidents. To put it briefly in more formal terms, there is colonization by a wide variety of forms but ecesis of only the cryptogams that come thus to establish the pioneer communities. For example, the dicotyledonous seedlings that first appeared on the Halekamahina tract were an ephemeral population as was Erechtites on the higher area. We would suppose that the substratum is unable to support these organisms except during exceptionally favorable conditions, largely of moisture.

Since these same organisms are common and consistently present on older surfaces, we must presume that the sere leads to conditions such that a population of them can live all the year around, reproduce and thus be recognizable as a community. It appears that the same accidents (perhaps wind, largely) deposit dissminules of both these flowering plants and the cryptogams. While the ferns appeared on wet areas early like the flowering plants, they, too, tended to drop out. However, some have matured under arches of rock where one would presume the evaporation was at a lower rate than on the open surface. The mosses, algae and especially the lichen, Stereocaulon, did not form obvious macroscopic growths so soon nor so often on surfaces exposed to wind and sun. With time these have been steadily increasing in prominence so that in the wettest places they cover the surface.

It would seem the first cryptogamic communities function in reducing surface temperatures and altering other conditions such as moisture and the chemistry of the substratum in such ways that the more advanced seral elements, for example the flowering plants, may come to form a secondary community rather than continue to be present as mere ephemerals.

It is to be noted that near the 460 meter elevation on the 1952 flows in South Kona a different moss, Rhacomitrium lanuginosum, and the tree Metrosideros collina became well established in addition to Nephrolepis within two years after the flow had ceased its movement. Perhaps the more rapid development in the South Kona district, a region having convectional showers, was due to the more regular occurrence of rain.

G- THE SEASIDE OR MARINE VEGETATIONS

Three situations from the rocks between the plant-covered areas along the shore and the open sea provide us with three categories of mature or climax habitat for descriptive and study purposes. A fourth category is the events in the development of these populations as they take place on new shores provided when a lava flow flows into the ocean. These we take up in turn below under these four titles:

(1) Littoral shores of the Park
  (a) The black zone
  (b) Marine caves
(2) Pools in the shores of the Park
(3) Intertidal shores of the Park
(4) Population development on new lava shores

Unfortunately, there has been little study of the organisms, the algae, that dominate these habitats nor of the communities themselves. For the Island of Oahu, a hundred and fifty miles away, beginnings have been made, but there are no studies published on algae for the Park area. The algae which dominate them belong for the most part to various botanical phyla, but to their serious modern students mostly they are not plants and botanists rarely recognize them. Of course,if one was brought up to believe in the dualistic system of good-bad, day-night, black-white, etc., there are only plants and animals. At that academic level these habitats are dominated by plants, but such strange plants. The Park does provide a splendid opportunity for algal study. Scientifically, it is almost an unknown area except for the preliminary surveys carried out in preparing this Atlas.

Though not in reference to the Park the marine ecological treatise edited by Hedgpeth (1957) would be the single publication of most use to a student of the ecology of this part of the Park. However knowing the marine algae would be an essential too, just as knowing the birds or insects would be an essential to studying them.

(1) Littoral shores of the Park

(a) The black zone is a community covering the occasionally wave-swept rocks and those kept free of soil by spray. In the rain or during prolonged high surf and spray periods, the black dry rocks take on a greenish sheen and may become very slick. The individuals in this community are inconspicuous and mocroscopic and in abundance usually appear black or grey when dry. Developed on the soil and sand which accumulates in low places among the rocks or just inshore of them this extensive community traces the shoreline on aerial photographs (*e.g.*, Aerial Photo 8-0024) with an irregular black line. Ideal places to study this community exist readily accessible to the Kalapana road at Kamoamoa and, as it is quite insensitive to rainfall, westward throughout Puna.

On less wave-swept rocks, but perhaps most developed in areas protected from erosion, Calothrix crustacea Thuret may develop so as to be the predominating member of the community. It can form a dense, usually greenish, layer of hair-tipped filaments on rocks and with or on other algae. This is a very widely distributed species on all sorts of littoral substrata. Sometimes it is difficult to distinguish it from the usually-coarser C. pilosa Harvey which forms mats of erect fascicles of filaments each of which terminates in a hemispherical cell. Fan (1956) has produced the most recent comprehensive taxonomic study of this genus; though the older work by Tilden (1910) is more often used.

Calothrix pilosa Thuret forms a felt of erect fascicles of filaments. While the dimensions are variable at their centers, the filaments are often about 20 microns in diameter. The trichomes within the sheaths, which together make up the filaments, are usually but little, if at all, tapered and many have a heterocyst at the middle. Since the heterocysts stick to the sheaths and are formed at irregular distances along the trichome, Scytonema-like branches are often found as a result of the force from growth in length pushing the trichome through the sheath material. This species has often been identified as a Scytonema for this reason. The felts may be a few millimeters thick and the individual fascicles of filaments visible to the naked eye. Within its gamut of habitats this alga largely comes to predominate where not exposed to the sun all day, even appearing in caves where it forms a dark bright green coating. C. pilosa is black when growing on directly sun-lit surfaces. Actually, under the microscope these colors can be seen to be the greenish color of the cytoplast masked by the color of the sheath which becomes beautifully golden. It is the presence of this color in the sheath that makes the filaments black to the naked eye. C. pilosa may appear a quarter of a mile inland from the shore as it does as an inhabitant of 10-year old 1955 lava surfaces at Kii to the east of the Park proper. At Kamoamoa, C. pilosa seems to be an ever less conspicuous element in the community inland to where it appears only occasionally on sand trapped in crevices with the first grass. It is, perhaps more than anything else, in the above habitat and as well as the morphology that this species is distinguished from C. crustacea.

A turf of Calothrix pilosa dominates some almost constantly wet, very-high tide rocks at Kamoamoa and is to be found at many places along the shores of the Park. It is common almost everywhere the sea's splash keeps the rocks wet except during calm weather and the lowest tide periods.

The seaward edge of the soil and sand caught in low places among the barren rocks is most often likely to be dominated by a mat of Microcoleus chthonoplastes (Mert.) Zanardini, as is any area which is exposed to strong desiccation by being immersed in sea water for a few days or exposed occasionally to strong sunlight for a few days between immersions in water. Drouet (1964) has published an excellently detailed study of the morphological variations, i.e., ecophenes, of this very widely distributed species. Actually the species is also reported from desert conditions where freezing and 125 degree Fahrenheit temperatures must both have been tolerated. On rather vertical rocks many places elsewhere in Hawaii and in the Park where Calothrix pilosa is well developed, Microcoleus chthonoplastes (or Oscillatoria laetevirens) appears or can be expected.

At the landward edge of the barren rock along the shore there are sometimes flat soil areas presumably in response to erosional material being deposited. Perhaps it is wind that then becomes functional and erodes the fine material so that in dry weather raised black algal crusts are left on the otherwise rather flat surface. In such cases Oscillatoria chalybea Mert. has been found to predominate with Microcoleus chthonoplastes and Calothrix crustacea as minor elements, the latter a depauperate ecophene. Perhaps this is a final level in leaving the sea and the typically-marine Calothrix is at the landward extreme of its distribution.

In crevices far above the sea, crevices that may be floored with sand bound by algal filaments, dark red to brown cushions of Polysiphonia howei Hollenberg are often found. The sand-binding algal filaments in such places are usually Microcoleus chthonoplastes at Kamoamoa but may have Rhizoclonium hookeri in with them. Actually this Rhizoclonium is more typically found in small green tufts or whisps in rock crevices holding a little sand and exposed to brighter light. A very interesting alga, Boodleopsis hawaiiensis, Gilbert has been found with the above Polysiphonia near McKenzie Park to the east of Hawaii Volcanoes National Park. A diligent search in Polysiphonia howei habitats within the Park might provide a rewarding find of this rare species.

Rock tops near the sea that are black when dry in the sun often develop a green sheen when wet for a few hours in the rain by the spray from large waves. This green sheen is usually Entophysalis deusta. While very commonly mixed in with the other algae of the littoral community it is most conspicuous as a widespread nearly-unialgal cover on smooth igneous rock surfaces. Enthophysalis deusta is the most widely spread of all algae on tropical rock shores. Often it covers much of the near-high-tide land, i.e., the calcareous or limestone materials, of an atoll island with a brownish coating at the levels regularly immersed in sea water or with a black coating at those levels normally out of water.

Further inland a smaller coccoid alga with smaller Anacystis-like cells appears which actually may be Anacystis montana (Lightfoot) Drouet & Daily. Again Kamoamoa is a desirable place to study this change in predominence among these organisms which crowd the rocks that are otherwise barren in appearance. Also inland Scytonema hofmannii predominates in any pioneer situation as, for example, on a recent lava flow. On old flows this species can be expected to be replaced in time by such algae as Stigonema. On a low flat place in the lava in the inshore half of the barren shoreside rocks at Kamoamoa, black somewhat dendritic excrescenses one to one and a half centimeters tall and with lobes a millimeter in diameter can be found. These may be Schizothrix thelepheroides with a few multicellular "eggs" of Anacystis-Entophysalis in them. Chunks boiled will come apart, when teased, into fan-shaped branching systems of sheaths in which one or more trichomes can be seen.

(b) In marine caves, where only rarely can one see without becoming very closely associated with the sea, the walls are lined with a pink crust. This is coralline algal material, the material principally responsible for the major features of Central Pacific atolls and reefs. Here in the shade and where often exposed to the air, rarely is it sufficiently developed that one can confidently identify the species. Sometimes in high tide pools in such caves as one finds at Kamoamoa, the corallines will be present on rocks that are otherwise quite devoid of other algal or marine life of any macroscopic kind. As a rule, one expects that these are crusts of Porolithon onkodes (Heydrich) Foslie for this is the widely spread pioneer coralline crustose alga of recent lava surfaces as well as being the principal builder of the ridge at the sea edge of reefs. The surface of a Porolithon crust is, like finely frosted glass, not glazed or shiny. Sometimes other coralline crusts found here have a glazed surface when dry and are probably of the genus Goniolithon.

At the highest levels during low or calm water periods the corallines in the pools or on air-exposed open rocks die, lose their color and become white. Often extensive patches of this material cover offshore rocks where, without noting their ecological relationships or biological origin, one may be inclined to think of them as evidence of a sea bird colony.

(2) Pools in the shores of the Park

In such cave pools as mentioned above there are traces of the algal communities of intertidal non-cave locations. The species are usually sterile or juvenile thalli and so unidentifiable. Lynbya aestuarii (Mertens) Liebmann is perhaps the most recognizable. It forms somewhat gelatinous tangles in which juvenile thalli of Sphacelaria, Cladophora, and various filamentous, sometimes Achrochaetium-like red algae, appear. Perhaps the gelatinous nature is provided by a Phormidium, the very slender trichomes of which are common, present with the above Lyngbya.

At Kaena, a pleasant 30-minute hike from the place where the Kalapana road turns inland for the last time, there is a delightful series of tide-pools and ponds with varying degrees of salinity. Most of them are closely surrounded by the flowering plant Sesuvium portulacastrum L. and, in turn, by flat sandy spots of soil dominated by Portulacca or planted Messerschmidea and Cocos or bush-like small trees of Morinda citrifolia. Just inland where a conventional flowering plant vegetation can be recognized, one is in the summer-drought climate and, often, a Heteropogon grassland.

In the smallest and most inland of the ponds at Kaena the bottoms may be covered with a suspended mass of fine material that is yellowish-brown on its surface. Small fishes, frightened by the shadows of an approaching man, dart into this and in stirring it a bit reveal its below-surface greenness. It is a combination of, largely, the blue-green algae and diatoms that are also to be found in the plankton above. Though many algae are present, only in individual granules of the material was any given species dominant. Among the blue-greens Gomphosphaeria aponina Kuetz., Anacystis dimidiata (Kuetz.) Dr. & Daily, Anacystis marina (Hansgirg) Dr. & Daily, and representatives of Calothrix, Lyngbya, Oscillatoria, Hydrocoleum, and Phormidium are present. None of these is typical of other than a brackish pond. A similar nondescript list of diatoms could be presented but among which some are distinctive; perhaps the most distinctive elements are Melosira, Surirella and a huge Campylodiscus.

Not to be overlooked in this habitat is the abundance of protozoans such as Arcella and an abundance of ciliates and flagellates, many of these latter actually members of algal phyla.

In the ponds at the seaward end of the series, i.e., the more saline, the bottom is covered by a generally gelatinous crust. Nearer the sea it is more nearly a plain continuous browner layer. Nearer the fresher ponds the material is an irregular reticulum of rounded lumps that are greener on the surface. In this material the gelatinous matter is mostly of Microcoleus chthonoplastes. Oscillatoria and slender Calothrix-like filaments are common as are Hormidium-like green algal filaments. Schizothrix-like trichomes of the Microcoleus are less common as are Gomphospheria aponia and Anacystis dimidiata, but the host of diatoms mentioned above is yet present. What we interpret as Anacystis marina is abundant. Occasionally thalli of what seems to be Mastigocoleus testarum Lagerheim, normally a dweller in dead calcareous material, can be found.

Brownish scums may be found wrinkled against the shores, protruding rocks and in the narrow passageways between ponds or against the Sesuvium portulacastrum which closely surrounds the shores. This scum, pushed by the wind, would seem, from the detritus in it and the non-planktonic organisms, to be matter stranded on the intertidal sandy shore surfaces and picked up from them as the tide rises.

(3) Intertidal shores of the Park

The intertidal communities vary with the degree of water turbulance, substratum and tide level. Three community variants have been recognized as those likely to be found in the Park by Mr. Roy Tsuda as 1) protected coves or areas not affected by wave action; 2) areas which are moderately wave-washed, and 3) areas which are affected by strong wave action, below the high sea cliffs. A good complement of these types is available between Kaimu and Kalapana outside the Park. Such areas are often not safely accessible within the Park.

One can expect the rocks of protected, or calm, areas to be dominated by Amansia glomerata C. Ag., Asparagopsis taxiformis (Delile) Coll. & Harv., Chnoospora implexa J. Ag., Microdictyon japonicum Setchell, Polysiphonia sphaerocarpa Boerg. and Valonia aegagropila C. Ag. Especially these can be expected to be found growing in tidepools. Looking down from overhanging cliffs one sees behind the dark background of the basalt rocks young pink patches of colorful crustose coralline algae with two articulated corallines, Jania capillacea Harvey and Jania ungulata Yendo.

In habitat type 2 of moderate exposure to waves, Ahnfeltia concinna J. Ag. with its long yellow and maroon thalli is found associated with thick green and red mats of Gelidium sp., Pterocladia sp., Hypnea pannosa

J. Ag., and Centroceras clavulatum (C. Ag.) Montagne. These species comprise the majority of the marine population in such places. High in the intertidal region, however, short brown tufts of Ectocarpus breviarticulatus J. Ag. predominate. They are about three centimeters in length and are most often seen attached on large basalt boulders. Occasional thalli of Chaetomorpha antennina (Bory) Kützing and Chnoospora minima (Hering) Papnefuss are also to be found in association with this Ectocarpus. Juvenile forms of Ulva fasciata Delile and a species of Enteromorpha, appearing as green blades and filaments respectively, are usually present on the lower portion of any wave-washed bench. Along the edge of a wave-washed bench, erect greenish thalli of Polyopes clarionensis S. & G. are often seen. A slippery black film of Lyngbya and other blue-green algae is often present on smooth basalt rocks making walking very difficult.

Short stubby forms of Sargassum echinocarpum J. Ag., juvenile forms of Turbinaria ornata (Turner) J. Ag., prostrate forms of Zonaria variegata (Lamx.) C. Agardh and Ralfsia pangoensis Setchell are conspicuous in tidepools on wave-washed benches. Small entangled thalli of Polysiphonia are also found in the smaller tidepools. The only epiphyte found thus far is a small Ectocarpus, probably E. indicus Sonder, found on Sargassum. Epiphytes are, however, abundant on these algae in most habitats.

Although collections have not been made from the third habitat situation in the Park, the predominant flora below the high sea cliffs is easily recognized to be the colorful thalli of Ahnfeltia concinna J. Ag. above stunted Sargassum scattered over a pinkish crustose coralline algal coating covering of the rocks. Below this, species of Gelidium occur as a redish turf.

Actually, in reference to tide or wave level little precise study within the Park has been feasible. A tide level or vertical distribution study does not seem likely to be rewarding for the reason that the generally heavy wave action seems to dwarf the effects of the tides. There are all degrees of basalt substrata, consolidated shores as cliffs or non-consolidated huge and relatively permanent boulders, or gravels, or even finer material. The smaller sizes are so mobile they do not remain in one position long enough for much in the way of a population to develop on them unless they are on rather flat bottoms as are present between the island of Kaoi and the Halape shore or between the near-shore bilsters of lava and the shore at Kaena.

Without going into the possible tide level relationships of the different, apparently dominant species, the highest-growing macroscopic alga may be taken as Ahnfeltia concinna. This species (Fig. 26) forms a yellow bunchy cover on the rocks with individual fronds often 25 centimeters long but varying greatly from place to place. At a distance a zone of it (Figs. 27 & 28) reminds one[8/] very much of the similarly located yellow-brown strands of Fucus or Pelvetia on North Temperate shores. Note (Fig. 26) the variation in standing crop with elevation indicated in the "blow up" of the intertidal part of the shore.

The zone just below the Ahnfeltia is generally of about the same width as the Ahnfeltia zone. It is usually (Fig. 27) one of several sorts: merely for the most part black rock; populated with Ulva or Enteromorpha; populated with Ralfsia above and Ulva below, or largely dominated by crustose corallines. Of course there are times when there are mixtures of all three or other species. Caulacanthus ustulatus occurs here, too. Sometimes this zone is

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[8/] Dickie (1876) in writing of the algae collected at Hilo by H. N. Moseley on the Challenger Expedition also mentions this resemblance.

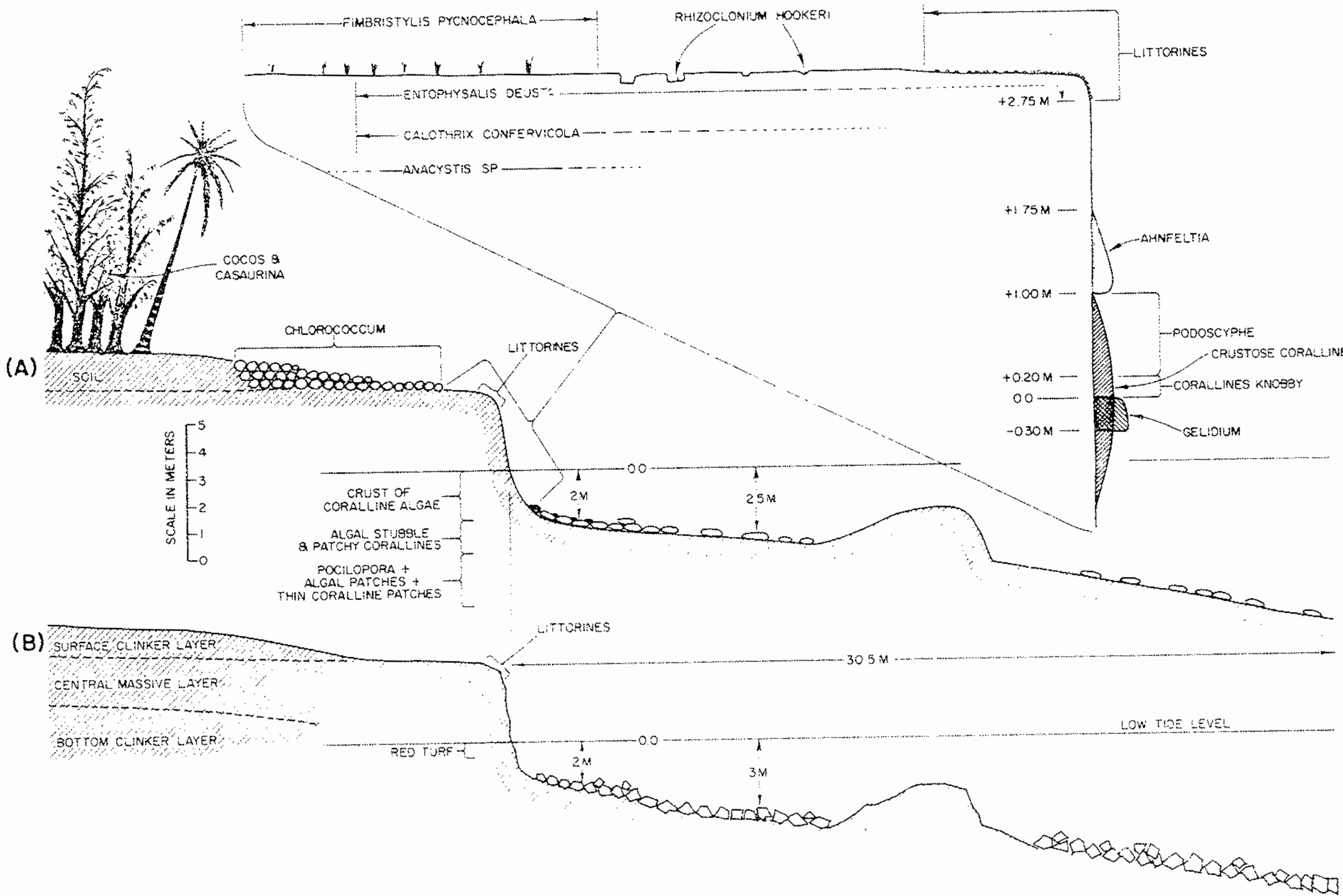


Fig. 26. Comparison of old (A) and recent (B) igneous shores by a diagrammatic presentation of the horizontal and vertical distributional features of the populations and some geological details.

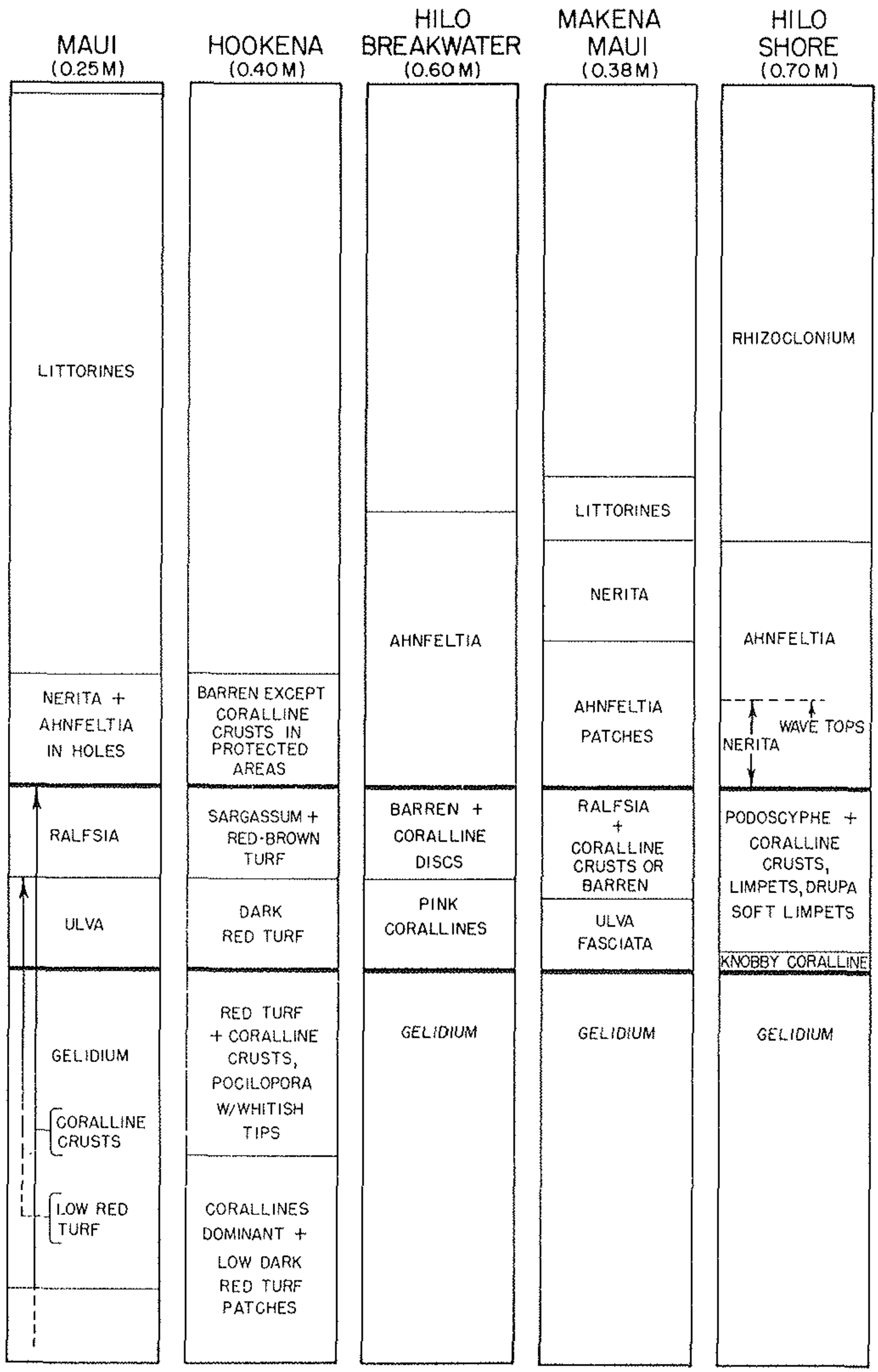


Fig. 27. The vertical distribution patterns common to Hawaiian shore areas similar to those to be expected within the Park. The distance between the two horizontal dark lines in meters is given at the top of each strip as well as the location of the two on Maui island and three on the island of Hawaii. This provides the scale for the whole diagram.

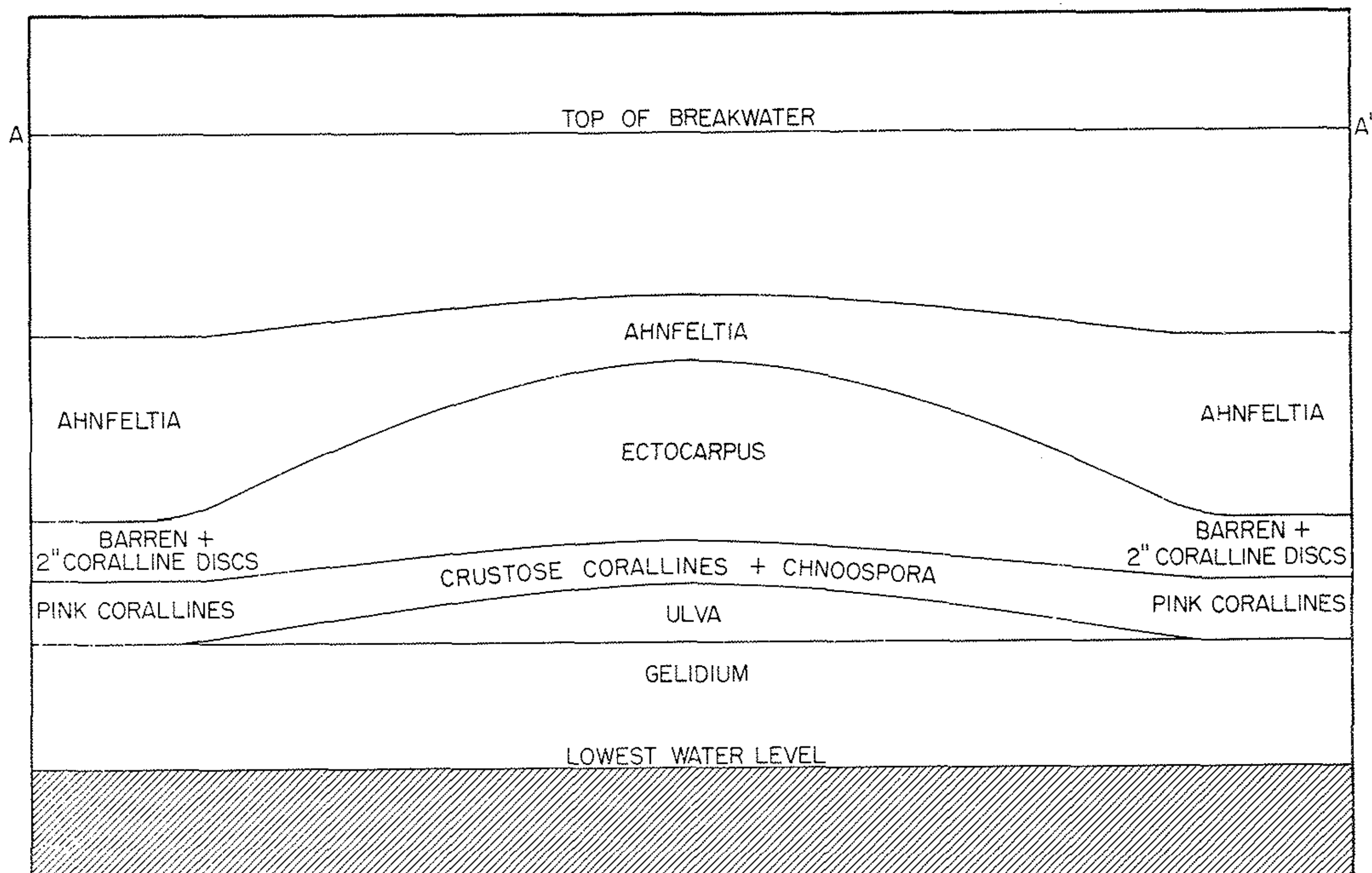


Fig. 28. Diagram of algal vertical distribution on a wave-exposed projecting angle of the *Hilo Breakwater in relation to the adjacent less* wave-exposed portions of the same breakwater. The diagram is essentially without scale.

subdivided with the rock of the lower part coated with crustose coralline algae, the upper part with non-coralline algae. The corallines, low in this zone (Fig. 27), may be rough-surfaced or produce small Porolithon-type heads. Podoscyphe, Drupa and limpets, when present, are here.

The next zone down is comparatively as broad or even broader than the two above together. It is underlain by smooth crustose coralline algae, often covered with Gelidium or other closely related genera. In the upper part of this zone the brownish genus, Sargassum, is common. If in a place where the water has a consistent direction of motion, the fronds will be a foot long, but as the water is more turbulent the fronds are shorter and may be merely irregular patches of stubble. At the lowest common level of the waves, the Gelidium cover rather abruptly terminates. When working on shore the abrupt upper limit of this alga ("A" in Fig. 26) can be used as zero datum level in measuring vertical distribution: when under water the abrupt lower edge can be used as a convenient zero. The dense Gelidium cover probably represents a zone between mean sea level and the lowest low tide level.

The shallow water communities are dominated by the crustose corallines extending on below the Gelidium-covered zone (Figs. 26 & 27), often completely covering all consolidated rock surfaces down to a depth of 1 to 1.5 meters below low tide line. They extend much further down (certainly to at least 7 meters) but as a thin cover gradually becoming yet thinner and covering the surface less completely as greater depths are reached. Of Oahu, crustose algae are still present at depths of 525 feet as determined from diving in a research submarine. About 2 meters below the bottom of the Gelidium, an algal stubble becomes dominant and is conspicuous for at least 5 meters on down. Conspicuous elements in this stubble are Dictyota friabilis and Griffithsia as well as the small algae commonly found in the Gelidium-levels and especially well developed in intertidal pools.

While pink coralline algae, the principal builders of reefs in the Pacific, are everywhere to be seen, the animal corals are but very few. Pocillopora, the only conspicuous coelenterate coral, often appears about 3 meters below low tide level with the individual heads being, perhaps, 3 meters apart down to the -8 meter level. No really sharp limits below the bottom of the Gelidium have been observed in Hawaii. From the results of dredging it appears that the algal standing crop may actually increase once depths below those affected by wave action are reached.

The vertical range of levels at which algae are found changes with the degree of wave action and the actual algae present may be there in relation to the degree of population (seral) development or seasonal progression. This latter is an unknown for the Park communities. In Figure 28 there is diagrammed a class of events which is useful in formulating an explanation of the change of elevation of communities with wave action and some events in their development. As an example of use in explaining phenomena in the Park: over the center of the basalt breakwater of Hilo Harbor there passes at times a lot of gravel as evidenced by a large pile of fresh appearance on the inner side and the growth of this pile with time. Wave action has been seen to be definitely less to the right and left of the center of the area. The upward shifting of horizons or zones illustrated (Fig. 28) is apparently in relation to the greater wave action at this place along the breakwater. The characteristics of the population indicated at the right and left ends of the diagram are consistent, respectively, toward shore and the sea. These conditions, shoreward and seaward, are thought to represent the stable community, or climax, conditions relative to the central region.

The Ulva and Ectocarpus populations at the center of the diagram would seem to represent disclimax or subclimax conditions depending upon their origin. Subsequent examinations of this place lead us to prefer the term disclimax as applicable in this and some other situations where the same algae have been observed to appear after a disturbance of the climax population. In another connection Randall (1958) has indicated phenomena possibly of this sort in connection with an hypothetical explanation for some poison fish occurrences.

(4) Population development on new lava shores.

Sooner or later it can be expected that within the Park a lava flow will reach the sea. In order to provide information to be used in interpreting the events that will follow and provide a guide for studies of these events an extract of the results of a study made on the 1955 lava where it went into the sea a few miles to the east of the Park is included here. It is also hoped this will be useful in interpreting phenomena concerning the present mature populations on prehistoric surfaces in the Park.

In the Hawaiian Islands there are historic lava flows in the intertidal regions dated from about 1750 down to the present. None of these has quite the same population on it as is to be found on the adjacent probably much older undated or prehistoric lava shores. This is a problem for in studies elsewhere observations in the intertidal region have led to the expectation only about five or six years are required for the "climax" situation to become established. Indeed some have said that in the case of intertidal populations there was "direct development" of the mature or "climax" populations. Fahey (1953) reviews this situation briefly.

Observations on the 1955 lava flow in the sea, itself, were made not only to provide a record of events but to provide a series of special observations to test certain hypotheses concerning the development of intertidal populations on them. These hypotheses are, largely, the separation and distinction of succession, seasonal progression, the events of zonation, the regulation of climax formation, and classification of the different algae and other organisms according to the part they plan in the populating process. Testing, observation and experimentation elsewhere (Northcraft, 1948; Fahey & Doty, 1949; Fahey, 1953) have been concerned with surfaces such as concrete, old rock or wood brought to the sea for the first time, with denuded surfaces, or (e.g., for review of subject, Williams, 1965) glass slides.

The initial hypotheses were that this phenomenon of slow development of a climax situation was related to the geographic position in the islands or the chemical or physical composition of the lava. These hypotheses were destroyed by a few simple experiments and measurements. For example, chunks from recent and old lava flows of different dates, composition and physical surface were seated in concrete blocks, sometimes enclosed in wooden forms and exposed in the sea. It was found that the pioneer and secondary populations developed about the same on all surfaces exposed, including the wood and concrete. This is a quite different result from that obtained in experiments with terrestrial forms on different substrata.

The 1955 lava flows ran into the sea along a shore (Fig. 24) where there was very little sand. Shortly after the flows had cooled, extensive beaches of black sand were seen extending along the shores to the left and right of the new lava flows. With time, as determined by successive observations, this sand moved off or away (often moving inland) from these first formed beaches.

Uniform samples of the water washing the intertidal surfaces taken from near the 1955 flows and from near the much older undated flows revealed a measurably larger amount of sand and sediment in the water from the new flow areas. Erosion of these 1955 shores has been high and, in some cases, several meters of the new lava surface have been removed in but a few months. In passing, it may be noted that the Honokua 1950 lava flow at Hookena, Hawaii, was so worn back by late 1955 that in many places the prehistoric flow under it was again exposed to the sea.

A different hypothesis finally arose after following the populations on these 1955 intertidal lava flow surfaces for some time. This is to the effect that the surface would have to become so stabilized that it would remain effectively constant for at least the five or six years one can expect it takes a climax population to appear. It seems true that wherever a dated flow is not yet worn back to the general coast line, it does not bear a sere-wise advanced population.

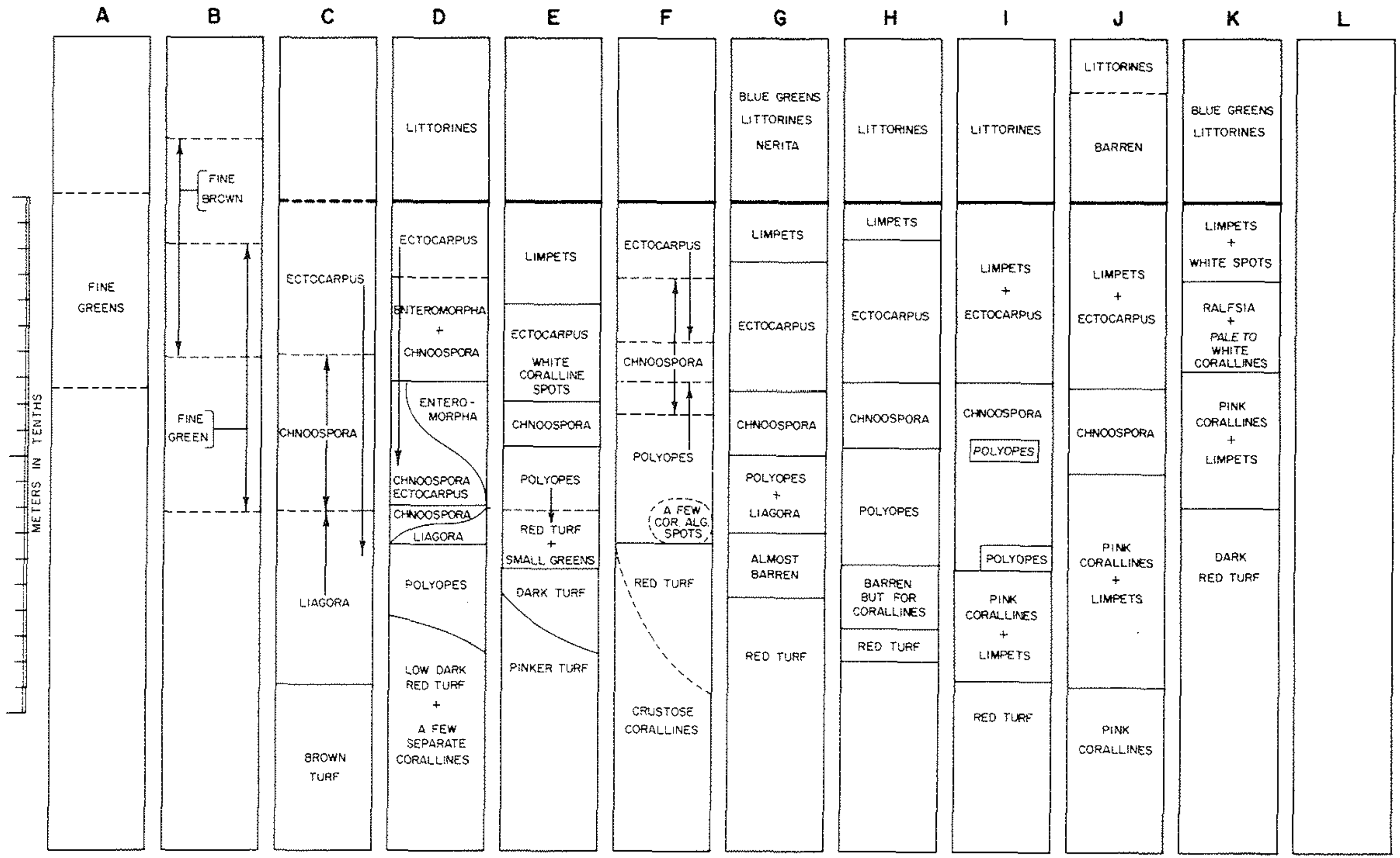
Somewhat similar statements can be made in regard to the presence of black sand. Where black sand is present nearby in quantity, the populations tend to be immature. Rigg (1914) and Dawson (1954: 10) both comment on the denuding action of such volcanic pumice and sand on nearby populations. In our case, no such observation of the removal of old nearby populations has been made. We do note that, as indicated by the contrast in Figure 26, there is a change in the rocks on the bottom. Not only with time have the rocks in the sea off the Kehena flow become smaller, more closely packed and more rounded, they have also become more completely populated, largely by crustose algae. Early visits to the area were marked by notes of the frequency stones were seen thrown by wave action higher and beyond the splash of the water itself. Likewise in skin and SCUBA diving, moving stones were often seen. The author observed stones, adjudged to be of 7 to 12 centimeter dimensions, in the turbulent water .3 to .7 meters off the bottom during a period of unusually rough seas while swimming under the large waves after having been washed off the study area. The author has not been in the water at this place under such rough sea conditions during the last few years, but the impression is that the bottom, which is of closely packed stones, is of fewer and more uniformly dense boulders not moving as freely as they did during the first two years of the study.

At the time of our observations in June, 1955, one of the dominant algae on the 1955 lavas was Liagora maxima. It was present both on pre-historic lava near the 1955 Keekee flow and on the 1955 Kehena flow. This alga was much less evident in December (1955) than it had been earlier in June and August, and by February and March (1956) none was seen at all. However, in May and in July (1956) it was again abundant. This we regard as a manifestation of seasonal progression or periodicity rather than as pioneer colonization without ecesis.

Our study has been rewarding in connection with the obtaining of observations that bear on the problem of distinguishing seral progression. As illustrated for the Kaueleau study site ("E" in Fig. 24) at "A" in Figure 29 the first macroscopic populant on the newly cooled lava was fine green strands of Enteromorpha. Specifically this green algal material is not identifiable further than to genus at this time. These populations were very hard to reach consistently for measurement or collection.

Subsequent more consistent study was possible when portions of the flow surface broke away and disappeared. In these cases regardless of time of year or vertical position in the intertidal region, the same Enteromorpha appears as a fine hair-like rather uniform coating on such "fresh" surfaces. Certainly this particular phenomenon is one of disclimax in consideration of the whole area, yet on the particular fresh lava surfaces the Enteromorpha

Fig. 29. Population changes in time on a vertical 1955 lava surface extruded into the sea and observed as follows: A at Kaueleau, VI-21-1955; B at Kehena, XII-30-1958; at Kaueleau respectively--- C, VIII-15-1958; D, XII-21-1955; E, III-24-1956; F, V-16-1956; G, VII-14-1956; H, VIII-18-1956; I, XI-10-1956; J, IV-20-1957; K, XII-30-1958.



is a pioneer. In time the Enteromorpha matures into isolated tufts of mature thalli that may eventually become somewhat brownish with the development of epiphytic diatoms and then disappears as succession takes place.

Ectocarpus breviarticulatus can be expected to appear ("B" and "C" in Fig. 29) shortly after the Enteromorpha has appeared and with it distributionally but also alone at still higher intertidal levels as well. While the Ectocarpus at first may be diffusely spread over the surfaces, intermixed with the hair-like coating of Enteromorpha, it too first becomes restricted to small tufts and these become fewer and larger as time goes on. In age the lower tufts of Ectocarpus may become intermixed with a Cladophora, the tufts of which other than for color are quite similar macroscopically.

As time goes on, the pioneers become replaced by other algae and zonation (Fig. 29) becomes evident and more stable as longer-lived organisms appear. While the Ectocarpus, all the time it remains, is the highest macroscopic algae, a blue-green coating began to appear ("D" in Fig. 29) conspicuously on the rocks above the Ectocarpus in December, 1955, six months after the flows had cooled here. We have gained the impression that with excessive abrasion during storms, many of the zoned organisms are removed. In fact, so many may be removed irregularly and replaced by pioneers (e.g., the Enteromorpha in "D" of Fig. 29) that zonation becomes obscured. It would seem this disclimatic process is related to that which holds some areas (Fig. 28) in subclimax condition semipermanently.

The series of events illustrated in Figure 29 was progressive. The blue-green population gradually became more dense so that it could be readily detected in its lower reaches even when dry. At first it was seen as a blue-green sheen only when wet. Littorina pintado became progressively more abundant as this happened. Lower down the same events were true for the high-growing limpets, Helcioniscus exaratus. Ralfsia and the crustose corallines appeared as small spots over a wide vertical range, became larger, tended to completely cover the surface in a smaller vertical range, and became fertile. The corallines often developed erumpent edges where adjacent crusts closed together. The early populants Estocarpus, Chnoospora and the various Chlorophyta by March, 1965, were no longer obvious except in an occasional spot where a chunk of lava had broken away. While not actually measured, it seems clear that the bottom depth adjacent to the Kehena and Kaueleau flows has increased.

The finger-shaped point of rock at Kehena ("D" in Figure 24) some 7 meters broad, perhaps 4 meters thick which jutted into the sea some 20 meters and bore the surface repeatedly studied, photographed and measured completely disappeared early in 1961. Perhaps this is related in part to its being undermined as the depth alongside increased. Even before that time disclimatic events had disrupted the study and such climax genera as Sargassum never did develop there. Other sizeable protrussions and seaward faces of the 1955 lava flows were noted to have disappeared between visits. As a result in 1965 these flows are hardly irregularities in the outline of the shore. Undoubtedly, this rapid wearing back of the flows to the general island contour is a major reason for the lack of bays in this younger part of Hawaii.

In the series of phenomena observed, we feel there was demonstrated seral progression as Sargassum echinocarpus, S. obtusifolium and the crustose coralline algae became well established only during the second year of observation of the 1955 flow surfaces. Similarly in time Corallina sandwicensis became present as dense fertile hemispheres at Kehena, as did occasional tufts of Alsidium sp. and Lophosiphonia villum at their characteristic high elevations. This seral progression, while it has resulted in populations having some of the more conspicuous algae and animals of the climax situation, has not yet progressed very far either qualitatively or quantitatively. On more protected less abraided areas and in pools the populations are much more advanced toward the climax situation and the standing crop is higher.

No one has yet been successful in determining the precise quantities of algae on a rough nearly perpendicular intertidal shore exposed to the full sweep of the surf, but comparative observations show that though forms conspicuous in climax populations are present and fertile, for example, crustose coralline algae, the cover was still (March, 1965) not as dense as it was on the prehistoric shores. It does seem likely that as the sere moves toward the climax situation a higher standing crop is maintained, though productivity may be lowered.

Certain qualities, e.g., the red algal species Ahnfeltia concinna, coelenterate corals, and the brown algal genus Ralfsia, were absent during the first year of observation at Kehena and Kaueleau. Of these during the second year small patches of Ralfsia appeared. Ahnfeltia was first noted in December, 1959, about four and a half years after the surface had cooled. Earlier, these two qualities had been found sparsely developed on the surfaces of flows five years old elsewhere (the 1950 flows). By April, 1962, 7 to 8 cm tall tufts of Ahnfeltia concinna were conspicuous on the 1955 Kaueleau lava flow study point. This alga while not forming a band was quite abundant, though not frequent elsewhere. Much of the flow surface inland from the study point was gone by March, 1965. It was largely loose clinker material, but some of the clinkers or chunks removed must have weighed at least a metric ton. This removal is slight in comparison to the complete removal of most of the study point at the Kehena site. There between two visits the whole small solid rock peninsula disappeared except for the tip which remains as an isolated islet perhaps 2 meters in diameter and constantly washed over by the waves at high tide.

It can be stated here that the idea of Fahey, Northcraft, and others, that the pioneer organisms, e.g., Enteromorpha and Ectocarpus, may be occasional organisms in climax situations seems to be borne out by our observations. To this group we would add Polysiphonia. Enteromorpha, which was the principal macroscopic pioneer, has become restricted to but a few spots on some of the population-wise most advanced surfaces. It appears in abundance, however, as a pioneer coating over any new surface such as is formed when a piece of the flow is broken away by the waves. Ectocarpus breviarticulatus, on the other hand, may remain as a rather regularly predictable populant of the highest intertidal regions for at least a year. It is much less conspicuous on older surfaces and absent for the most part where Ahnfeltia concinna is abundant on prehistoric flows.

It is to be noted that the more permanent crustose colonizers, e.g., Ralfsia and the crustose corallines, appear as small spots and grow so as to occupy most of the surface. In doing so, they leave less and less space free on which the frondose earlier more conspicuous or dominant and short-lived populants can grow.

Should a lava flow enter the sea within the Park a photo series, including vertical aerial views, should be made at intervals such as one week for the first few months and a biological study begun at once that can be carried on intensively for at least five years. Planning for such a study should be done in advance for such a study could become a biological classic.

Chapter VIII- The Vegetation Map and Vegetation Profiles

By Dieter Mueller-Dombois

Utilizing the aerial photographs discussed above in Chapter I a vegetation map has been prepared for the Park area on a scale of approximately 1:12,000, the scale of the aerial photographs themselves. The mapping was done on transparent plastic overlays in the form of 53 sheets each 27 x 27 inches in size with the details in a polygonal area selected so that the 53 provide complete coverage of the Park.

In preliminary form the different types of vegetation were first outlined by F. R. Fosberg utilizing, indoors, the field knowledge he had accumulated through his years of experience with vegetations. The preliminary vegetation units so mapped were studied and checked out in the field by the writer and modified as necessary. From the 53 finished maps a revised, partially new, classification of the vegetation units was developed. Abbreviations of the names of the predominant plants in these units provided (Table I) the symbols used on the maps and in the text below. Table II reviews the classification. Perhaps even more usefully, a series of vegetation profiles (Figs. 30-34) related to climate, topography and soils was prepared. Figure 18 shows the locations of the profiles which are referred to as Transects 1 through 5 in the text below.

Field mapping involved correlating ground conditions with the patterns found on the photographs. This was done by exploring all unknown photographic patterns in the field and by running transects through those areas that showed a maximum of variation in pattern on the photographs. The vegetation types were defined by physiognomic and floristic critera and in some instances in relation to topographic and substrate features. Extrapolation was kept to a minimum in the more accessible areas, where all

Table I. Symbols used in the vegetation map for Hawaii Volcanoes National Park. The symbols are largely abbreviations of the generic names of species. For example, a front symbol "oM," indicating open Metrosideros forest might be combined with an attribute symbol, such as "(Sa)" indicating a scattering of Sapindus occurred with the Metrosideros. Often more than one front or attribute symbol is combined. In use and in the following alphabetic list the attribute symbols are enclosed in parentheses. These symbols were recorded on the transparent overlays made to correspond to the aerial photographs described in Chapter I.

(Ac)-	Scattered *Acacia koa*.
AcSaM-	Mixed *Acacia koa*—*Sapindus*—*Metrosideros* forest.
(ad)-	Admixed trees in lower story (*Myrsine lessertiana*, *Myoporum*, *Coprosma rhynchocarpa*, *Cheirodendron*, *Pelea*, etc.) and arborescent shrubs (*Pipturus*, etc.).
Al-	Forest dominated by *Aleurites moluccana*.
(Al)-	Scattered *Aleurites*.
An-	*Andropogon* grassland (includes *A. virginicus* and *A. glomeratus*).
(An)-	*Andropogon*.
ash-	Ash deposits with little or no vegetation.
(ash)-	Much barren ash.
C-	*Cibotium* forest.
(C)-	*Cibotium*.
Ch-	Dense *Chrysopogon*—*Cynodon* grassland on loess-like, yellow ash (Puu Kaone).
clf-	Closed mixed lowland forest, mostly fragmented by urbanization and strongly modified and variable from tree planting (*Mangifera*, *Samanea*, *Aleurites*, *Cocos*, *Pandanus*, *Psidium guajava*, *Thespesia*, *Schinus*, etc.).

Table I. (continued).

cls- Closed lowland scrub, mostly low-growing.

cM- Closed *Metrosideros* forest.

E- *Eragrostis tenella* grassland.

(E)- Abundant annuals, *Eragrostis tenella* and *Bulbostylis capillaris.*

(e)- Abundant epiphytes (*Astelia*, *Freycinetia*, *Cheirodendron*, mosses and liverworts).

fu- Fumarole areas with dwarf shrubs, *Andropogon virginicus*, *Nephrolepis*, *Gleichenia*, and barren ground.

(G)- *Gleichenia*.

H- *Heteropogon* grassland.

(H)- *Heteropogon contortus*.

(i)- Introduced shrub (*Psidium guajava*, *Stachytarpheta jamaicensis*, *Lantana*, *Cassia* spp., *Solanum* spp., etc.).

it- Stand composed of introduced trees.

(it)- Introduced trees (*Eucalyptus*, *Jacaranda*, etc.).

(L) Lichens (*Cladonia* spp., *Stereocaulon*, etc.).

(ls)- Sprawling or short lowland scrub (*Waltheria*, *Osteomeles*, *Cassia leschenaultiana*, *Indigofera*, *Psilorhegma*, etc.).

lsi- Mixed lowland scrub composed largely of introduced species.

(M)- Scattered, old *Metrosideros*.

Table I. (continued).

MAc- Mixed *Metrosideros*—*Acacia koa* forest.

MAl- Mixed *Metrosideros*—*Aleurites* forest (the latter scattered) with other mesophytic forest tree species (*Myrsine lessertiana*, *Santalum*, etc.).

MD- Mixed *Metrosideros*—*Diospyros* forest, almost always open, with other dryland forest species (*Antidesma*, *Canthium*, etc.).

(Me)- Abundant *Melinis* patches.

mx- Mixed grassland (mxg = grazed).

(mx)- Mixed grass (above 4000 feet elevation).

(N)- *Nephrolepis* patch communities on a'a lava.

ns- Native shrubs (includes *Styphelia*, *Vaccinium*, *Dodonaea*, *Dubautia*, *Coprosma ernodeoides*, *Metrosideros*, *Myoporum*, *Wikstroemia*, *Sophora*, etc.).

(ns)- Native shrub (*Styphelia*, *Dodonaea*, etc.).

o- Open (only used in combinations).

olf- Open mixed lowland forest, mostly fragmented by urbanization and strongly modified and variable from tree planting (*Mangifera*, *Samanea*, *Aleurites*, *Cocos*, *Pandanus*, *Psidium guajava*, *Thespesia*, *Schinus*, etc.).

ols- Open lowland scrub, mostly low-growing.

oM- Open *Metrosideros* forest.

P- *Prosopis* forest.

(poik)- Poikilophydrous (*i.e.*, xerophytic) plants and annuals (Kau Desert).

Table I. (continued)

r-	Lava flows with little or no vegetation (r for rockland).
(R)-	Scattered *Rhacomitrium* moss.
(r)-	Much barren lava.
rb-	Lava flows, completely barren (summit of Mauna Loa down to 11,000 feet, and further down where indicated).
(Sa)-	Scattered *Sapindus*.
scM-	*Metrosideros* scrub.
(scM)-	*Metrosideros* scrub.
(So)-	Scattered *Sophora*.
spr-	Salt-spray and other shore communities.
(spr)-	Salt-spray and other shore communities.
(T)-	*Tricholaena repens*.
x-	Cleared or strongly disturbed areas that have not been left for long enough to establish a recognizable vegetation types.
(x)-	Much modified by man.

major variations were investigated. In the less accessible areas, which involved about 20% of the total, vegetation was determined by matching photographic patterns. Indirect mapping was necessary for the higher altitude vegetation on Mauna Loa, where vegetation cover is not dense enough to show on the photos. Here topographic lines and substrate types were matched to approximate the correct vegetation limits.

The symbols used (Table I) on the vegetation maps prepared as overlays of the aerial photographs (Chapter I, above) are derived from the names of genera or other predominant surface cover. They are usually in two parts, a front symbol of letters indicating the more obvious stand or surface features and an attribute symbol added in parentheses after the front symbol. The attribute symbol denotes a finer variation. More systematically, a front symbol indicates a major cover type, an attribute symbol, a breakdown within the cover type, commonly recognized by a change in the subdominant species. For example, oM(C) stands for open *Metrosideros* forest with *Cibotium*, and oM(G) stands for open *Metrosideros* forest with *Gleichenia*. There are 29 front symbols. The 28 attribute symbols provide further characterization. Symbols denoting a species are capitalized abbreviations of the generic name. Symbols denoting other vegetational or surface features are also similar simple abbreviations, but in lower case.

TOPOGRAPHIC VEGETATION PROFILES

The vegetation profile diagrams (Figs. 30-34) are intended for map interpretation as well as for a classification of the vegetation in the Park. The diagrams follow the transect lines 1-5 shown on the orientation map (Fig. 18) in the chapter on climate. Their location was selected to give the maximum of information about the arrangement of the vegetation cover in the Park as permitted by the chosen geographic scale.

The segments shown by sequential numbers and vertical separation lines on each profile diagram portray the more important vegetation types in the Park. However, several of the separately numbered profile segments represent the same vegetation type. For example, segment 12 on Figure 30, segment 8 on Figure 32, and segment 7 on Figure 33 represent the closed Metrosideros-Cibotium forest type. The same applies to other geographically widely distributed or frequently recurring types, e.g., to the Heteropogon grassland type, which recurs on three profiles (segment 2, Fig. 32, segment 2, Fig. 33, segments 1 and 3, Fig. 34) and even twice on one profile (Fig. 34). Therefore, the total number of profile segments, 47, is greater than the number of vegetation types recognized, 31.

The profile segments coincide closely to the vegetation units recognized on the map sheets. However, the degree of abstraction has been carried a little further on the profile diagrams to eliminate unnecessary detail. For example, the mixed Acacia koa—Sapindus forest (segment 9 on Fig. 30 and segment 8 on Fig. 31), which here represents the vegetation type of Kipuka Puaulu (Bird Park), shows as two types on the map sheet, a closed mixed Acacia koa—Sapindus forest [map symbol AcSaM(ad)] and an open mixed Acacia koa—Sapindus forest (or savannah) with Metrosideros [map symbol mx-AcSaM]. Both types appear on aerial photo 8-0079. Another example may be illustrated by referring to the profile diagram Figure 34, segment 5. Here the diagram refers to only one type, the mixed lowland scrub, map symbol ls(i). On aerial photos 14-0016 and 6-16 the type is further subdivided into open lowland scrub [symbol ols(i)] and closed lowland scrub [symbol cls(i)]. There are numerous other examples. The finer variations recognized by finer type designations on the vegetation overlays would not add any relevant information to the profile diagrams. Therefore, they are omitted.

The numbered segments shown on the profile diagrams and the vegetation types that they represent are related primarily to significant variations in macroclimate, but in part also to variations in substrate and stand development. The latter two variations occur wherever there is more than one vegetation type within a climate type.

The climate, substrate and stand structure relationships are presented as simple, factual relationships. They do not imply any causal relationship. The establishment of cause and effect relationships requires further study.

In order to facilitate map interpretation each vegetation type name will be supplied with the map symbol in the following discussion of the profile diagrams. They are arranged alphabetically in Table I and systematically in Table II.

Vegetation types along the east slope of Mauna Loa. Transect 1 (Fig. 18). Profile diagram Figure 30.

The vegetation was explored on a two-day field trip (August 17/18, 1965) that began from the summit of Mauna Loa. Transect 1 follows the approximate course of the Mauna Loa Park Trail from 12,000 to 6600 feet elevation. From the 6600 foot elevation on down it follows a straight-line course independent of any road or trail to 3900 feet. The area is covered by aerial photos 4-0015, 6-0124, 2-0081, 4-0038, 5-0014, 4-0066 and 8-0079.

The vegetation types are portrayed on the profile diagram Figure 30, segments 1-12. The vegetation type limits and floristic records were checked with an altimeter. The discussion follows the number sequence of the profile segments on Figure 30.

Segment 1 (Fig. 30). Unvegetated stone desert; map symbol rb; aerial

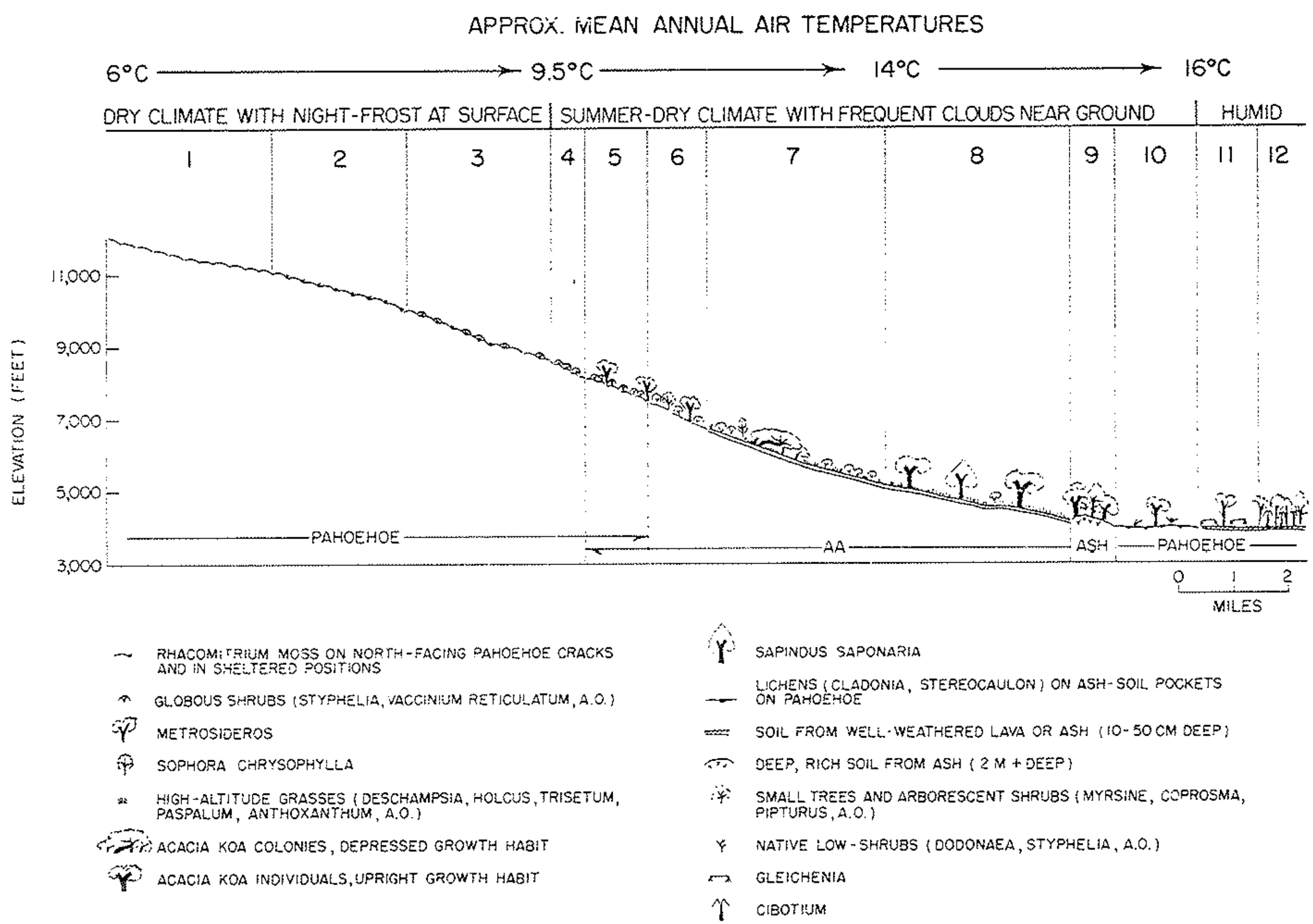


Fig. 30. Profile of vegetation types on the east slope of Mauna Loa from 12,000 feet down to 3900 feet on prehistoric and dominant substrates, 22 miles from Ohaku O Hanalei over Puu Ulaula, Kipuka Puaulu (segment 9) to Kilauea Iki surroundings. This is Transect 1 of the text and Figure 18.

photos 1-0090, 1-0092, 1-0094, 4-0015, 4-0017, 4-0019.

The upper east slope of Mauna Loa, from its summit at 13,676 down to 11,000 feet, can be classified as unvegetated stone desert. Only a single bunch grass of Deschampsia nubigena was noted on the trail at 11,400 feet. Here it was thriving, apparently with good vigor, on an area strewn with olive-black pumice consisting of 0.5 to 3 cm diameter fragments. The air temperature at noon (12:30 p.m.) was 12.5^{o} C, the soil temperature (1 cm in the olive-black pumice) was 28^{o} C on a bright, sunny day (August 17, 1965). In spite of its complete bareness of vegetation, the stone desert area is rather colorful—glistening, greenish-black pahoehoe (smooth, ropy lava) interchanges with steel-gray, older pahoehoe and with buff-colored, more weathered old prehistoric pahoehoe that appears as white fields on the aerial photos (e.g., photos 4-0015, 4-0017 & 6-0124). Also, black and dark-brown a'a (coarse, clinker-like) lava occurs here and there. In addition, one finds local areas of reddish pumice and cinder (that also appear as white flecks on the aerial photos) and areas of olive-black pumice and ash. Other signs of life besides that one clump of grass were the occasional Epilobium seeds that drifted in the afternoon upwinds within 10 m height across the barren lava fields and here and there old horse droppings along the trail. These were completely bleached and straw-like showing no signs of decomposition through microorganisms. (No old horse droppings were sighted below 10,000 feet.)

Segment 2 (Fig. 30). Rhacomitrium moss type; map symbol r(R); aerial photos 6-0124, 6-0126, 6-0128, 7-0014, 11-0007.

The type is composed of small (4 x 10 cm), whitish-gray cushions of Rhacomitrium lanuginosum var. pruinosum that are not readily noticed as they are found only on north-facing cracks of the buff-colored, prehistoric pahoehoe lava and in sheltered blister-holes. The cushions are extremely scattered. Many north-facing lava cracks are barren. Occasionally denser colonies can be observed in association with gypsum crystals. The first cushion-colony was observed at 11,000 feet just below Dewey's cone (aerial photo 11-0007, where overlooking a larger area, Rhacomitrium could be seen here and there clinging to the north-facing cracks. Apparently, this moss has been observed right on the summit of Mauna Loa (Bartram, 1933). This is a noteworthy record that would indicate its distribution continues through the stone desert. However, if it does, it certainly cannot be considered as forming a vegetation type above 11,000 feet, where the writer did not see any specimens. It is important to note that Rhacomitrium was found only in the cracks of the old, buff-colored pahoehoe at 11,000 feet. From 10,500 feet on down it was noted also in the cracks of more recent, dark-gray pahoehoe and on dark-brown a'a.

At 3:30 p.m. a sudden fog appeared from the north that reduced the visibility to 10 m distance. It lasted only for half an hour. It is possible that a short afternoon fog is a rather regular phenomenon in the Rhacomitrium moss type, which seems probable from the discussion of wind movements at the Mauna Loa Observatory by Price & Pales (1963).

Fosberg (1959) found at this elevational range along the Kulani Mauka Road in the somewhat moister northeast slope area two other plants in isolated deep cracks, the fern Pellaea ternifolia, and the grass Trisetum glomeratum.

Segment 3 (Fig. 30). Scattered, low globous scrub type; map symbol r(ns); aerial photos 2-0081, 4-0038, 11-0007.

This type starts at 10,000 feet and extends down to 8500 feet. It consists of only two shrubs, Vaccinium reticulatum and Styphelia douglasii. These shrubs occur first as small (up to 30 cm tall), gnarled individuals with loose, cushion-like crowns. The term cushion applies here and in the following unit descriptions only to the semi-globose crown shape of the shrubs and does not imply a tightness or density feature of the crown habit. The distribution of the shrubs, from 10,000 to 9400 feet, is extremely scattered.

They occur at distances of about 50 to 100 m apart only in the cracks of the buff-colored and steel-gray pahoehoe lava and on red pumice. The latter substrate is only of very restricted distribution. The older a'a flows at this elevation are still barren, except for the presence of Rhacomitrium lanuginosum var. pruinosum that continues also through this shrub type in the north-facing pahoehoe cracks. Trisetum glomeratum dominates as a scattered thin bunch grass on the few small areas strewn with cinder and red pumice. However, these areas are too small for recognition as a separate type on this scale.

Other components in the scattered scrub type include the grass, Deschampsia nubigena (only where there is an accumulation of fine materials), the ferns, Pellaea ternifolia and Asplenium trichomanes, the composites, Tetramolopium humile, Gnaphalium sandwicensium var. kilaueanum, Hypochaeris radicata, and Carex wahuensis var. rubiginosa (in a sheltered blister-hole). All of these are extremely sparsely distributed in the cracks of the old, buff-colored pahoehoe.

Soil temperature (1 cm deep in red pumice) at 10,000 feet was 0° C at 7:30 a.m. on a warm, sunny, summer morning(August 18,1965).

Segment 4 (Fig. 30). Open to closed cushion scrub type; map symbol ns; aerial photos 2-0081, 4-0036, 4-0038, 5-0035.

At 8500 feet shrubs began rather suddenly to grow taller (up to 75 cm) and to be more densely distributed, i.e., at every 5-10 m. They also tended to occur in clumps of several (about 3 or more) individuals with combined crown coverages of 1-3 m^2. This change occurred on the same substrate, i.e., the prehistoric, buff-colored pahoehoe, while on the older a'a lava, at parallel elevations, shrub growth appeared to be as sparse as in the previous type (segment 3, Fig. 30) on pahoehoe. In addition new shrub species appeared, Dodonaea viscosa, at 8400 feet, Coprosma ernodeoides at 8250 feet, Dubautia ciliolata var. laxiflora at 8150 feet. At 8400 feet, the writer noted the first lichens, an Usnea clinging to the branches of a shrub and a minute specimen of a green Cladonia. This observation differs from that made on the north slope of Mauna Loa, where a few colonies of Stereocaulon were noted on lava at this elevational range. However, the absence of lichens above this area is remarkable as the upper vegetation has been described formerly as a moss-lichen type (Robyns & Lamb, 1939). Another noteworthy feature in this type was the occurrence of Trisetum glomeratum in association with the shrub colonies, commonly forming a thin fringe around these, where apparently wind-borne finer soil particles and litter had accumulated.

The sudden change in shrub size and density on the same substrate seems to indicate a rather sudden change in climate beginning with this type. From calculations of daily temperature fluctuations, combined with the small annual range, it is quite conceivable that the effect of nocturnal ground frost suddenly disappears at about this elevational range (e.g., 8100 feet). Thus, a change in climate type has been indicated at this point on Figure 30.

Segment 5 (Fig. 30). Cushion shrubs with scattered Metrosideros; map symbol ns(M); aerial photos 4-0038, 5-0012, 5-0035.

This can also be called the timber line type which extends from 8100 down to 7500 feet. Metrosideros collina appears suddenly as a full-grown tree (3-5 m tall) at 8100 feet. Metrosideros was not seen among the shrubs of the previous type, which would indicate that it does not form an alpine "krummholz." Instead it stands out as a distinct tree occurring in a widely scattered formation of one individual at every 100 to 200 m. The trees showed a slight up-slope lean and shrub growth was distinctly denser and taller beneath the trees indicating a fog drip effect. Metrosideros appeared to be correlated in this type with old, brown a'a lava, rather than with pahoehoe. However, this observation needs further checking. A'a lava became distinctly more dominant at 8100 feet and prevailed from here on down to 3900 feet. At the same time a more advanced degree of surface weathering was noted, as evidenced by the somewhat smoother edges of the a'a chunks and the presence of shallow pockets with finer soil. The strong white-black color contrast on the aerial photos, so characteristic for the upper slope area, also disappears abruptly at about the 8100 feet elevation.

Other new components in this type were the shrubs, Coprosma montana and Dubautia scabra, and the ferns, Pteridium aquilinum var. decompositum and Asplenium adiantum-nigrum. An interesting associate observed at 8100 feet was Argyroxyphium sandwicense (silversword) that occurred here in a local depression with three or four individuals. One of these was flowering and 170 cm tall. While these appeared to be of natural distribution, only one other specimen planted at 10,035 feet was observed along the transect. Thus, silversword has a wide altitudinal range as was noted already by Hartt & Neal (1941) and thus can hardly be used for a fine distinction of the altitudinal vegetation types on Mauna Loa, except in a negative way due to its extreme rareness.

Segment 6 (Fig. 30). Open Metrosideros—Sophora forest; map symbol oM(So-ns);

aerial photos 5-0012, 5-0035.

This upper subalpine forest extends from 7500 down to 6600 feet elevation. It has been observed only on a'a lava showing a reasonable degree of surface weathering. The pockets between the a'a chunks were filled with soil and the rock itself could be broken apart by kicking with the foot. In contrast to the preceding two types, however, the type boundary is less sharp. This type is particularly characterized by relatively denser tree growth, with the individuals from 10 to 50 m apart as opposed to a density of 100 to 200 m/individual in the preceding timberline type. Tree height increase was not so pronounced, but tree height averaged 5 m. Sophora chrysophylla occurred here as a scattered tree, first noticed at 6900 feet. Coprosma montana assumed tree stature, growing up to 3 m tall, but occasionally these shrubs were taller (up to 1.5 or occasionally 2 m) and tended to fill-in, forming the main matrix instead of the barren rock matrix of the preceding types. Thus the tendency of shrub clumping beneath individual trees, so characteristic for the timber line type (segment 5), appeared lost. Pteridium became denser and Deschampsia nubigena more common. Noteworthy new components besides Sophora were the shrub, Geranium cuneatum var. hypoleucum (at 7500 feet) and an occasional Luzula hawaiiensis.

Segment 7 (Fig. 30). Tall cushion scrub savannah with scattered Acacia koa colonies; map symbol mx-ns (AcSoM); aerial photos 4-0066, 5-0014.

This type occurs from 6600 down to about 5000, or in places to 4200 feet. It occurs on soil varying from about 10-50 cm deep and which appears to be in part derived in situ from weathered a'a lava and in part from ash. A significant difference from the preceding type is the abundance of mixed high-altitude grasses that form the matrix. These are composed largely of Deschampsia nubigena, Trisetum glomeratum, Holcus lanatus, Anthoxantum odoratum, Festuca ernoides, Eragrostis atropioides and Paspalum urvillei.

They commonly exhibit a tussock-like habit where not too dense. Their general height is about 75 cm to 1 m. A dominant component in the herb layer is Pteridium aquilinum var. decompositum. Other common herbaceous plants are Luzula hawaiiensis and Hypochaeris radicata. There appears to be no ground exposed. The type transition is very abrupt, which may be correlated with the sudden difference in substrate. The same shrubs of the preceding unit continue to form a major element in the vegetation. However, they occur in patch-communities from but a few meters square to several 100 m^2 in size. The dominant shrubs are Styphelia and Dodonaea which are commonly 1.5 to 2 m tall, with dense globular crowns. A third major element is Acacia koa that grows here in circular or eliptic colonies of 30-100 m in diameter. These colonies usually consist of one or two central trees with relatively large trunk diameters of 70-100 cm and maximum crown heights of 15 m. The trunks are commonly gnarled at about breast height and the upper trunk part may then spread like a branch. Smaller koa trees are associated with the fringe area of the colonies. The crown-outline of these koa colonies is umbrella-shaped. Occasional dead branches are heavily covered with Usnea. In addition widely-scattered single trees of Metrosideros and Sophora occur that are usually not taller than 5 to 10 m. This type, which appears to correspond to the mountain parkland formation of Robyns & Lamb (1939), can be viewed as a complex of three types, grassland, shrubland, and forest. However, their pattern is rather diffuse and the communities are generally too small for separate mapping on the scale of 1:12,000 used.

Segment 8 (Fig. 30). Mixed Acacia koa—Sapindus tree savannah; map symbol mx-AcSaM; aerial photos 4-0066, 8-0079.

This type begins at about 5000 and extends down to 4000 feet. It occurs on the same well-weathered substratum and soil. The main difference from the preceding type is the absence of the tall cushion shrub communities. Instead relatively tall (15-25 m), scattered and rather isolated trees are found growing among tall grasses, largely composed of the same species as of the preceding type. The tussock-habit is absent and Pteridium aquilinum appears to be even more abundant. Occasional shrubs, a 2-3 m tall Dodonaea or even a Pipturus may be found, but they are rather insignificant components. A new tree component is Sapindus saponaria growing with beautiful, high, umbrella-shaped crowns. Acacia koa individuals dominate and seem to find their ecological optimum in this type together with the Sapindus. Scattered, tall Metrosideros is present as well as Sophora, which never seems to get as tall as the other three.

Segment 9 (Fig. 30). Mixed Acacia koa—Sapindus forest with lower-story trees and arborescent shrubs; map symbol AcSaM (ad); aerial photo 8-0079.

This is the closed forest type of Kipuka Puaulu (Bird Park), which is however also represented by Kipuka Ki and others in the summer-dry climate on deeply weathered soil. The soil here is composed of deep (up to 6 m) volcanic ash, probably of dune origin (Mueller-Dombois & Lamoureux, 1964), and it is much enriched with organic colloids. These closed forest types occur usually as islands (kipukas) throughout the same elevational range as the preceding savannah type, i.e., between 5000 and 4000 feet. However, this particular kipuka (Puaulu) ranges from about 4200 to 3900 feet exhibiting a broadly undulating secondary topography. All preceding types occurred on the typically smooth, gently-sloping east-flank of Mauna Loa showing no pronounced secondary topography. The taller trees (20-30 m) are dominantly of Acacia koa, Sapindus and Metrosideros. A well-developed lower tree layer (of 2-10 m height) comprises a number of tree species among which Myrsine lessertiana, Coprosma rhynchocarpa, Myoporum sandwicense, Psychotria hawaiiensis, Osmanthus sandwicensis and Sophora chrysophylla are the most common. Several species of Pelea are also present. An abundant arborescent shrub, which dominates this stratum locally, is Pipturus albidus. The understory in the less dense parts of the forest is comprised largely of a native fern, Microlepia setosa. There are several noteworthy patch communities beneath the tree canopy. Of particular interest are the Peperomia cookiana patches on pig-scarified ground, and the introduced plants now forming communities such as the two shrubs, Rubus penetrans and Solanum pseudocapsicum, and the herb, Commelina diffusa. The oldest trees are partly covered with epiphytic mosses.

An open forest (Acacia koa, Sapindus, Metrosideros) or savannah occurring in a tall-grass-Pteridium matrix occurs within this kipuka. It corresponds closely to the preceding type, but here it also grows on the deep ash soil. The kipuka is surrounded in its upper part by a Metrosideros forest belt on more recent a'a.

Segment 10 (Fig. 30). Open Metrosideros—lichen forest with native low shrubs; map symbol oM (L-ns); aerial photo 8-0079.

An abrupt change occurs from the kipuka forest to this open forest on old, but little-weathered, pahoehoe. Here Metrosideros grows in the old pahoehoe cracks, that appear to largely control the density of stocking. The trees, though appearing old, are rather short (3-10 m). The depressions between the outcropping convex pahoehoe blocks are covered with finer soil and ash, about 10-30 cm deep. This finer material is still relatively coarse textured and supports only a poor growth of lichens (Cladonia spp. and Stereocaulon) grasses and herbs (e.g., scattered, short Pteridium, Bulbostylis capillaris). Also, mostly in association with the cracks, low (up to 1 m tall) shrubs grow, such as Dodonaea viscosa, Styphelia tamaiamaia, Dubautia scabra and Coprosma ernodeoides (creeping habit).

Segment 11 (Fig. 30). Open Metrosideros—Gleichenia forest; map symbol oM(G); aerial photo 8-0079.

This forest appears just east of the previous type, and at the same elevation (3900 feet), but where the climate changes rather suddenly from summer-dry to humid (near the Military Camp). There is a broader transition zone than between the two preceding types. This is, however, somewhat obscured by a large fumarole area (fu) west of Park headquarters and much modification by man. However, the type is evident in less disturbed areas. It consists of a stand of pure Metrosideros similar to the preceding type, but instead of lichens and scattered herbs and shrubs the associated vegetation is largely formed by matted thickets of the fern, Gleichenia linearis. In places not dominated by this creeping fern one can find Dianella, Hedyotis centranthoides, Lycopodium cernuum and the tall grass, Andropogon virginicus.

This forest type is considered to be a developmental variation of the montane rain forest, which is exemplified by the next type.

Segment 12 (Fig. 30). Closed Metrosideros—Cibotium forest; map symbol cM(C); aerial photo 8-0106.

This is the dominant montane rain forest type in the Park. It is characterized by a pure stand of relatively even-sized Metrosideros trees, with diameters at breast height of 40-65 cm and uniform crown-canopy heights ranging between 14 and 20 m. The branches are more crowded on the upper one-third of the bole and grow at steep angles upward into a somewhat umbel-shaped crown. Tree boles are rather naked and rarely covered with epiphytes. A distinct second tree layer is formed by the tree fern

(Cibotium spp.) that grows here to a relatively uniform crown height of about 2-5 m. The Cibotium understory is characteristically rather dense and, in this area (i.e., near Kilauea Iki), commonly mixed with the other tall fern, Sadleria cyatheoides (which is however not a tree fern). Where there is an interruption in the Cibotium canopy, there is usually some tree fern regeneration, but a variety of less dominant species can be found. These include the small and extremely scattered trees Myrsine lessertiana, Ilex anomala, Coprosma montana and Gouldia terminalis, the shrubs Wikstroemia, Vaccinium calycinum, Pipturus albidus, Cyrtandra platyphylla, the herbs Gahnia gahniaeformis, Briza minor, Isachne distichophylla, Lycopodium cernuum, Hedyotis centranthoides and Peperomia spp. Epiphytic mosses and ferns, such as Acroporium fusco-flavum and Elaphoglossum reticulatum can be found on the lower trunks of Metrosideros.

Vegetation types along south-north transects through the Park. Transects 2, 3 and 4 (Fig. 18). Profile diagrams Figures 31, 32 and 33.

Three roughly parallel south-north transects (for location see Fig. 13, in chapter on climate) are represented as topographic vegetation profiles (Figs. 31-33). These can be used in categorizing the vegetation from sea level to mid-altitudes of, e.g., 5000 feet. They also serve to illustrate the variations from west to east across the main area of the Park along the south and southeast slopes of Kilauea.

Transect 2, from sea level to 5000 feet through Kau Desert. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 31. Of the eleven profile segments shown, only seven (numbers 1-6 and 11) represent new vegetation types that have not already been described before in the discussion of Transect 1. The discussion follows in sequence of the profile segments shown on Figure 31.

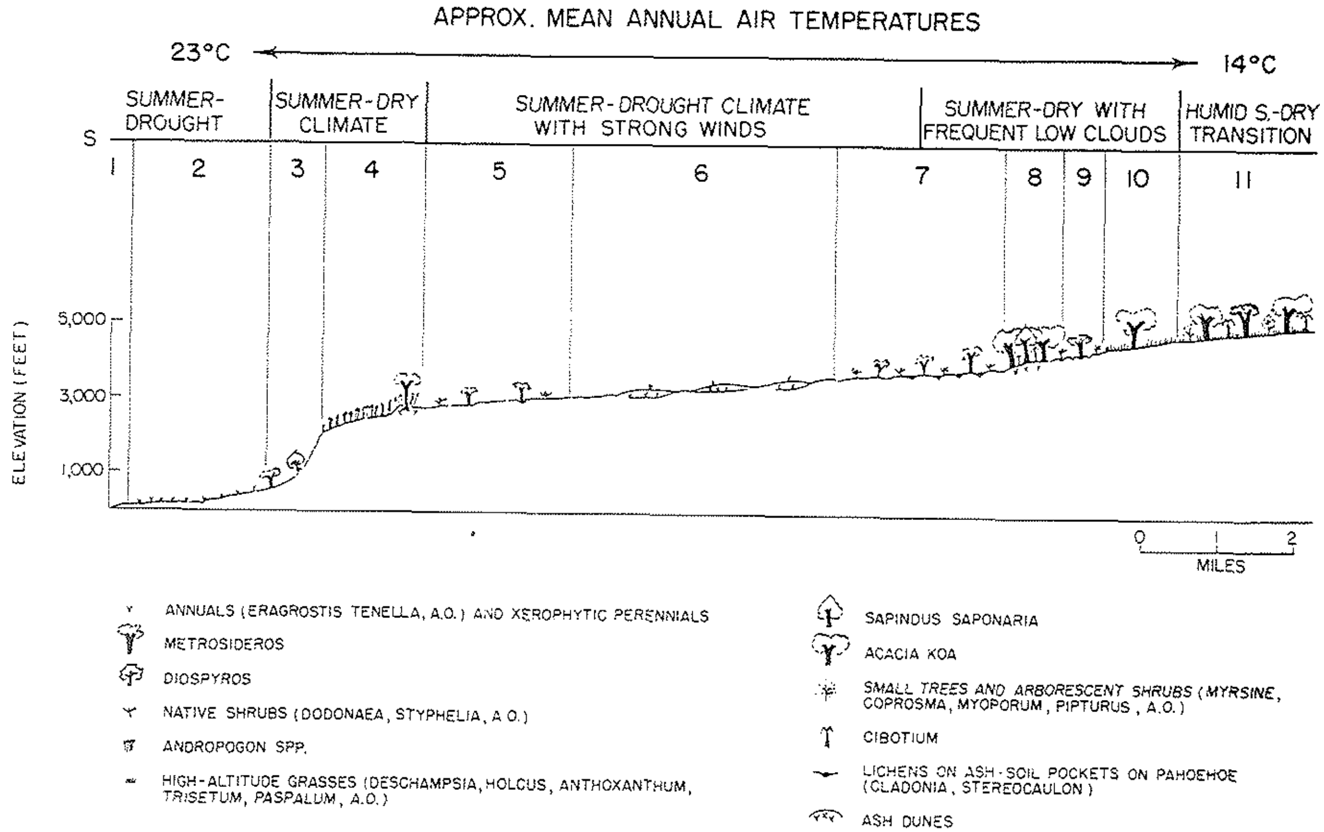
Segment 1 (Fig. 31). Salt spray and other shore communities; map symbol r(spr) and spr; all aerial photos showing shoreline (see Chapt. I, Fig. 6).

This type encompasses several distinct communities that occur on the narrow strip of land along the coastline that marks the seaward boundary of the Park. They are described in detail in Chapter VII, above. The reason for treating this zone as one type is simply a matter of convenience for the vegetation patterning is too small for the scale of mapping used. The predominantly coastal salt-spray zone is comprised of lava barren of macroscopic vegetation and often ending in cliffs vertical to the water line. These cliffs extend above sea level from a few feet to about 50 feet and bear only a few higher plants. These as found on the salt-swept cliff faces or in the extremely scattered, soil-filled cracks are, for example, Portulaca cyanosperma and Fimbristylis cymosa. However, this area is densely covered by a thin coating of algae.

In a few places, where the lava surface is right at sea level or even somewhat submerged and covered with sand of coral and lava origin, there are a few scattered strand communities with the trailing Ipomoea pes-caprae and occasional individuals of the tree, Tournefortia argentea. These occur on somewhat elevated sand, whereas a few halophytic communities, dominated by Sesuvium portulacastrum, are found on patchy sand flats that are periodically inundated with the incoming tide. These more densely vegetated communities are designated by the symbol spr on the map sheets. (The only Prosopis pallida stand in the Park is at Keauhou Landing aerial photo 8-0102 . It has been mapped separately and designated by the symbol P.)

Segment 2 (Fig. 31). Eragrostis tenella grassland; map symbol E(r); aerial photos covering the shore (see Fig. 6 in Chapt. I).

<u>Fig. 31</u>. *South-north profile of vegetation types in the west-central area of the Park from sea level to 5000 feet, i.e., for 17 miles from the shore (segment 1) through Hilina Pali (segment 3), the Kau Desert (segment 6) and Kipuka Puaulu (segment 8) to the Kilauea Forest Reserve (segment 11). This is Transect 2 of the text and Figure 18.*



This is one of the two dominant dry grass types of the coastal lowland area. The other is Heteropogon contortus, shown on the remaining profile diagrams, Figures 32-34. Most of the area between the salt-spray zone and the foot of Hilina Pali is segment 2 in Figure 31, Eragrostis tenella grassland. It gives a straw-yellow hue to this area during the summer-drought season. However, its cover is relatively thin. The grass is confined to the ash-filled depressions that occur as patchy flats between the outcropping pahoehoe mounds. An equally abundant, but less conspicuous associate is the annual Bulbostylis capillaris. The very similar Fimbristylis hawaiiensis is less common. A poikilohydrous liverwort, that in dried-up condition during the summer-drought season looks like spotty crustations of salt, grows in small patches beneath these two annuals. Another associate is a tiny legume, Desmodium triflorum, which forms small rosettes at the surface that remain green during the summer. The density of the Eragrostis tenella grassland is related to the availability of ash pockets or depressions. In the very rarely exposed soil-filled pahoehoe cracks (which constitute a different habitat type), one finds occasionally the grasses Chrysopogon aciculatus, Chloris inflata and Heteropogon contortus.

A small area of especially dense grass cover occurs east of this transect on Puu Kaone (aerial photos 8-0073, 8-0102), which remains green during the summer-drought season. It occurs on deep, yellow, loess-like ash and is comprised largely of Chrysopogon aciculatus and Cynodon dactylon. In certain areas it is heavily mixed with the small legume shrub, Indigofera suffruticosa. This grassland has been mapped separately with the symbol Ch. It is the central gathering place for the goat herds that roam particularly through segments 2-5 on Figure 31 and segments 2-4 on Figure 32.

Segment 3 (Fig. 31). Very open Metrosideros—Diospyros forest; map symbol MD(r); aerial photos 8-0073, 8-0102, 8-0070.

This extremely open forest type occurs on the steep slope of the Hilina Pali where the trees grow singly or in small groups on almost barren, colluvial a'a. Both tree species have distinctly sclerophyllous foliage and rather broad and open crowns. The trees are relatively short (5-8 m), branchy and have thick trunks (30-50 cm) and a somewhat corky and scaly bark. Native shrubs are conspicuously rare, a few scattered small introduced shrubs are found near the lower end of the slope, such as Waltheria indica var. americana and Pluchea odorata. Widely scattered herbaceous plants are found throughout the type. These include the two ferns, Doryopteris decora and Pityrogramma calomelanos, and the composite Ageratum conyzoides, etc.

Segment 4 (Fig. 31). Andropogon grassland; map symbol An(M); aerial photos 4-0060, 4-0068, 8-0075.

This dense tall-grass type extends from the top of Hilina Pali (at about 2000 feet elevation) to the southern edge of the Kau Desert (segment 5). The name-giving grass includes two species, Andropogon glomerata and A. virginicus. The first is the more dominant. An additional dominant component is Pteridium aquilinum var. decompositum. Occasionally patches of the creeping molasses grass (Melinis minutiflora) have gained local dominance. A few scattered native shrubs of Dodonaea and Styphelia are also present. Metrosideros trees are conspicuous, but they are of very irregular distribution. They occur as widely scattered single trees and in form of larger north-south oriented, open tree colonies. The latter may, in some cases, represent kipukas (islands of remnant vegetation). However, the species composition in these open tree colonies differs but little from the rest of the area. The main undergrowth is the Andropogon.

Of particular interest is the abrupt boundary of this grassland to the north, where it is fringed by a series of ash dunes. Also here one finds little difference in species composition, but the vegetation differs considerably in structure. The dunes are occupied by more or less open Metrosideros patch forests with Andropogon undergrowth and a few scattered native shrubs. Some of the dunes are up to 10 m high. Here one can find snags of Metrosideros that may have been killed as a result of the eolian sand-like ash deposits increasing in depth rapidly. Fallen trees, in places where the dunes have been ripped open by winds from the Kau Desert, show layers of adventious roots from the base of the stem upwards; as though they had formed as a result of locally increasing depths of the dune deposits. The dune fringe is correlated also with a change in slope (Fig. 31). It is conceivable that the southwest blowing winds from the Kau Desert lost velocity rather suddenly at the point of slope increase. Thus, the dune fringe can be considered as conditioned primarily through topography, rather than vegetation. The three described cover variations, open Andropogon grassland, Andropogon—Metrosideros savannah and Metrosideros—Andropogon patch forests that are here treated as one type have been mapped as separate entities wherever possible.

Segment 5 (Fig. 31). Metrosideros scrub forest; map symbol scM(r); aerial photos 4-0062, 4-0064, 8-0075, 8-0077.

This open scrub forest forms a broad fringe at the south, east and north sides of the Kau Desert and can be considered as semi-desert vegetation. It occurs only on old pahoehoe. The western fringe area of the Kau Desert is formed by a similar Metrosideros scrub forest, which however occurs on a'a lava. Though not shown separately on Figure 31, its distribution is very much like segment 9. The major difference is in the stocking density of Metrosideros, which on pahoehoe is extremely open (varying from 20-60 m distance between individuals). Here the trees are found only in the broader and deeper pahoehoe cracks. Shallower cracks are vegetated with native shrubs of predominantly Styphelia tameiameiae and Dodonaea viscosa, occasionally also with small Metrosideros of shrub stature. Most of the surface matrix is barren exposed pahoehoe lava. Stabilized, flat ash pockets in depressions here and there are covered with a sparse cover of Bulbostylis capillaris. The southern boundary of this stand is formed by the fringe of dunes discussed before, which causes an abrupt change in vegetation. The boundary to the north is more gradual and a transitory native scrub type has been recognized on the map sheets in which Metrosideros, if present at all, has lost its tree stature entirely.

Segment 6 (Fig. 31). Extremely sparse desert vegetation; map symbol r-ash(poik); aerial photos 4-0064, 8-0077.

This type represents the central area of the Kau Desert which consists of almost barren lava with shifting ash dunes that are extremely sparingly vegetated with annuals and mostly poikilohydrous perennials. Dwarfed woody plants of Styphelia and Dodonaea are found occasionally in lava cracks. The poikilohydrous perennials on shifting ash dunes include Cyperus polystachyos, Eragrostis variabilis, Gnaphalium sandwicense var. kilaueanum, Euphorbia hirta, Cenchrus echinatus var. hillebrandii, Silene struthioloides and Cynodon dactylon. Only one annual was noted, Agrostis avenacea. The absence of Bulbostylis capillaris was rather striking as this annual is otherwise distinctly associated with ash deposits in summer-dry and -drought climates (e.g., segment 2, Fig. 31). However, it seems to occur only when ash deposits are well stabilized. Many of these plants were partly buried in the sand-like, shifting ash. This fact may provide an explanation for the bareness of this area. Not necessarily the young age of the substrate (much of the sand-like ash was deposited as a result of the 1924 Kilauea explosion), but the instability of the substrate appears to be a major factor in this desert formation, which here is correlated with a pronounced summer-drought during which desiccation by the trade winds appear to have a strong effect. They apparently unload their moisture before reaching the Kau Desert, where they sweep across with unimpeded velocity as evidenced particularly by the frequency of dunes found at the southwest side of the Kau Desert. Sulfur fumes from Halemaumau, at the north end of Kau Desert, may be a contributing factor. Killing of plants occurs only a relatively short distance downwind from other constantly fuming areas in the Park.

Segment 7 (Fig. 31). Open Metrosideros—lichen forest with native low shrubs; map symbol oM (L-ns); aerial photos 4-0064, 8-0077.

This type has already been described as segment 10 on Figure 30. At its southern connection to the Kau Desert, it coincides more closely with the Metrosideros scrub forest described as segment 5 of Figure 31. On the map sheet, the two variations have been mapped as such. However, the transition is very gradual. The boundary between summer-drought and summer-dry climate seems to approximately coincide with the points of departure in structural and floristic variation. The structural variation is shown mainly by a gradual decrease in tree height and wider spacing of trees and shrubs and the floristic variation by the gradual disappearance of lichens in the southern variation.

Segment 8 (Fig. 31). Mixed Acacia koa—Sapindus forest with lower-story trees and arborescent shrubs; map symbol AcSaM (ad); aerial photo 8-0079.

This is the major vegetation type of Kipuka Puaulu shown as segment 9 on Figure 30, and described above.

Segment 9 (Fig. 31). Open *Metrosideros*—native shrub forest; map symbol oM (ns); aerial photo 8-0079.

This forest occurs on a'a lava that forms the north wall around Kipuka Puaulu. The tree layer is comprised only of *Metrosideros* and the associated shrubs are mainly *Styphelia* and *Dodonaea*. The forest is very similar to segment 7 (Fig. 31) on pahoehoe, however it lacks the lichen and grass-covered ash pockets and shows denser stocking in parts. The same type marks also the western border of the Kau Desert, where it extends on the late prehistoric Keamoku a'a flow along the Kona Highway. Here *Metrosideros* is, however, more of a shrub in stature.

Segment 10 (Fig. 31). Open Acacia koa grazing savannah; map symbol mxg-AcM; aerial photo 8-0079.

This is a variation of the type represented by segment 8, Figure 30, described above. The area lies outside the Park boundary, where it is used for cattle grazing. The grass composition is depauperated and here dominated by *Anthoxantum odoratum*. Several snagged and fallen *Acacia koa* trees were noted. A subdominant tree component is *Metrosideros* and possibly, elsewhere but not on this profile, *Sapindus*.

Segment 11 (Fig. 31). Mixed *Acacia koa*—*Metrosideros* forest with arborescnet shrubs and *Cibotium*; map symbol AcM (ad-C); aerial photo 8-0081.

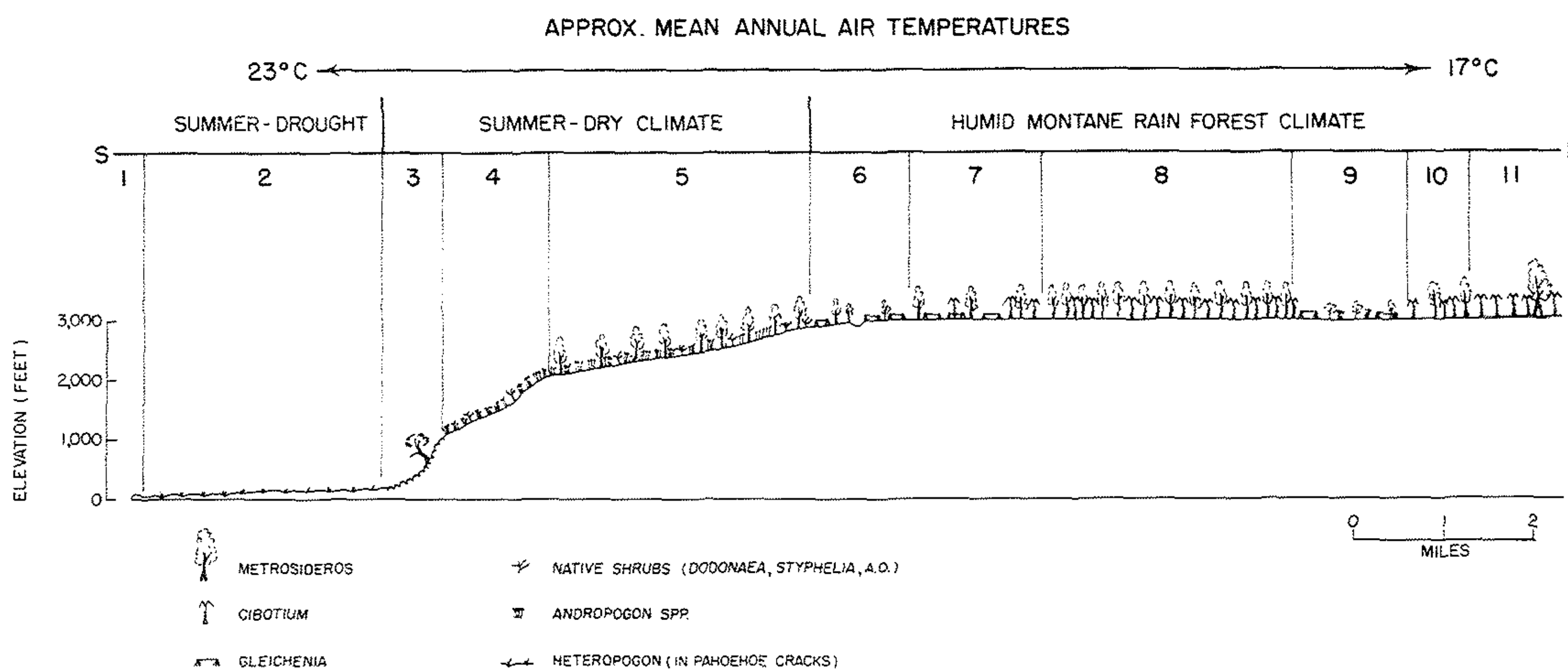
This type represents a transition form between the typical *Acacia koa* forest and the *Metrosideros* rain forest. Neither of these latter is shown on this profile because the typical *Acacia koa* forest (without *Cibotium*) occurs above this zone (*i.e.*, from about 5000 to 6000 feet, upper Kilauea Forest Reserve and outside the Reserve), and the typical *Metrosideros* rain forest occurs below this zone (from about 4500 feet downward). This Acacia koa--Metrosideros forest with Cibotium is well represented south of Kulani Prison Camp. It occurs on relatively deep, well-weathered soil. The upper tree canopy is dominated by tall (20-30 m), full-crowned Acacia koa trees with large (80-150 cm) trunk diameters. Metrosideros, though not so large in crown diameter is similarly tall. A second tree layer is dominated by tree ferns (Cibotium spp.), but contains also a number of other smaller trees, such as Myrsine lessertiana, Myoporum sandwicense and Coprosma spp. Occasional openings in the tree canopy are covered with mixed grasses.

Transect 3, from sea level at Apua Point to 3000 feet through Alae crater. The transect covers most of the east-central area of the Park north and south of the Chain-of-Craters Road. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 32. The lower left side of this profile diagram (segments 1-4) shows similarity to the lower left-hand side (segments 1-4) of Figure 31 (Transect 2). Also, the humid montane rain forest on the upper right-hand side of Figure 32 has already been introduced by two types (segments 11 and 12) on Figure 30 (Transect 1). Therefore, in spite of the 11 divisions shown on Figure 32, the profile introduces only three entirely new types. These are represented by segments 2, 5 and 11. The discussion follows again the sequence indicated by the segment numbers on the profile diagram Figure 32.

Segment 1 (Fig. 32). Salt spray and other shore communities; map symbol r(spr) and spr; aerial photo 8-0070.

For description see above under Transect 2. It may be noted that an unusually broad strand community (spr) can be seen near Apua Point, the start of this profile.

Fig. 32. South-north profile of vegetation types in east-central area of the Park from sea level to 3000 feet, 16 miles (from Apua Point through Alae Crater to Olaa Forest Reserve). This is Transect 3 of the text and Figure 18.



Segment 2 (Fig. 32). Heteropogon grassland; map symbol H(r); aerial photo 8-0070.

This is not a homogeneous vegetation type, but it is distinct from the other coastal lowland dry-grass types, the Eragrostis tenella grassland (Fig. 31, segment 2). The main ecological difference is the absence of ash pockets on the pahoehoe, which in this type exposes more soil-filled cracks that are the particular habitat of Heteropogon contortus. But several other grasses are found here as well, such as Chrysopogon aciculatus, Sporobolus diander, Chloris inflata, Tricholaena repens, Dactyloctenium aegyptium, and other herbs such as Fimbristylis cymosa, Emilia javanica and Portulaca cyanosperma. Various low shrubs may be found in association with the herbs, such as Waltheria indica var. americana, Pluchea odorata, Cassia leschenaultiana, C. bicapsularis, Osteomeles anthyllidifolia and Indigofera suffruticosa. Depending on the number of available cracks, age of pahoehoe and various other factors, which include the goat browsing pressure in this area, the Heteropogon grassland may vary from extremely thin cover, where most of the surface is barren lava [map symbol r(H)] to a relatively dense cover, in which the introduced, thin-stemmed and low-growing leguminous shrubs (Cassia and Indigofera) may become rather dense [map symbol H(lsi)].

Segment 3 (Fig. 32). Very open Metrosideros—Diospyros forest; map symbol MD(r); aerial photo 8-0070.

See previous description under Transect 2. Here, the area of this slope type is locally not as large as that on Hilina Pali (Fig. 31, segment 3). Thus it is symbolized only by one sclerophyllous tree, Metrosideros, on the colluvial a'a slope. The relative abundance of Diospyros varies from place to place within the type and there are areas where it is difficult to locate an individual.

Segment 4 (Fig. 32). Andropogon grassland; map symbol An(ns-i); aerial photos 8-0068, 8-0070.

See description above under Transect 2. In this area of the Park the Andropogon grassland varies in that there is no dune fringe at its northern border. Also, Metrosideros, as trees, is almost absent, instead shrubs are more prevalent. It is interesting that introduced shrubs have penetrated into this type, apparently from the lowland areas, while they are rarely found higher up in the next types. The introduced shrubs include Lantana camara, Psidium guajava and Stachytarpheta jamaicensis. The native shrubs are mostly represented by Dodonaea, Wikstroemia, Styphelia and Myoporum. The thick-mat forming grass, Melinis, is particularly "advancing" in this area of the type. Where this type is grazed by cattle (Ainahou Ranch) Sporobolus africanus becomes dominant in place of Andropogon.

Segment 5 (Fig. 32). Open Metrosideros—Andropogon forest with native shrubs; map symbol oM(ns-An); aerial photo 8-0068.

This type can also be called the seasonal evergreen forest, since it occurs in the summer-dry climate. It is, next to the montane rain forest, the most dominant forest type in the Park that extends, with some structural variations from the Andropogon-grassland at 2000 feet to the Metrosideros—Gleichenia rain forest at about 3000 feet, near the Chain-of-Craters Road. From west to east it extends from the fringe forest around Kau Desert (segments 5 and 7 on Fig. 31) to near the southward sloping part of the Kalapana Road (south of Makaopuhi Crater).

The forest is composed of pure Metrosideros in the tree layer, which varies in size and density with degree of weathering of the substrate. On more strongly weathered pahoehoe, the trees are as tall as in the adjacent rain forest to the north and they form, occasionally, relatively closed stands. More dominant is an open growth pattern, where the spaces between the trees (about 5-10 m apart) are occupied by a loose growth of native shrubs, such as Styphelia tameiameiae, Dodonaea viscosa, Wikstroemia sandwicensis and Dubautia scabra. The herb layer is distinctly dominated by Andropogon spp., where here the more prevalent species is A. virginicus rather than A. glomeratus. Other, commonly associated herbs are Gahnia gahniaeformis, Silene gallica and Sporobolus africanus.

In all places visited, pahoehoe lava was found to crop out at the surface, thus fine soil occurs only in cracks and the more or less deep (20-40 cm) depressions between the outcropping mounds. In these pockets the soil is formed primarily from coarse, sand-grained ash. Such ash pockets are often occupied by Bulbostylis capillaris, and occasionally by lichens in very open places.

In spite of a similar tree stand the type is well distinguishable from the rain forest by the complete absence of Gleichenia and Cibotium and the prevalence of Andropogon.

Segment 6 (Fig. 32). Disturbed Metrosideros scrub forest with Gleichenia and Andropogon patches; map symbol scM(G-An); aerial photos 8-0068, 8-0066.

This forest occurs along the Chain-of-Craters Road around Alae Crater (the crater is indicated by a depression of Fig. 32). The disturbed condition is caused in part by a fire that went through this particular area about 30 years ago, in part by the proximity of fumarole areas and scattered, individual steam vents and in part by relatively recent lava flows. The type recurs as segment 9 (Fig. 32) far within the humid montane rain forest climate, where the disturbance is primarily due to the recency of the underlying substrate. From extrapolation of relatively undisturbed types in the vicinity it became clear that this type (segment 6, Fig. 32) can be considered a seral form of the humid montane rain forest. It is characterized by scattered small (1-5 m) Metrosideros trees, some of which are sprouts from stumps. Also, smaller seedlings may be present. The ground cover is dominated by thickets of the creeping fern, Gleichenia linearis, and by patches of Andropogon virginicus. Other common plants are Lycopodium cernuum, Machaerina angustifolia, Carex wahuensis var. rubiginosa, Isachne distichophylla and Briza minor. The Gleichenia cover in this type is somewhat similar to the Gleichenia mats found at mid-slope on the windward ridges of Oahu. However, ecologically the two Gleichenia areas are quite different, with the main physiognomic difference being the much greater frequency of Metrosideros trees in the Hawaii Volcanoes National Park type (segments 6 and 9, Fig. 32). The Gleichenia itself is different in the Park, being G. linearis var. tomentosa.

Segment 7 (Fig. 32). Open Metrosideros—Cibotium—Gleichenia forest; map symbol oM(C-G); aerial photo 8-0066.

This type is of wide-spread occurrence in the continuously humid montane rain forest climate and it can be considered an intermediate developmental form between the disturbed Metrosideros—Gleichenia scrub forest type (segment 6) and the closed Metrosideros—Cibotium forest (segment 8). Its major characteristics are the open growth of Metrosideros trees (5-15 m apart), the dense patch formations of Gleichenia in the openings, and the abundance of tree ferns (Cibotium spp.). The taller Cibotium individuals (1.5-3 m) are roughly equal in number to the Metrosideros tree individuals. In this type Gleichenia can often be seen to have grown into the lower crowns of the Metrosideros trees (up to heights of 3-5 m). Other common associates include Vaccinium calycinum, Wikstroemia sp., and Sadleria cyatheoides in the shrub layer, and Lycopodium cernuum, Isachne distichophylla and Hedyotis centhranthoides in the herb layer together with the dominant Gleichenia.

Segment 8 (Fig. 32). Closed Metrosideros—Cibotium forest; map symbol cM(C); aerial photos 8-0064, 8-0066.

This is the same as segment 12 on Figure 30. For description see discussion under Transect 2, above.

Segment 9 (Fig. 32). Disturbed Metrosideros scrub forest with Gleichenia and Andropogon patches; map symbol ScM(G-An); aerial photo 8-0066.

This type is the same as represented by segment 6 on Figure 26. However, steam vents are absent in this area near the Volcano Road. Instead the disturbed condition is primarily caused by the recency of the lava substrate and, in part, locally aggravated by the clearing of vegetation for land development. Andropogon virginicus cover dominates locally over Gleichenia in the most recently disturbed areas.

Segment 10 (Fig. 32). Open Metrosideros—Cibotium forest; map symbol oM(C); aerial photos 8-0062, 8-0064.

The spacing of Metrosideros compares very closely to the open growth described for segment 7 (Fig. 32). However, the intervening spaces between the trees are filled with dense growths of Cibotium, while Gleichenia is very rare or absent. Other occasional components in the tree fern layer are Pipturus, Cyrtandra and Myoporum. The herb layer is very poorly represented because of the dense shade beneath the Cibotium fronds. This type occurs on shallow soil pockets on pahoehoe as well as on deeper soil formed from well-weathered ash. It seems to represent a later developmental form of segment 8, in which several Metrosideros trees have died, broken down and been replaced by Cibotium. This type is found only north of the Volcano Road, i.e., outside the Park boundary.

Segment 11 (Fig. 32). Cibotium forest with scattered old Metrosideros trees that are covered with epiphytes; map symbol C(M^e); aerial photos 8-0062, 8-0064.

This type is characterized by a distinct cover-dominance of Cibotium, which here attain occasionally a height of 4-8 m, and by the presence of scattered, often very tall (20-25 m), Metrosideros trees. These have commonly a split lower "trunk," which indicates that they germinated on higher objects (usually tree ferns) and then sent their roots downward into the soil. The tree-fern substrates are still alive in many cases, as Metrosideros collina does not form an anastomozing root system around the substrate-host as does Metrosideros robusta in New Zealand (Walter, 1964). There are also many trees in this type that germinated in the soil, and even smaller trees can be found in this same category. The latter may have germinated in open places created by the breakdown of over-mature Metrosideros, which gave the seedlings a chance to grow through the Cibotium layer before the tree canopy overhead closed. Germination on higher objects that provide sufficient light for growth for the obviously shade-intolerant Metrosideros, shows a remarkable adaptation to survival in densely vegetated, old stands. Another important characteristic is the abundance of vascular epiphytes, such as Astelia menziesiana, Freycinetia arborea, Peperomia spp. and Cheirodendron trigynum. The latter is also found as a soil-rooted tree in more open places. In addition, trunks and branches of the old, tall Metrosideros trees are often covered with epiphytic ferns and bryophytes, the latter may often provide suitable habitat conditions for the vascular epiphytes. Even a tree fern and, in several cases, a small Metrosideros tree were observed to have grown epiphytically on old Metrosideros trees. Such old trees typically have rather rough, scaly bark, aerial roots along the trunk, and often enormous branches that though crooked have some horizontal segments which are particularly crowded with epiphytes. There are many other small trees and arborescent shrub species in this type, but they are not dominant. Among these are Myrsine lessertiana, Coprosma rhynchocarpa, Pipturus albidus, Pittosporum sp., Myoporum sandwicense, Pelea sp. and Cyrtandra. Occasional patches or individuals of the native palm, Pritchardia, can be found. Wherever this stand was observed, it occurred on deep, melanized soil from well-weathered ash.

Transect 4, from sea level to 2500 feet through Naulu Forest to Napau Crater. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 33. The diagram shows seven profile segments. Segments 1 and 2 represent the same vegetation type as segments 1 and 2 on Figure 32 (Transect 3) and segment 7 represents the same humid rain forest type as segment 8 on Figure 32 and segment 12 on Figure 30 (Transect 1). Segments 3-6 (Fig. 33) represent new type variations found in this, more eastern part of the Park. The discussion follows the segment number indicated on the profile diagram Figure 33.

Segment 1 (Fig. 33). Salt spray and other shore communities; map symbol r(spr); aerial photo 8-0024.

For description see Transect 2, above.

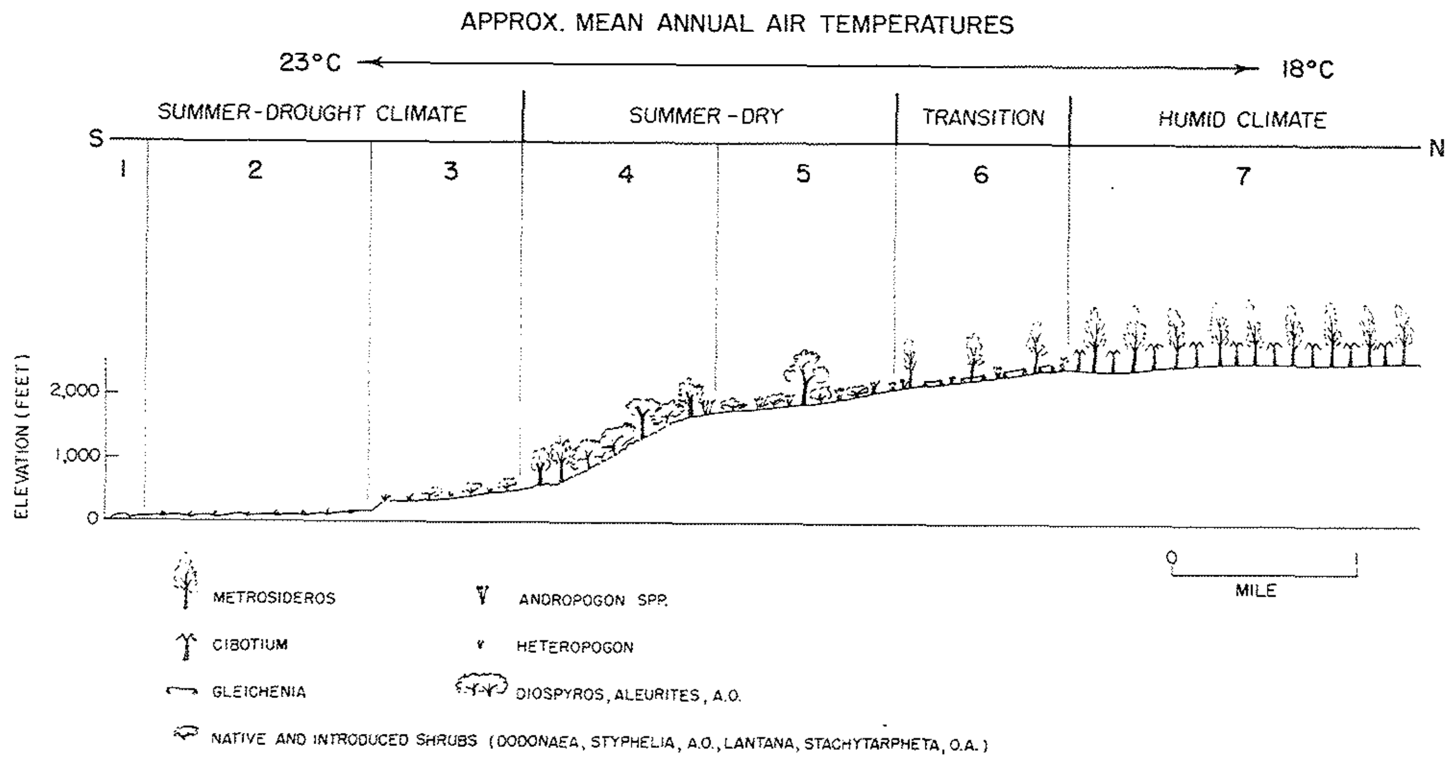
Segment 2 (Fig. 33). Heteropogon grassland; map symbol H(r): aerial photo 8-0024.

For description see Transect 2, above.

Segment 3 (Fig. 33). Heteropogon grassland with low shrubs; map symbol H(ls-i); aerial photo 8-0024.

This type differs from the previous type particularly in the prevalence of low, spreading shrubs that occur together here with the grasses, including Heteropogon contortus and others, such as Chrysopogon aciculatus,

Fig. 33. South-north profile of vegetation types in the eastern area of the Park from sea level to 2500 feet, an area 7 miles long extending from Kealakomo through the Naulu Forest to Napau Crater. This is Transect 4 of Figure 18 and the text.



Sporobolus diander, Tricholaena repens, Chloris inflata. The shrubs consist of such native species as Osteomeles anthyllidifolia, Canthium odoratum, Styphelia and Dodonaea. The first two are typical lowland species, whereas the other two are distributed over a wide range of altitude. Most of the shrubs are, however, introduced species that have their range dominantly in the hot lowland. These include Waltheria indica var. americana, Pluchea odorata, Indigofera suffruticosa and Cassia leschenaultiana. Another characteristic of this type, apart from the presence of a scattered shrub component, is a closer vegetative cover. The outcropping barren pahoehoe mounds, so conspicuous in the Heteropogon grassland type, are mostly hidden here beneath the vegetative cover. The ecological difference is attributable primarily to a higher degree of weathering giving rise to larger soil pockets that can store more rain water. The somewhat higher rainfall may also contribute to the difference, as this type is transitional to more heavily vegetated types (segment 4, Fig. 33, and segment 5, Fig. 34) in the summer-dry climate. This type is found only on pahoehoe lava and not on a'a.

Segment 4 (Fig. 33). Metrosideros—Diospyros mixed forest with patchy stands of Aleurites; map symbol MD(Al-ns-i-An-N); aerial photo 8-0024.

This type is quite variable, forming open to scattered Metrosideros—Diospyros ferrea stands with either grassy undergrowth dominated by Andropogon virginicus (symbol An) and mixtures of native (ns, i.e., Styphelia, Dodonaea) and introduced shrubs (i, i.e., Lantana camara, Stachytarpheta jamaicensis, and small Psidium guajava, or occurring on almost barren colluvial a'a lava surfaces with patch colonies of the fern, Nephrolepis exalta (symbol N), or thirdly, forming closed patch-forests dominated by Aleurites moluccana (symbol Al). Wherever permitted by the scale, these variations were mapped separately. The profile diagram emphasizes particularly the latter variation (Aleurites patch forest), as this represents the more obvious variation. The area is known as Naulu Forest. The type represents the eastward continuation of the pali vegetation type on colluvial a'a lava shown first as segment 3 on Figures 31 & 32.

Here Aleurites occurs (segment 4, Fig. 33) as a new element, which becomes still more abundant further east in the more humid climate (not shown on profile diagrams). The most westerly Aleurites tree was spotted near Transect 3 (in the east-central part of the Park). A few scattered individuals and groups occur between Transects 3 and 4. Comparison of the habitats of Aleurites with those on Oahu may be in order. On Oahu pure patch communities of Aleurites are found around the island from mid-altitudes (about 1800 feet) downward in deep ravines. They form larger stands on the windward than on the leeward side, but they are always restricted to ravines. Here, on the more recent surfaces in the Park there are no such ravines. However, both habitats have three things in common, the upper altitudinal limit, the slope, and the coarse, stony surface. While the stones as such do not appear to have any causative relation to Aleurites, the seepage water occurring in these habitats appears to be significant. A solid core of lava is always found beneath the coarse a'a rubble surface at about 1 m depth. While in the gulches on Oahu most seepage water may run superficially, here (segment 4, Fig. 33) it is probably providing subsurface-irrigation. A closer investigation of these relationships would be desirable. Obviously, the increasing abundance of Aleurites towards the more humid climate eastward shows another moisture relationship (which may act through more abundant seepage) and the altitudinal relation, from about 1800 feet downward, indicates a relation to a mean air temperature of about 20° C upwards. Aleurites can hardly be expected to eventually form a climax formation as was suggested by Robyns & Lamb (1939).

Beside the three main tree components, Metrosideros, Diospyros and Aleurites, there are several other woody species found here. These include Canthium odoratum, Myoporum sandwicense, Bobea timonioides, Alphitonia ponderosa, Antidesma pulvinatum, Myrsine lessertiana and M. sandwicensis. A more complete list is shown in "Guide to the Kalapana-Chain-of-Craters Road," a mimeographed publication of Hawaii Volcanoes National Park.

Segment 5 (Fig. 33). Shrubland with Andropogon and scattered old Metrosideros; map symbol ns(i-An-M); aerial photos 8-0024, 8-0026.

This type is related to the Andropogon grassland (segment 4 on Fig. 32 & 33). However, the shrub component is dominant over the grass in this type. The shrubs are comprised mainly of Dodonaea and Styphelia, but individuals of the introduced shrubs, Lantana, Stachytarpheta and Psidium guajava are here found to reach their upper altitudinal invasion limits except for some locally disturbed places higher up, e.g., near fumaroles. The shrub layer forms locally-impenetrable thickets. A third component is represented by scattered old Metrosideros trees (20 m tall) with large globose crowns (10-15 m in diameter) that were in full bloom throughout the summer-dry season of 1965. Many of these trees have died and occur as snags in this type, and there seems to be no seedling reproduction of Metrosideros here.

Segment 6 (Fig. 33). Open Metrosideros—Gleichenia—Andropogon forest; map symbol oM(G-An); aerial photo 8-0026.

This forest occurs a little north but particularly south of the old Kalapana Trail. It has the characteristics of a transition forest between the humid montane rain forest (segment 7 of Figs. 32 & 33) and the evergreen seasonal forest (segment 5, Fig. 32). In spite of the fact that its dominant components (Metrosideros, Gleichenia and Andropogon) are the same as in the disturbed rain forest (segments 6 & 9, Fig. 32), its character is quite different.

The grass, Andropogon virginicus, forms pure patch communities up to 10 x 20 m across and the same applies to the Gleichenia mats beneath the trees, which sometimes may even be larger. Pig scarification was observed to be particularly prevalent in this area and it is possible that the two herbaceous patch communities form a pattern that is related to pig damage. Where the same degree of pig scarification occurs in the true humid montane rain forest, the scarified ground is soon invaded by either Peperomia in shaded places or by Gleichenia in more open places. Andropogon is not found upon such small-scale disturbances. However, in this type (segment 6, Fig. 33) Andropogon takes a strong foothold. This appears to be related to a certain reduction in summer-rainfall in this zone.

In addition to Metrosideros occasionally one can find an individual of Santalum ellipticum var. paniculatum in this type, which may be of tree or shrub stature. Other common shrubs are Vaccinium calycinum, Coprosma menziesii, Dodonaea viscosa and Styphelia tameiameiae. Common herbs in addition to Andropogon and Gleichenia are Machaerina angustifolia, Rhynchospora scleroides and Gahnia gahniaeformis.

Segment 7 (Fig. 33). Closed Metrosideros--Cibotium forest; map symbol cM(C); aerial photo 8-0026.

This is the same as segment 8 on Figure 32 and segment 12 on Figure 30. For description see above under discussion of Transect 2.

Vegetation types in the coastal lowland, east-part of the Park. Transect 5 (Fig. 18). Profile diagram Figure 34.

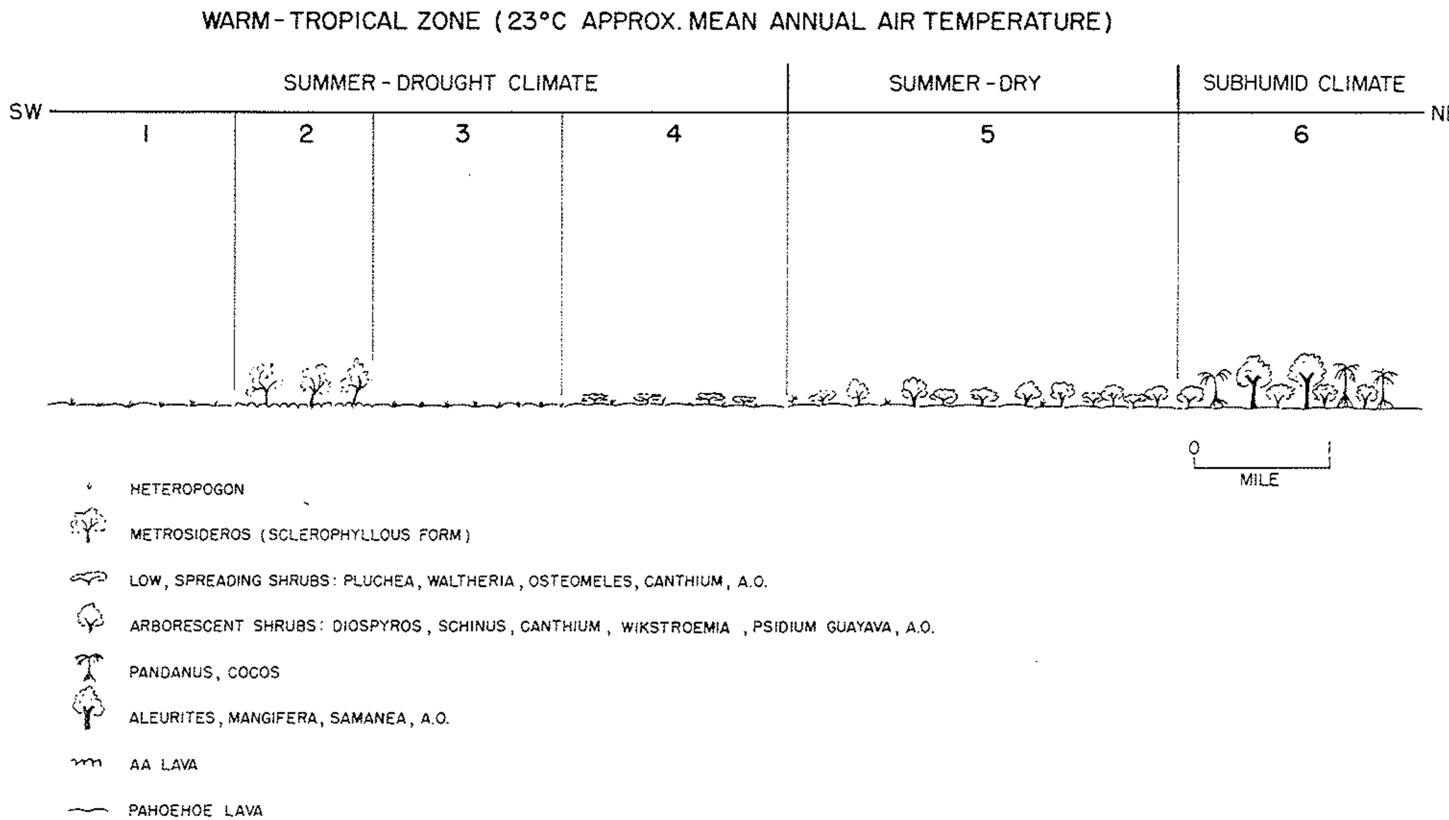


Fig. 34. Profile of vegetation types inland of the salt-spray zone in the eastern lowland area of the Park from Kaena (SW) to Kalapana (NE), a distance of 10 miles at elevations of between 30-60 feet. This is Transect 5 of Figure 18 and the text.

Transect 5 extends along the coastal lowland from Kaena to Kalapana (for location see map, Fig. 18). The profile diagram on Figure 34 portrays the lowland vegetation types as they occur along this transect in relation to a change in climate from summer-drought to humid. There are no significant variations in elevation, and the mean annual air temperature is thus likewise rather constant.

The major lowland types in the west-central (Eragrostis tenella grassland, segment 2 on Fig. 31) and the east-central area (Heteropogon grassland, segment 2 on Figs. 32 & 33) of the Park have already been described in the discussion of Transects 2 and 3. These two grassland types occur in a distinctly warm, tropical summer-drought climate. A more interesting variation in the same climate is the scattered Metrosideros stand which is shown on Figure 34 as segment 2. Therefore, Transect 5, though only short (10 miles) encompasses the major vegetation variations in the coastal lowland inland of the seashore communities.

The discussion follows in order of the six profile segments shown on Figure 34.

Segment 1 (Fig. 34). Heteropogon grassland; map symbol H(r); aerial photos including the shore.

For description see discussion of Transect 2, above.

Segment 2 (Fig. 34). Scattered old Metrosideros on nearly barren a'a lava; map symbol r(M); aerial photos including the shore.

This type represents a remarkable variation in the lowland vegetations of the summer-drought climate. It shows a close relationship to the pali type (segment 3, Figs. 31 & 32). It is quite possible that Diospyros ferrea may be present as well, but Metrosideros is definitely by far the more prevalent tree. Here it has extremely sclerophyllous leaves. The type is found wherever old a'a lava extends, often in finger-like patterns, into the coastal lowland area which is otherwise dominated by pahoehoe. Thus, the type occurs also, for example, below Hilina Pali (near Transect 2) and between Transects 3 and 4.

Tree growth on a'a can be explained by the fact that a solid lava core is always associated with and under the coarse, clinker-like a'a rubble at a depth of about 1 m or so. This soild lava core acts as an impervious base on which rain water collects and does not evaporate. Metrosideros seedlings may become established in moist years, when rapid extension of its roots into the moist zone above the impervious layer is permitted.

Grasses do not get established on this material as their fibrous root system is not adapted to growth in such coarse material. Their typically intensive root system does not extend very deep and it would rapidly be desiccated on this substrate. Grasses are better adapted to growth in shallow soil-filled cracks on pahoehoe, which cracks are much too small a habitat for Metrosideros trees. Seedlings that do appear soon perish because of lack of soil water. However, one can observe Metrosideros trees widely scattered on pahoehoe outside the a'a areas, particularly along the summer-drought climate of this transect. This is related to a distinct variation in the pahoehoe lava, which seems to be only local. Here the pahoehoe surface forms a very uneven microtopography. Surface rock plates have been pushed together resulting in small hills (2 m or so high) that have cracked open at the apex. On these small hills, Metrosideros trees are sometimes found that have extended their roots into those deep cracks, at the bottom of which rain water is held by a solid lava core similar to that beneath the a'a surface.

Segment 3 (Fig. 34). Heteropogon grassland; map symbol H(r); aerial photos 8-0020, 8-0024.

This is a recurrence of segment 1 on the very same substrate. For description see discussion under Transect 2, above.

Segment 4 (Fig. 34). Heteropogon grassland with low shrubs; map symbol H(ls-i); aerial photos 8-0020, 8-0024.

This is the same as segment 3 on Figure 33. For description see discussion under Transect 2, above.

Segment 5 (Fig. 34). Mixed lowland scrub; map symbol ls(i); aerial photos 8-0020, 8-0024, 14-0016, 6-16.

This type is formed on much the same well-weathered pahoehoe substrate as segment 4. The increase in density and shrub size is obviously related to an increase in rainfall from a summer-drought to a summer-dry climate.

The dominant native shrubs are Canthium odoratum, Wikstroemia phillyraefolia(?) and Diospyros ferrea (shrub stature). In addition there are many introduced shrubs such as Schinus terebinthifolius, Eugenia cumini, Psidium guajava and Pluchea odorata. Also, several of the smaller shrubs of the preceding type are present. The taller shrubs are from 2-5 m tall, usually showing globose crowns. Grasses are rare, but Chrysopogon, Trichloaena and Sporobolus diander can be found in openings between the shrubs. However, shrub density throughout most of the type is such that the crowns are just touching each other. Thus, there are no thickets and the type is easily accessible.

Segment 6 (Fig. 34). Mixed lowland forest; map symbol lf; aerial photos 14-0016, 6-16.

This type occurs near the eastern Park border and mostly outside the

Park near the village of Kalapana. It occurs in the humid to subhumid rain-forest climate, but the forest is much interrupted and restricted to stand fragments as a result of urban development. With few exceptions the forest is comprised of introduced, probably, mostly planted trees. These are distributed in patch forests so that the dominant trees vary from patch to patch. The more common trees are Mangifera indica, Samanea saman, Aleurites moluccana, Cocos nucifera, Pandanus and Thespesia.

6- Summary. The vegetation types of Hawaii Volcanoes National Park have been described on the basis of five vegetation profiles (Figs. 30-34) intended as an interpretation of the vegetation map that was prepared from plastic overlays on 53 aerial photos at an approximate scale of 1:12,000. There is some overlap of vegetation types on the five profile diagrams. As reviewed in tabular summaries (Tables I & II), the map symbols are explained in the form of a legend, and each type is shown as one or more segments along the profile diagrams and identified by the appropriate map symbol in the text. References to aerial photographs are provided to facilitate their ordering and use.

Table II. The vegetation types of Hawaii Volcanoes National Park as these units are distinguished on the five vegetation profiles (Figs. 30-34) and discussed in the text.

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Dry climate with night-frost near surface. Vegetation types on upper east slope of Mauna Loa. Elev. 8500-11,000 feet. Figure 30.	Rhacomitrium moss type	r(R)	Fig. 30, Seg. 2
	Scattered, low globous scrub	r(ns)	Fig. 30, Seg. 3
Summer-dry climate with frequent clouds near ground. Downslope continuation on east slope of Mauna Loa. Elev. 3900-8500 feet. Figures 30 & 31.	Open to closed globous scrub	ns	Fig. 30, Seg. 4
	Globous shrub with scattered Metrosideros	ns(M)	Fig. 30, Seg. 5
	Open Metrosideros—Sophora forest	oM(So-ns)	Fig. 30, Seg. 6
	Tall globous shrub savannah with scattered Acacia koa colonies	mx-ns(AcSoM)	Fig. 30, Seg. 7
	Mixed Acacia koa—Sapindus tree savannah	mx-AcSaM	Fig. 30, Seg. 8; Fig. 31, Seg. 10
	Mixed Acacia koa—Sapindus forest with lower-story trees and arborescent shrubs	AcSaM(ad)	Fig. 30, Seg. 9; Fig. 31, Seg. 8
	Open Metrosideros—lichen forest with native low shrubs	oM(L-ns)	Fig. 30, Seg. 10; Fig. 31, Seg. 7
	Open Metrosideros—native shrub forest	oM(ns)	Fig. 31, Seg. 9

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Humid to summer-dry transition climate above montane rain forest in Kilauea Forest Reserve, lower east slope of Mauna Loa. Elev. 5000 feet. Figure 31.	Mixed *Acacia koa*—*Metrosideros* forest with arborescent shrubs and *Cibotium*	AcM(ad-C)	Fig. 31, Seg. 11
Humid montane rain forest climate in northern part of Park, from Chain-of-Craters Road in north and beyond northern Park boundary. Elev. from below 5000 feet at lower east slope on Mauna Loa to 2500 feet at Napau crater. Figures 30, 32 & 33.	Closed *Metrosideros*—*Cibotium* forest	cM(C)	Fig. 30 Seg. 12; Fig. 32, Seg. 8; Fig. 33, Seg. 7
	Open *Metrosideros*—*Gleichenia* forest	oM(G)	Fig. 30 Seg. 11
	Open *Metrosideros*—*Cibotium*—*Gleichenia* forest	oM(C-G)	Fig. 32 Seg. 7
	Disturbed *Metrosideros* scrub forest with *Gleichenia* and *Andropogon* patches	scM(G-An)	Fig. 32, Segs. 6 & 9
	Open *Metrosideros*—*Cibotium* forest	oM(C)	Fig. 32 Seg. 10
	Cibotium forest with scattered old *Metrosideros* that are covered with epiphytes	C(M^{e})	Fig. 32 Seg. 11
Humid to summer-dry transition climate below montane rain forest in eastern part of Park. Elev. about 2000 feet. Figure 33.	Open *Metrosideros*—*Gleichenia*—*Andropogon* forest	oM(G-An)	Fig. 33 Seg. 6

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Summer-dry climate of mid-altitudes on south slope of Kilauea. Elev. 1000-3000 feet. Figures 31, 32 & 33.	Open *Metrosideros*—*Andropogon* forest with native shrubs	oM(ns-An)	Fig. 32, Seg. 5
	Andropogon grassland	An(M) and An(ns-i)	Fig. 31, Seg. 4; Fig. 32, Seg. 4
	Shrubland with *Andropogon* and scattered old *Metrosideros*	ns(i-An-M)	Fig. 33 Seg. 5
	Metrosideros—*Diospyros* mixed forest with patchy stands of *Aleurites*	MD(Al-ns-i-An-N)	Fig. 33 Seg. 4
	Very open *Metrosideros*—*Diospyros* forest	MD(r)	Fig. 31, Seg. 3; Fig. 32 Seg. 3
Summer-drought climate at mid-altitudes with strong winds in west-central part of Park. Elev. 2500-3500 feet. Figure 31.	Extremely sparse desert vegetation	r-ash(poik)	Fig. 31 Seg. 6
Warm-tropical climate in coastal lowland from summer-drought (west) to subhumid (east). Figures 31, 32, 33, & 34.	*Eragrostis tenella* grassland	E(r)	Fig. 31 Seg. 2
	Heteropogon grassland	H(r); r(H); and H(lsi)	Fig. 32, Seg. 2; Fig. 33, Seg. 2; Fig. 34, Segs. 1 & 3
	Heteropogon grassland with low shrubs	H(ls-i)	Fig. 33, Seg. 3;
	Scattered old *Metrosideros* on nearly barren a'a lava	r(M)	Fig. 34, Seg. 2

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
	Mixed lowland scrub	ls(i)	Fig. 34, Seg. 5
	Mixed lowland forest	lf	Fig. 34, Seg. 6
	Salt spray and other shore communities	r(spr) and spr	Fig. 31, Seg. 1; Fig. 32 Seg. 1; Fig. 33, Seg. 1

Chapter IX- Bibliography

The following list of literature has been prepared as a guide. The user will find it short in entries concerning the geological aspects of the Park. The splendid annotated bibliography by Macdonald (1947) covers this subject for the island up into 1946. The lists of literature in the papers on the Park's more recent geology which are cited should satisfy most of the biologist's needs. Natural History Bulletin No. 5 issued by the Hawaii National Park and Western Museum Laboratories in 1940 is another extensive source of useful bibliographic information. Miss Margaret Titcomb of the B. P. Bishop Museum and Dr. Dieter Mueller-Dombois both have contributed further useful lists of bibliographic material for which we are thankful.

An effort has been made to include some of the less well known minor publications as a matter of record and at the same time a number of the very early and the more generally informative or basic publications even though not specifically biological but referred to in the text. In some fields it has not been possible to be thorough, *e.g.*, in the fields of invertebrate zoology and cryptogamic botany, but in such fields the principal works for the Park or the islands are given with the hope that interested individuals will find it easier to begin the work of determining the status of the Park's biota in such fields from the particular few starting points given.

Actually the hope is that through the stimulus of this Atlas, or data assemblage, scientific work in the different fields of biology and ecology will be encouraged and that, as a result, this first-generation effort will soon be far outdated.

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Chapter X- Generic Index to Organisms Known from the Park

The following alphabetical list of genera is an index to the organisms known to occur in the Park as recorded in the text of this Atlas or in the publications listed with the particular name. An asterisk (*) before a generic name means that the organism is recorded from near, but not within, the Park. The citations which follow a generic name lead to the bibliography, the previous chapter of this Atlas, or to the chapters within the Atlas where the record may be found. One citation, the year date of which is followed by an asterisk, is given as a useful general reference for the genus and does not necessarily refer to the Park. In parentheses following each generic entry are one or more words providing clues as to the kind of organism to which the generic name applies and, in some cases, to a reference where it is mentioned in the text above or to other supplementary information.

Amphidium (moss): Bartram, June 1933.* (Chapt. VI, C.)

Amsinckia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anabaena (alga): Prescott, 1951.* (Chapt. VI, A.)

Anacystis (alga): Prescott, 1951.* (Chapt. VI, A.)

Anagallis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Ananas (plant): Degener, 1930; Neal, 1965.*

Anas (bird): Munro, 1960.* (Chapt. VI, H.)

Anastrophyllum (moss): Miller, 1963; (Chapt. VII, E.)

Andropogon (plant): Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, C; VIII.)

Anemone (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anoectochilus (plant): Fagerlund & Mitchell, 1944; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Anous (birds): Munro, 1960.* (Chapt. VI, H.)

Anser (bird): Munro, 1960*. (Chapt. VI, H.)

Anthemis (plant): Fagerlund & Mitchell, 1944, Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anthoxanthum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapts. VI, D; VII, B; VIII.)

Antidesma (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Antirrhinum (plant): Neal, 1965.* (Chapt. VI, D.)

Apium (plant): Neal, 1965.* (Chapt. VI, D.)

Araucaria (plant): Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Arcella (shelled amoeba): Kudo, 1960.* (Chapt. VII, G.)

Arctotis (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Ardisia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Arenaria (bird): Munro, 1960.* (Chapt. VI, H.)

Argemone (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B.)

Argyroxiphium (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VIII.)

Artemisia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* Hillebrand, 1888.* (Chapt. VI, D.)

Artocarpus (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI,D.)

Arundina (plant): Neal, 1965.* (Chapts. VI, D; VII, C, F.)

Arundinaria (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Asarina (plant): Neal, 1965.* (Chapt. VI, D.)

Asclepias (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI,D.)

Asio (bird): Munro: 1960.* (Chapt. VI, H.)

Asparagopsis (alga): Dawson, Oct. 1954.* (Chapt. VII,G.)

Asparagus (plant): Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Asplenium (plant): Fagerlund & Mitchell, 1944; Rock, undated; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VII, B; VIII.)

Astelia (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Degener, 1930; Neal, 1965;* Hillebrand, 1888.* (Chapts. VI, D; VII, D; VIII.)

Aster (plant): Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Athyrium (plant): Fagerlund & Mitchell, 1944; Neal, 1965*: Hillebrand, 1888.* (Chapt. VII, B.)

Avena (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888.* (Chapt. VI, D.)

Axonopus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapt. VI, D.)

Bazzania (moss): Miller, 1963.* (Chapt. VII, E.)

Begonia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Beta, (plant): Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Bidens (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Bobea (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Boerhavia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Boodlea (alga): Taylor, 1950.* (Chapt. VI, A.)

Boodleopsis (alga): Gilbert, 1965.* (Chapt. VII, G.)

Botrydiopsis (alga): Smith, 1950.* (Chapt. VI, A.)

Bougainvillea (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Brachiolejeunea (moss): Miller, 1963.* (Chapt. VII, E.)

Brachymenium (moss): Bartram, June, 1933.* (Chapt. VI, C.)

Branta (bird): Lamoureux (App. B), 1963; Munro, 1960.* (Chapt. VI, H.)

Brassaia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapts. VI, D; VII, B.)

Brassica (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Briza (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888.* (Chapts. VI, D; VII, B; VIII.)

Bromus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Broussaisia (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965; Hillebrand, 1888.* (Chapts. VI, D; VII, C.)

Broussonetia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Brugmansia (plant): Degener,1930; Neal, 1965.*

Bryum (moss): Bartram, June, 1933.* (Chapt. VII, E.)

<u>Buddleja</u> (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, D.)

<u>Bufo</u> (toad): (Chapt. VI, G.)

<u>Bulbostylis</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Willis, 1960.* (Chapts. VI, D; VIII.)

<u>Buteo</u> (bird): Munro, 1960.* (Chapt. VI, H.)

<u>Buxus</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Caesalpinia</u> (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Cajanus</u> (plant): Fagerlund & Mitchell, 1944, Fagerlund, 1947; Degener, 1930; Neal, 1965.*; Hillebrand, 1880.* (Chapt. VI, D.)

<u>Caladium</u> (plant): Degener, 1930; Neal, 1965.*; Hillebrand, 1888.*

<u>Calipidia</u> (plant): Rock, undated, Unpub. ms; Degener, 1930.* (Ref. to only).

<u>Callistemon</u> (plant): Neal, 1965. (Chapt. VI, D.)

<u>Calophyllum</u> (plant): Neal, 1965. Hillebrand, 1888.*

<u>Calothrix</u> (alga): Smith, 1950.*; Prescott, 1951.* (Chapts. VI, A; VII, G.)

<u>Calymperes</u> (moss): Botany group, 1963; Bartram, June, 1933.*

<u>Camellia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

<u>Campylodiscus</u> (alga): Smith, 1950.* (Chapt. VII, G.)

<u>Campylopus</u> (moss): Bartram, June, 1933.* (Chapt. VI, C.)

<u>Canavalia</u> (plant): Neal, 1965.*; Hillebrand, 1888.* (Chapt. VII, E.)

<u>Canna</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* Hillebrand, 1888.* (Chapt. VI, D.)

<u>Canthium</u> (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

<u>Capparis</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

<u>Capsicum</u> (plant): Stone, 1959; Hillebrand, 1888.*

Coniogramme (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VII, B.)

Conyza (plant): Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, C.)

Coprosma (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964; unpubl. ms; Degener, 1930; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, B, C, D; VIII.)

Corallina (alga): Taylor, 1960.* (Chapt. VII, G.)

Cordia (plant): Fagerlund & Mitchell, 1944; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Cordyline (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Coreopsis (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Coronopus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cosmos (plant): Fagerlund & Mitchell, 1944; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Cotoneaster (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cotula (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Crocethia (bird): Munro, 1960.* (Chapt. VI, H.)

Crotalaria (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Cryptomeria (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cucumis (plant): Neal, 1965.* (Chapt. VI, D.)

Cucurbita (plant): Neal, 1965.* (Chapt. VI, D.)

Cunninghamia (plant): Fagerlund & Mitchell, 1944,; Neal, 1965.* (Chapt. VI, D.)

Cuphea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B., C.)

Cuscuta (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Cyanea (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Cyanisticta (lichen): Magnusson & Zahlbrucker, I: 86, 1943.* (Chapt. VI, B.)

Cyathodes (plant): Degener, 1930; Hillebrand, 1888.* (Chapt. VI, D.)

Cyclosorus (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D, VII, B.)

Cydonia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cylindrocapsa (alga): Prescott, 1951.* (Chapt. VI, A.)

Cynodon (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Cynoglossum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cyperus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VII, B, C, D; VIII.)

Cyrtandra (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VIII.)

Cyrtomium (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VII, B.)

Cytisus (plant): Fagerlund, & Mitchell, 1944; Neal, 1965.* (Chapt. VI,D.)

Dactylis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Lawrence, 1951*, (merely mentioned); Hitchcock, 1935.* (Chapts. VI, D; VII, B.)

Dactyloctenium (plant): Hitchcock, 1935.* (Chapt. VIII.)

Dahlia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Daucus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Doryopteris</u> (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

<u>Dovyalis</u> (plant): Fagerlund & Mitchell, 1944, Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Dracaena</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Drepanis</u> (bird): Smathers, 1963a; Unpub. report; Munro, 1960.* (Chapt. VI, H.)

<u>Drupa</u> (mollusc): Edmondson 1946.* (Chapt. VII, G.)

<u>Drynaria</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E.)

<u>Dryopteris</u> (plant): Fagerlund, & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Neal, 1965.* (Chapt. VII, B.)

<u>Dubautia</u> (plant): Botany group, 1963; Neal, 1965.* (Chapts. VI, A; VII, C; VIII.)

<u>Echinochloa</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Ectocarpus</u> (alga): Dawson, 1956.*(Chapts. VI, A; VII, G.)

<u>Edwardsia</u> (plant): Degener, 1930; Neal, 1965.*

<u>Elacagnus</u> =?Elaeagnus (plant): Neal, 1965.

<u>Elaeagnus</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Elaphoglossum</u> (plant): Fagerlund & Mitchell, 1944; Botany group. 1963; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VII, B, C; VIII.)

<u>Eleocharis</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Eleusine</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Elymus</u> (plant): Hitchcock, 1935.* (Chapt. VI, D.)

<u>Embelia</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965.* (Chapts. VI, D; VII, B.)

Emilia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII F; VIII.)

Enteromorpha (alga): Taylor, 1950.* (Chapt. VII, G.)

Entophysalis (alga): Drovet & Daily, 1956.* (Chapts. VI, A; VII, G.)

Epilobium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*(Chapt. VI, D; VIII.)

Eragrostis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Erechtites (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund,1947; Neal, 1965.* (Chapts. VI, D; VII, C, D, E, F.)

Erigeron (plant): Fagerlund & Mitchell, 1944; Fagerlund,1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Eriobotrya (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Erioderma (lichen): Magnusson & Zahlbruckner, I:78, 1943.* (Chapt. VI,B.)

Erodium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Erythraea (plant): Rock, undated. Unpub. ms; Neal, 1965.*

Erythrina (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Erythrotrichia (alga): Taylor, 1950.* (Chapt. VI, A.)

Escallonia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Eschscholtzia (plant): Neal, 1965.* (Chapt. VI, D.)

Eucalyptus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VIII.)

Eucapsis (alga): Smith, 1950.* (Chapt. VI, A.)

Eugenia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Eupatorium (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Lamoureux (App.B), 1963; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, D.)

Euphorbia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gelidium (alga): Loomis, 1960.* (Chapt. VII, G.)

Geopelia (bird): Munro, 1960.* (Chapt. VI, H.)

Geranium (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Gerbera (plant): Neal, 1965.* (Chapt. VI, D.)

Gladiolus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Gleichenia (plant): Fagerlund & Mitchell, 1944, Botany group, 1963; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gloeocystis (alga): Smith, 1950.* (Chapt. VI, A.)

Cnaphalium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gomphosphaeria (alga): Smith, 1950.* Drouet & Daily, 1956.* (Chapt. VI, A; VII, G.)

Goniolithon (alga): Taylor, 1950.* (Chapt. VII, G.)

Gossypium (plant): Degener, 1930; Neal, 1965.*

Gouldia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C; VIII.)

Grammitis (plant): Botany group, 1963; Hillebrand, 1888.* (Chapts. VI, D; VII, C.)

Grevillea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Griffithsia (alga): Taylor, 1950.* (Chapt. VII, G.)

Gymnogramme (plant): Rock, undated Unpub. ms; Hillebrand, 1888.*

Gynopogon (plant): Degener, 1930.*

Haplostachys (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hebe (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hedera (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hedychium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B.)

Hedyotis (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Heimerliodendron (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapts. VI, D; VII, B.)

Helcioniscus (mollusc): Edmondson, 1946.* (Chapt. VII, G.)

Heliotropium (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Helichrysum (plant): Neal, 1965.* (Chapt. VI, D.)

Hemerocallis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1944; Neal, 1965.* (Chapt. VI, D.)

Hemignathus (bird): Smathers, 1963a, Unpub. report; Munro, 1960.* (Chapt. VI, H.)

Hemitrema (alga): Dawson, 1957.* (Chapt. VI, A.)

Hesperocnide (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Heterocentron (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Heterococcus (alga): Fritsch, 1961; (Chapt. VI, A.)

Heteropogon (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VII, G; VIII.)

Heteroscelus (bird): Munro, 1960.* (Chapt. VI, H.)

Hibiscadelphus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Lamoureux (App.B), 1963; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Hibiscus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Himatione (bird): Smathers, 1963a, unpub. report; Munro, 1960.* (Chapt. VI, H.)

Hippeastrum (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Holcus (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Hillebrand, 1888.* (Chapts. VI, D; VII, B, C, VIII.)

Homaliodendron (moss): Bartram, June 1933.* (Chapt. VI, C.)

Hordeum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Lawrence, 1951.* (mentioned only); Hitchcock, 1935.* (Chapt. VI, D.)

Hormidium (alga): Smith, 1950.* (Chapt. VI, A.)

Hunnemannia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*(Chapt. VI, D.)

Hydrangea (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hydrocoleum (alga): Prescott, 1951.* (Chapt. VII, G.)

Hydrocotyle (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

Hymenophyllum (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C.)

Hyparrhenia (plant): Fagerlund & Mitchell, 1944; Hitchcock, 1935.* (Chapt. VI, D.)

Hypericum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B, C.)

Hypnea (alga): Taylor, 1950.* (Chapts. VI, A; VII, G.)

Hypochaeris (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Iberis (plant): Neal, 1965.* (Chapt. VI, D.)

Ilex (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Impatiens (plants): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Indigofero (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Impomoea (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

<u>Iris</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Isachne</u> (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Stone, 1959; Degener, 1946.* (Chapts. VI, D; VII, C; VIII.)

<u>Isotoma</u> (plant): Degener, 1930.*

<u>Jacaranda</u> (plant): Neal, 1965.* (Chapts. VI, D; VIIII.)

<u>Jacquemontia</u> (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Jania</u> (alga): Taylor, 1950.* (Chapts. VI, A; VII, G.)

<u>Jasminum</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Jatropha</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Juncus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Juniperus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Justicia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Kadua</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Kalanchoe</u> (plant): Neal, 1965. (Chapt. VI, D.)

<u>Kniphofia</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Koeleria</u> (plant): Rock, undated. Unpub. ms; Hitchcock, 1935.*

<u>Kokia</u> (plant): Neal, 1965. (Chapt. VI, D.)

<u>Korthalsella</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Labordia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Lactuca</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Laculia</u> (plant): Fagerlund & Mitchell, 1944. (Chapt. VI, D.)

<u>Lampranthus</u> (plant): Neal, 1965.

<u>Lantana</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts.VI,D; VII,A,E; VIII.)

<u>Lastrea</u> (plant): (Chapt. VI, D.)

<u>Lathyrus</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Laurencia</u> (alga): Yamada,1931.* (Chapt. VI, A.)

<u>Lecanidium</u> (lichen): (Chapt. VI, B.)

<u>Lecanora</u> (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

<u>Leiothrix</u> (bird): Munro, 1960.* (Chapt. VI, H.)

<u>Leonurus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Lepidium</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Leptospermum</u> (plant): Fagerlund & Mitchell, 1944; Neal,1965.* (Chapt. VI, D.)

<u>Leucaena</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, A, F.)

<u>Leucobryum</u> (moss): Bartram, 1933.* (Chapts. VI, C; VII, E.)

<u>Liagora</u> (alga): Abbott, 1945.* (Chapt. VII, G.)

<u>Ligustrum</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Lilium</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Linaria</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Lindernia</u> (plant): Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Linociera</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Linum</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal,1965.*

<u>Liparis</u> (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

<u>Lipochaeta</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965.* (Chapt. VI, D.)

<u>Littorina</u> (animal): Tinker, 1958;*(Chapt. VII, G.

<u>Lobelia</u> (plant): Degener, 1930; Neal, 1965.*

<u>Lobularia</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Lolium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947, (Chapt. VI, D.)

Lonicera (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Lophortyx (bird): Munro, 1960.* (Chapt. VI, H.)

Lophosiphonia (alga): Smith, 1964.* (Chapt. VII, G.)

Loxops (bird): Smathers, 1963a, Unpub. report; Munro, 1960.* (Chapt. VI, H.)

Luculia (plant): Neal, 1965.* (Chapt. VI, D.)

Lunularia (moss): (Chapt. VI, C.)

Lupinus (plant): Neal, 1965.* (Chapt. VI, D.)

Luzula (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapts. VI, D; VIII.)

Lycopersicon (plant): Neal, 1965.* (Chapt. VI, D.)

Lycopodium (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Botany group, 1963; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Lyngbya (alga): Smith, 1950.* (Chapts. VI, A; VII, G.)

Lysimachia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Lythrum (plant): Fagerlund & Mitchell, 1944, Smathers, 1963b,; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D;VII, B, D.)

Maba (plant): Neal, 1965.* (Chapt. VI, D = Diospyros)

Macadamia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Machaerina (plant): Botany group, 1963; (Chapts. VI, D; VII, C; VIII.)

Macromitrium (moss): Bartram, 1933.* (Chapt. VI, C.)

Malva (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Malvastrum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Mangifera (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E; VIII.)

Marattia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Mastigocoleus (alga): Tilden, 1910.* (Chapts. VI, A; VII, G.)

Matthiola (plant): Neal, 1965.* (Chapt. VI, D.)

Maurandya (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Medicago (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Megalospora (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Melaleuca (plant): Neal, 1965.* (Chapt. VI, D.)

Meleagris (bird): Munro, 1960.* (Chapt. VI, H.)

Melia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Melilotus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Melinis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapts. VI, D; VIII.)

Melosira (alga): Prescott, 1951.* (Chapt. VII, G.)

Mentha (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Merremia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Mesembryanthemum (plant): Neal, 1965.* (Chapt. VI, D.)

Messerschmidia (plant): Fagerlund & Mitchll, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, G.)

Metrosideros (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. V, E; VI, C, D, F, H; VII, A, B, C, D, E, F; VIII.)

Microcoleus (alga): Prescott, 1951.* (Chapts. VI, A; VII, G.)

Nannochloris (alga): Smith, 1950.* (Chapt. VI, A.)

Narcissus (plant): Neal, 1965.* (Chapt. VI, D.)

Nasturtium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.*

Neochloris (alga): (Chapt. VI, A.)

Neottopteris (plant): Stone, 1959; Hillebrand, 1888.*

Nephrolepis (plant): Neal, 1965*; Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Degener, 1930; Stone, 1959. (Chapts. VI, D; VII, B, C, D, E, F; VIII.)

Nephroma (lichen): Magnusson & Zahlbruckner, I:93, 1943.* (Chapt. VI, B.)

Neraudia (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VI, D.)

?Nertera (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VI, D.)

Nestegis (plant): (Chapt. VI, D.)

Netrium (alga): Smith, 1950.* (Chapt. VI, A.)

Nicandra (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*

Nicotiana (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959, Neal, 1965.* (Chapts. VI, D; VII, F.)

Nostoc (alga): Smith, 1950.* (Chapt. VI, A.)

Nothocestrum (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965.* (Chapt. VI, D.)

Nototrichium (plant): Neal, 1965.* (Chapt. VI, D.)

Nycticorax (bird): Munro, 1960.* (Chapt. VI, H.)

Ocellularia (lichen): Magnusson & Zahlbruckner, 1943.* (Chapt. VI, B.)

Ochrosia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms;

Odontoschisma (bryophte): (Chapt. VII, E.); Miller, 1963.*

Oenothera (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

Oocystis (alga): Smith, 1950.* (Chapt. VI, A.)

Operculina (plant): Neal, 1965.* (Chapt. VI, D.)

Ophioderma (plant): Degener, 1930.* (Chapt. VI, D.)

Ophioglossum (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Neal, 1965.* (Chapts. VI, D; VII, C.)

Oplismenus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E.)

Optunia (plant): Fagerlund, 1947; Neal, 1965.*

Oreobolus (plant): Fagerlund & Mitchell, 1944. (Chapt. VI, D.)

Orthocarpus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Oscillatoria (alga): Smith, 1950.* (Chapts. VI, A; VII, G.)

Osmanthus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms.; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Osteomeles (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Oxalis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Padina (alga): Taylor, 1960.* (Chapt. VI, A.)

Palmelia (alga): Smith, 1950.* (Chapt. VI, A.)

Palmeria (bird): Munro, 1960.* (Chapt. VI, H.)

Palmogloea (alga): Drouet & Daily, 1956.* (Chapt. VII, F.)

Pandanus (plant): Fagerlund & Mitchell, 1944; Degener, 1930, Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Panicum (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Neal, 1965.* (Chapt. VII, B.)

Pannaria (lichen): Magnusson & Zahlbruckner, 1943.* (Chapt. VI, B.)

Pariti (plant): Degener, 1930.* (Chapt. VI, D.)

Parmelia (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Paspalum (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C, D, E; VIII.)

Passer (bird): Munro, 1960.* (Chapt. VI, H.)

Passiflora (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, E.)

Pastinaca (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Pelargonium (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Peiea (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. IV, D; VII, B, C; VIII.)

Pellaea (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, B; VIII.)

Pelvetia (alga): Smith, 1964.* (Chapt. VII, G.)

Pennisetum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*

Pennula (bird): Smathers,1963a; Unpub. report; Munro, 1960.*

Penstemon (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Pentas (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Peperomia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C, E; VIII.)

Perrottetia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B.)

Persea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Pertusaria (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Petroselinum (plant): Neal, 1965.* (Chapt. VI, D.)

Phaeornis (bird): Munro, 1960.* (Chapt. VI, H.)

Phaethon (bird): Munro, 1960.* (Chapt. VI, H.)

Phaius (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947, Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Phalaris (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Phaseolus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Phasianus (bird): Munro, 1960.* (Chapt. VI, H.)

Philacte (bird): Munro, 1960.* (Chapt. VI, H.)

Philadelphus (plant): Neal, 1965.* (Chapt. VI, D.)

Phleum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Lawrence, 1951.* (mentioned only); Hitchcock, 1935.* (Chapt. VI, D.)

Phlox (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Phormidium (alga): Smith, 1950.* (Chapt. VI, A; VII, G.)

Phormium (plant): Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Phyllostegia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Physalis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapt. VI, D; VII, B.)

Phytolacca (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D; VII, B.)

Pilea (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Pinnularia (alga): Smith, 1950.* (Chapt. VI, A.)

Pipturus (plant): Fagerlund & Mitchell, 1944; Mueller-Dombois & Lamoureux, 1964; unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C, F; VIII.)

Pisonia (alga): Taylor, 1950.* (Chapt. VI, A.)

Pisum (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Pithecellobium</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Pithecolobium</u> (plant): Fagerlund, 1947; Neal, 1965.*

<u>Pittosporum</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

<u>Pityrogramma</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, B; VIII.)

<u>Plantago</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Plectonema</u> (alga): Smith, 1950.* (Chapt. IV, A.)

<u>Plectranthus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Plectronia</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Pleomele</u> (plant): Stone, 1959; Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Pleopeltis</u> (plant): Stone, 1959; Neal, 1965.* (Chapt. VII, B.)

<u>Pluchea</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C, F; VIII.)

<u>Plumbago</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Plumeria</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, F.)

<u>Pluvialis</u> (bird): Munro, 1960.* (Chapt. VI, H.)

<u>Poa</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Pocillopora</u> (coral): Edmondson, 1946.* (Chapt. VII, G.)

<u>Podocarpus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Podoscyphe</u> (alga): (Chapt. VII, G.)

<u>Polycarpon</u> (plant): Neal, 1965.* (Chapt. VI, D.

<u>Polycystis</u> (alga): Smith, 1950.* (Chapt. VI, A.)

<u>Polyopes</u> (alga): Kylin, 1956.* (Chapt. VII, G.)

<u>Polypodium</u> (plant): Fagerlund & Mitchell, 1944; Botany group, 1963, Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, A, C, E.)

<u>Polypogon</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapt. VI, D.)

<u>Polypremum</u> (plant): Willis, 1960.* (Chapt. VI, D.)

<u>Polysiphonia</u> (alga): Hollenberg, 1961.* (Chapt. VI, A; VII, G.)

<u>Polytrichum</u> (moss): Bartram, June 1933.* (Chapt. VI, C.)

<u>Porolithon</u> (alga): Taylor, 1950.* (Chapts. VI, A; VII, G.)

<u>Portulaca</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, G; VIII.)

<u>Pritchardia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D; VIII.)

<u>Priva</u> (plant): Hillebrand, 1888.* (Chapt. VI, D.)

<u>Prosopis</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, A; VIII.)

<u>Prunus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Pseudomorus</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Psidium</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947, Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, A, B, C, E; VIII.)

<u>Psilorhegma</u> (plant): Hillebrand, 1888.* (Chapt. VIII.)

<u>Psilotum</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, B, C, E.)

<u>Psittacirostra</u> (bird): Munro, 1960.* (Chapt. VI, H.)

<u>Psychotria</u> (plant): Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

<u>Pteridium</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

<u>Pteris</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms.; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B, C.)

<u>Pterocladia</u> (alga): Kylin, 1956.* (Chapt. VII, G.)

Pterodroma (bird): Munro, 1965.* (Chapt. VI, H.)

Pueraria (plant): Neal, 1965.* (Chapt. VII, F.

Pyracantha (plant): Fagerlund & Mitchell, 1944; Neal, 1965* (Chapt. VI, D.)

Pyrenula (lichen): Magnusson & Zahlbruckner, I:13, 1943.* (Chapt. VI, B.)

Radula (bryophte): Miller, 1957.* (Chapt. VII, E.)

Raillardia (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Degener, 1930; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VII, D.)

Raimannia (plant): Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Ralfsia (alga): Smith, 1964.* (Chapt. VII, G.)

Ramalina (lichen): Magnusson&Zahlbruckner, III: 2, 1945.* (Chapt. VI, B.)

Ranunculus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Raphanus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Rauvolfia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Reseda (plant): Neal, 1965.* (Chapt. VI, D.)

Reynoldsia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Rhacomitrium (moss): Botany group, 1963; Bartram, June 1933; Chapt. VI, C; VII , C, F; VIII).

Rhacopilum (moss): Bartram, June 1933.* (Chapt. VII, E, F.)

Rheum (plant): Neal, 1965.* (Chapt. VI, D.)

Rhizoclonium (alga): Taylor, 1960.*(Chapt. VI, A; VII, G.)

Rhizogonium (moss): Bartram, June 1933.* (Chapt. VII, E.)

Rhododendron (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Rhus (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E.)

Rhynchospora (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Hillebrand, 1888.* (Chapt. VI, D; VIII.)

Richarida (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Richmondena (bird): Munro, 1960.* (Chapt. VI, H.)

Ricinus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Rockia (plant): Neal, 1965.

Rollandia (plant): Degener, 1930; Neal, 1965.*

Rosa (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Rosenvingea (alga): Dawson, 1954.* (Chapt. VI, A.)

Rubus(plant): Neal, 1965*; Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Lamoureux (App.B), 1963; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964; unpub. ms; Degener, 1930; (Chapts. VI, D; VII, B, C, D; VIII.)

Rumex (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms.; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII B.)

Saccharum (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Sacciolepis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Hitchcock, 1935*. (Chapt. VI, D; VII, C.)

Sadleria (plant): Fagerlund & Mitchell, 1944; Lamoureux (App. B), 1963; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, A, B, C, E; VIII.)

Salvia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Samanea (plant): Stone, 1959; Neal, 1965.* (Chapt. VIII.)

Sambucus (plant): Fagerlund & Mitchell, 1944; Neal, 1955.* (Chapt. VI, D.)

Santalum (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VIII.)

Sapindus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Botany group, 1963; Mueller-Dombois & Lamoureux, 1964, ms; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Sargassum (alga): Lemmerman, 1905.* (Chapts. VI, A, G; VII, G.)

Scabiosa (plant): Neal, 1965.* (Chapt. VI, D.)

Scaevola (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Scenedesmus (alga): Smith, 1950.* (Chapt. VI, A.)

Schinus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Schizophyllum (fungus): Smathers, 1936b; Taylor, 1950.* (Chapt. VII, D.)

Schizothrix (alga): Tilden, 1910.* (Chapts. VI, A; VII, G.)

Scytonema (alga): Tilden, 1910.* (Chapts. VI, A; VII, A, F, G.)

Secale (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Lawrence, 1951.* (mentioned only); Hitchcock, 1935.*

Selaginella (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C.)

?Sempervivum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Senecio (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B, C.)

Sesbania (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Sesuvium (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, G; VIII.)

Setaria (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B, D.)

Sicyos (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Sida (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Silene (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VIII.)

Sisymbrium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

Sisyrinchium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Smilax (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Solanum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Solidago (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Sonchus (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D, H; VII, B,D.)

Sophora (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms.; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D, H; VII, B; VIII.)

Spathoglottis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, C, E, F.)

Spatula (bird): Munro, 1960;* (Chapt. VI, H.)

Specularia (plant): Lawrence, 1951.* (mentioned only). (Chapt. VI, D.)

Spermolepis (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Sphacelaria (alga): Taylor, 1960.* (Chapt. VI, A; VII, G.)

Sphenomeris (plant): Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C.)

Spiraea (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Sporobolus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Stachytarpheta (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C, E, F; VIII.)

Stellaria (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Stenogyne (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Stenoloma (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.*

Stenotaphrum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D; VII, B.)

Stereocaulon (lichen): Botany group, 1963; Magnusson, II:36, 1944.* (Chapts. VI, B; VII, C, E, F; VIII.)

Stichococcus (alga): Smith, 1950.* (Chapts. VI, A; VII, F.)

Stichogloea (alga): (Chapt. VI, A.)

Stictina (lichen): Magnusson, I:85, 1943.* (Chapt. VI, B.)

Stictocardia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Stigonema (alga): Smith, 1950.* (Chapts. VI, A; VII, C, F, G.)

Stokesia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Stonogylodon (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VI, D.)

Straussia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.*

Streptopelia (bird): Munro, 1960.* (Chapt. VI, H.)

Streptosolen (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Stylurus (plant):Degener, 1946.* (Chapt. VI, D.)

Styphelia (plant): Neal, 1965*; Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Stone, 1959. (Chapts. VI, D; VII, A, B, C, D; VIII.)

Surirella (alga): Smith, 1950.* (Chapt. VII, G.)

Suttonia (plant): Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Symploca (alga): Smith, 1950.* (Chapt. VI, A.)

Taetsia (plant): Degener, 1930.* (Chapt. VI, D.)

Tagetes (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Tamarindus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Tectaria (plant): Fagerlund & Mitchell, 1944; (Chapt. VI, D.)

Tephrosia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Tetracystis</u> (alga): (Chapt. VI, A.)

<u>Tetragonia</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Tetramolopium</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Tetraplasandra</u> (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

<u>Thelypteris</u> (plant): Hillebrand, 1888.* (Chapts. VI, D; VII, C.)

<u>Thespesia</u> (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

<u>Thuidium</u> (moss): Bartram, June 1933.* (Chapt. VI, C.)

<u>Thuja</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Tibouchina</u> (plant): Fagerlund & Mitchell, 1944; Lamoureux (App.B), 1963; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

<u>Tigridia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Tolypiocladia</u> (alga): Dawson, 1956.* (Chapt. VI, A.)

<u>Tournefortia</u> (plant): Neal, 1965.* (Chapts. VI, D; VIII.)

<u>Trematolobelia</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Tricholaena</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VIII.)

<u>Trichomanes</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Trifolium</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Triodanis</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Trioza</u> (insect): Zimmerman, 1948*. (Chapt. VI, F.)

<u>Trisetum</u> (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

<u>Triticum</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; (Chapt. VI, D.)

Tritonia (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B, D.)

Trochalopterum = Garrulax (bird): Munro, 1960.*

Tropaeolum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

Turbinaria (alga): Taylor, 1950.* (Chapt. VI, A; VII, G.)

Ulva (alga): Smith, 1950.* (Chapt. VII, G.)

Uncinia (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Hillebrand, 1888.* (Chapt. VI, D.)

Urera (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Usnea (lichen): Magnusson, III:19, 1945.* (Chapts. VI, B; VIII.)

Vaccinium (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C, D; VIII.)

Valonia (alga): Egerod, 1952.* (Chapts. VI, A; VII, G.)

Vanda (plant): Neal, 1965.* (Chapt. VII, F.)

Vandenboschia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Hubbard, 1952.* (Chapt. VI, D.)

Verbascum (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Verbena (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959, Neal, 1965.* (Chapts. VI, D; VII, B.)

Vernonia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959, Neal; 1965.* (Chapts. VI, D; VII, C.)

Veronica (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

Vestiaria (bird): Smathers, 1963a; Unpub. report; Munro, 1960.* (Chapt. VI, H.)

Vicia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Vinca (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Vincentia (plant): Degener, 1930; Hillebrand, 1888.*

Viola (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Viscum (plant): Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Vitis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Vrydagzynea (plant): Degener, 1930.*

Waltheria (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Watsonia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Weisia (moss): Bartram, June 1933.* (Chapt. VII, E.)

Wikstroemia (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, E; VIII.)

Wisteria (plant): Neal, 1965.* (Chapt. VI, D.)

Xanthium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Xanthoria (lichen): Magnusson, III:41, 1945.* (Chapt. VI, B.)

Xylosma (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Youngia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* Chapts. VI, D; VII, C.)

Yucca (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Zantedeschia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Zanthoxylum (plant): Neal, 1965.* (Chapt. VI, D.)

Zingiber (plant): Degener, 1930; Neal, 1965.*

Zinnia (plant): Neal, 1965.* (Chapt. VI, D.)

Zonaria (alga): Doty and Newhouse, 1966* (Chapt. VII, G.)

Zosterops (bird): Smathers, 1963a, Unpub. report; Munro, 1960.* (Chapt. VI, H.)

The soil sampling included work toward distributional studies of the microorganisms of which the algal work completed (Table II in Chapter VI, above) indicates interesting and correlated variations.

In the steam vent zone and open Andropogon (oAn on Fig. 23) area temperatures of 48 to 89° C were measured. Much of the soil is white as though it were ash from a fire. The closed Andropogon area (An) is warm at the surface, the temperatures measuring 46-47° C. The scrub Metrosideros area has normal surface temperatures, but it is presumed those of the tree root zone are high. Actually some aerial photographs show a large outer contour to this spot not shown in the present figure.

4- Napua Crater area.

The Napau sulfur-affected area (Figs. 5 & 8; Aerial Photos 8-0026 & 8-0028) just west of the crater, the crater floor itself, and kipukas on the crater floor were briefly examined in November, 1963, and re-examined on March 15, 1964, though because of unfavorable weather perhaps certain aspects were not studied as carefully, even as the limited time available would otherwise have permitted. The crater floor and kipuka areas were completely covered (Fig. 5) by lava earlier during March, 1965, one year later. The following notes are included to assist future students of the area.

About 300 m below the side trail around the rim of Makaopuh Crater on the Napua trail, a spot was noticed where the air seemed appreciably warmer than elsewhere. A trace of steam could be seen and a small area of the generally luxuriant Gleichenia tangle was dead or apparently so. This was only a few meters across.

Along the trail a few dead shoots of Lycopodium cernuum were noticed here and there, but most plants of this species seemed healthy. Shortly before reaching the pulu factory, the numbers of these seemed to be greater. It is not suggested that these have died since November, 1963, but that, since at that time this species was seen to be affected by sulfur fumes, more attention was paid to it in the upper parts of the trail. Whether or not the dead shoots in the area between Makaopuhi and the pulu factory were, in March 1964, due to the sulfur is hard to guess. Sulfur fumes undoubtedly reached here, but the bulk of the Lycopodium population was certainly not visibly affected. There was only a small proportion of dead or unhealthy-looking plants. No other unusual effects were evident.

Toward Napau Crater from the pulu factory, the number of dead Lycopodium shoots increased rapidly along the trail and by the time the somewhat smaller and more open Metrosideros forest was reached, almost all the mature shoots were either dead or only had the main rachis green. However, numerous green, actively growing shoots were growing up from the prostrate stolons below.

In the neighborhood of the pulu factory, some Cibotium ferns showed dead lower leaves though the newer leaves were healthy. Dead fronds were not noticed here in November, 1963, but may have been present.

In the more open area on the 1840-flow, starting somewhat east of the pulu factory, not much of an abnormal appearance could be seen except for the dead Lycopodium shoots mentioned above. The Metrosideros trees had largely recovered from the partial defoliation observed in November though they still were a bit sparse. Along the trail somewhat below the beginning of the sparse, 1840-flow area, there were many dead fronds on the Gleichenia, but vigorous, newer, immature to mature ones were abundant. Here, also, Machaerina angustifolia and the much rarer M. meyenii, showed many dead or partly dead leaves, but also many, young healthy ones. Some plants of firmer species were flowering. Just below here above the steeper stretch of trail, the sparseness of the Metrosideros became more striking, seemingly more so than as remembered from November. Here also, about 50% of the fronds of the Gleichenia were dead, the rest green.

On the zone of steeper slope, the vegetation was much less dominated by Metrosideros. Here was a somewhat open mixture of Androgogon with a few other grasses, Machaerina, Cyperus and other sedges, Gleichenia, Arundina, Polypodium pellucidum, and some scattered dwarfed Metrosideros. The Arundina seemed normal, but here the recovery of Lycopodium cernuum from the severe damage noted in November was much retarded. The Andropogon and Cyperus polystachyos had both the leaves and inflorescences dead above. Sacciolepis contracta showed no bad effects. Below this slope on the relatively level, but still open ground, the Gleichenia, at least, and perhaps also the Lycopodium showed more recovery or less damage than on the slope.

Beyond the fork in the trail on the right branch, the forest was much taller and greener for a short distance, and nothing showed much damage. Only the Lycopodium and Gleichenia showed some dead parts. The Metrosideros trees here had begun to show many leafless branches and some trees were completely leafless. These had dead bark, also. In an area to the left of the trail, there were many dead trees and but few healthy ones. After this and further toward Napua Crater, there was a stretch of trail through forest that looked almost normal. Then an area of tall Metrosideros forest with a conspicuous understory of Cibotium extended to the edge of Napau Crater. The Metrosideros showed little evidence of the defoliation evident in November, 1963. The Cibotium which had no living fronds then, now all had 2 or 3 fully developed green fronds. In this area Coprosma, Gouldia, Cheirodendron, Alyxia, and Pelea showed no evidence of any damage and Vaccinium calycinum very little except that all leaves seem to be rather young. Broussaisia was putting out vigorous, young shoots from otherwise leafless shrubs.

Away from the crater the Lycopodium cernuum was still producing some new shoots, but near the crater none at all. The most persistent and striking effects seemed to be on the epiphytes, bryophytes, and ferns. All bryophytes in this forested area were dead (with the possible exception of terrestrial forms covered by an unusual amount of dead fallen leaves) as were Polypodium tamariscinum, Grammitis tenera, Elaphoglossum hirtum, Hymenophyllum spp., Psilotum, and Selaginella cf. menziesii. Elaphoglossum reticulatum, however, had completely recovered and showed no effects whatever. Its leaves were bright green, firm, and leathery, and its rhizome hard and alive. Some distance to the right toward the gulch leading to the crater floor, abundant new shoots of Selaginella had appeared both on the ground and epiphytically. Whether these represented recovery or new sporelings was not determined.

At the crater's edge, the Styphelia and Coprosma ernodeoides had produced new, vigorous, leafy shoots. Isachne distichophylla had resumed active growth from its stem tips. Vaccinium and Gouldia were healthy, and the Metrosideros looked almost normal. On the trail, Youngia japonica had appeared in abundance. There was considerable Cyperus polystachyos and C. brevifolius that seem almost normal. Hypericum was very common as was a broad-leafed sterile unidentified grass. Sacciolepis and Paspalum orbiculare were common and healthy. The Youngia was common locally in the woods away from the trail in spots that were not too densely covered by dead leaves.

In the gulch leading down to the crater floor, the damage, as before, seemed to be generally less conspicuous than on the flat above. Some bryophytes were still living, but most of the epiphytic bryophytes as well as epiphytic ferns were thoroughly dead. *Cibotium* fronds here were partly brown but not dead. *Selaginella*, also, was somewhat brown but not dead. *Peperomia* and *Thelypteris* seemed to have recovered very well.

On the new (1963-) lava crater floor no plants had appeared (except a tiny seedling found deep in a crack by Lamoureux). In a small kipuka in this 1963-lava pool devoid of any living plants in November, seedlings of a number of species had appeared. With one or two exceptions, the seedlings have appeared on scorched, peaty soil lying on the surface of the old lava rather than on the 1963-lava itself. Their number, names, and sizes are listed:

1 *Andropogon virginicus* (3cm).

1 *Conyza bonariensis*? (small rosette).

1 *Cyperus* cf. *polystachyos*.

Many *Dubautia scabra* (to 1 cm).

9 *Erechtites valerianifolia* (very small to 50 cm tall, one budding).

1 *Gnaphalium sandwicense* (10 cm).

Many *Isachne distichophylla* (mostly small, one 10 cm).

Many *Machaerina angustifolia* (small to 4 cm).

4 *Pipturus albidus* (red veined) (to 4 cm).

1 *Pluchea odorata* (small rosette).

8 *Rubus rosaefolius* (several cm).

1 *Senecio sylvatica* (15 cm).

1 Unidentified plant with firm, opposite, obtuse leaves to 15 mm long.

A tiny satellite kipuka, very near the large one which had apparently no living plants in November, also showed some growth. One Metrosideros shrub out of two was putting forth a few tiny sprouts at the base. There were three Erechtites valerianifolia seedlings, one budding, 25 cm tall; one Pluchea odorata 10 cm; a few very tiny Hypericum; and many Machaerina augustifolia up to 6 cm. In sheltered places and crevices on old lava fern gametophytes and tiny sporelings were abundant. A few small patches bore tiny moss plants.

The larger kipuka looked perhaps a bit drier than in November, but most plants were showing some recovery except Lycopodium. No L. phyllanthum was seen, and not a single living sprout or stem of the more abundant L. cernuum was seen. Machaerina angustifolia was alive but not flowering. Dubautia scabra was flowering abundantly and Vaccinium reticulatum somewhat less so. Styphelia was sending out some new sprouts. Gleichenia showed both dead and green fronds.

On the scorched peripheral area on the north side of the kipuka, seedlings of Erechtites valerianifolia, E. hieracifolia, Pluchea odorata, and Pipturus albidus, as well as many tiny unrecognized seedlings and sporelings had become established.

Almost no steam was issuing from the new lava surface on the crater floor except along a line stretching east-west across the crater to the north of the above mentioned kipuka. On the flat just west of the crater, to the north of the trail in line with the line of steaming vents on the crater floor below, was a hot, abundantly steaming area which, judging by its vegetation, had not been hot or at least not so hot for very long. The steam from many of the vents was uncomfortably hot. The area was covered by Gleichenia linearis and Andropogon virginicus in a dense mass, with clumps of Machaerina angustifolia and a sparse stand of dwarf Metrosideros as well as scattered other plants including Lycopodium cernuum. The Metrosideros, Andropogon, and Gleichenia were mostly dead, the Machaerina mostly still alive. In the hottest areas the Lycopodium was completely dead, but where there was any green vegetation, the mature Lycopodium shoots were dead but green, new sprouts were growing from the basal stolons. The gas from the numerous fumaroles smelled sulfureous but not strongly so. This suggested that sulfur fumes below a critical concentration may not have a serious effect on Lycopodium. The dead shoots may probably date from the time of the October eruption when stronger sulfur fumes covered the area.

There were numerous fumaroles in the area, some producing jets of uncomfortably hot steam, and in much of the area where the fumaroles were hottest and most numerous, the vegetation was entirely dead, but mostly not yet disintegrated. Immediately around some of the fumaroles, open areas were beginning to appear and the dead Gleichenia was becoming rather low. It seems probable that in the near future, an open area similar to that near Aloi Crater (the "hot area" described above) may develop here.

This area should be accurately mapped and described in the very near future and periodic checks made on the development or retrogression of the vegetation. In fact, it would be of interest to map and describe the Aloi area and any other new warm or hot spots that appear, as well as any areas where fumaroles occur or develop. Both physiognomic and floristic comparisons should then be made at fairly short intervals. Photos should also be taken regularly from fixed points. These variably-hot sites are unique study areas provided in Hawaii Volcanoes National Park.

D- PUU PUA'I AND THE DEVASTATED AREA

The 1959 November-December eruption in the wall of Kilauea Iki (Fig. 10) produced a new lava surface flooring this crater, produced the cinder cone Puu Pua'i and, beyond it, produced as a shadow to this cinder cone a field of windblown ash. The article by Zahl (1959) and its accompanying photo record illustrates the initial events of this eruption. In the area all organisms were destroyed or damaged.

Thus, this section is in three parts describing 1) the eruption, 2) recovery of the devastated area and 3) succession where the previous population was completely destroyed. There are on file various sets of notes on these events by Smathers (18-month summation, 1963b), Wentworth (Initial report, 1960) and Wentworth and Haugens (Early recovery, 1960). Very conveniently, similar old areas remained undamaged nearby and these serve very well as control areas. This study has been continued by the University of Hawaii team and its notes are on file in the Park as well.

1- THE ERUPTION AND THE ORIGINAL POPULATION

(From C. K. Wentworth's "Initial Report")

Kilauea Iki is an ancient pit crater, near Kilauea on the east rift zone. Its sides are steep in places but nearly everywhere well wooded. The major shape of the crater with somewhat sloping sides gives a rough estimate of its age as several hundred and, probably, several thousand years. There were very small flows down its west side and into the bottom in 1832 and 1868. The less weathered surfaces of the latter flow in the bottom were covered with a scattering of ohia trees but were less wooded than the sides.

The adjacent edge of the floor of Kilauea is nearly bare of trees but has a sparse scattering of shrubs and trees that have commenced slowly to grow on the surface; that side to the north was covered by lava flows in 1919. The greater part of Kilauea is essentially devoid of trees. Otherwise, the area surrounding Kilauea Iki is forested, heavily at the east but dwindling a mile or so west and southwest of the crater.

The 1959 eruption caused various kinds of damage to adjacent vegetation, from complete killing by burial under the pooled lava in the Kilauea depression or the cinders of the three hundred foot cone, Puu Pua'i (Fig. 10), to only temporary effects of fume or retardation or augmentation in relation to lesser cinder cover over a wide area. If the natural forest under the existing climate is considered, the story of the ultimate reforestation which will be restored to the top and lee sides of this new cone, Puu Pua'i, may be written a hundred years hence.

The vegetation and trees in the lower 300 feet of the former pit were wholly consumed. Around the margin of the lake, where lava reached only during surges, a few tree molds were left. As lava rose in successive episodes, trees at the margin, already dried by the heat of the encroaching lake, caught fire and added their flares to the lurid scene. Many of the fires burned a strip up the sides of the crater and threatened surrounding country. Whether any considerable number of tree molds are preserved under the deeper parts of the fill of lava in the lake is not known; their preservation was threatened by the vigorous remelting of the lava which later enveloped them, but it seems certain that some have been preserved.

Burial and killing of vegetation over the base area of the cone Puu Pau'i where the thickness of the cinder is over 25 feet is certain. There seems little evidence that any trees survived a surrounding cover of so much as 10 feet. Beyond the periphery of the completely bare area of the cone, there begins a belt of fallen and completely defoliated trunks of the former forest. A few yards wide it merges outward with a belt of tree molds, followed by another narrow belt where the trees are still standing but scorched and defoliated. Outside this belt the trees have been severely excorciated by falling pumice and clots of lava, but these are recovering as their trunks are heavily furred by a new growth of leaves on the trunks. For months the tops of these trees were covered with the stripped and dead, smaller branches.

In the central area of deep burial, there was no survival of trees or roots or seedlings. Here is an area which we may suppose will be reforested, perhaps with seed from the surrounding undamaged country.

Some trees and shrubs were temporarily buried and widely defoliated by mechanical impact from falling debris. Though annual weeds, ferns and such were destroyed or covered at the time of eruption, many of the trees and larger plants at the margin survived and regrew from their buried bases. Ferns were particularly responsive in recovery and showed new fronds in a few days. The climate is such that vegetative growth takes place at all seasons. It appears that growth of fern buds toward the surface in cinder can certainly take place from depths of three or four feet. Refoliation of the trunks of small trees that had been excoriated was a conspicuous process in the weeks that followed the eruption.

In several areas where there was a heavy fall of slung clots of lava, which molded somewhat together, but was of lava insufficiently molten to flow as a whole. The heat of three of four feet of this was sufficient to burn off the trunks of the trees and form numerous tree molds. These are from less than an inch in diameter to over a foot and show the usual features of the shape and branching of the trunks. There are, no doubt, many of them under the coverings of cinders where the lava clot layer lies below the cinder layer. In many cases the fallen trunks lie close to the mold and show a tapered burnt end with the final tip unburnt but broken.

In an area adjacent to the impressions molded in lava, where the layer of cinders is but a few inches thick over the lava molds, the cinders have slumped into the underlying lava mold forming another type of tree mold, funnel-like in form.

In areas where observation could be made the fallout of cinders and even cobble-size blobs was at the rate of several feet of depth per hour but mostly for quite short periods. This environment at that time, was untenable for humans except by inadvertance and rough on trees and the few buildings in the area, particularly those at the old summer camp. Trees were stripped of their leaves, bark and smaller branches, and many are now either buried or remain denuded today. Farther from the source of the lava fountains, trees were heavily scarred but the trunks retained enough vitality so that subsequent recovery took place in the form of numerous small leaves and then quickly a rather lush foliation from the trunk, including flower buds which went on into a conspicuous blossoming of the red lehua. The furry refoliation of the lower ohia trunks, with increasing flowering of certain trees, and the bare, killed slender twigs at the top gave a very bizarre appearance to many of the trees.

In the heavy fallout areas, flung blobs of soft lava landed in the forks of trees. Some fell at once, others clung long enough to scorch the tree but fell after the cooling due to crumbling. A few remained draped in trees which still stand and can be seen today. A number of larger trees intercepted enough clots and cinder that when they fell they formed a mound on the near side of the tree.

Some of the small fires that burned up the inner sides of the crater burned several months after the close of the eruption. Some even occasioned enough alarm that the National Park fire department was called out, but there was no spreading.

At times during the eruption, the winds were aberrant enough, or calm enough, that fumes from the eruption sat low and people living in certain districts noticed fume damage to certain plants. It does not seem that this was severe enough or of long enough duration to cause definable economic damage. Other eruptions, at certain times, have affected plants enough or persisted long enough to occasion crop loss or have an appreciable effect on humans, especially those in delicate health. At times the fumes have been restrained under an inversion layer in the atmosphere, and thence at a given level have drifted against the mountains to make their effect, but not in this case.

2- RECOVERY OF THE DEVASTATED AREA

By Garrett Smathers

Where the ash fall was light and the plants were merely denuded or superficially buried, the woodier tended to recover. To be able to follow the recovery, a belt transect, which forms part of the major axis of the cinder and pumice fallout area, was laid out (Fig. 10) to determine floristic conditions and composition resulting from the devastation. Data from this will help in analyzing vegetative recovery corresponding to the climatic, physiographic, biotic, and edaphic factors involved. This major transect extends from a point near the summit of Puu Pua'i for a distance of 4800 feet, 200 degrees west of south, to a high point in the Kau Desert. It has been laid off in 15 meter sections, each marked with a wooden stake about four inches above ground. Four weather stations were located (Fig. 10), three at 2600 foot intervals along this line and a fourth in the crater of Kilauea Iki, itself.

These stations will provide data on meteorological phenomena occurring in the transitional zone between the leeward and windward climates. The transect has not been mapped; thus we do not know the floristic composition, distribution, devastation and vegetational recovery throughout its length.

Photo stations were established and near them bisects were made to ascertain methods of recovery; also photos were made of recovery in shelters such as tree molds, cracks, lee side of trees, tree holes (both dead and living trees), and similar habitats. Other vegetative manifestations such as aerial roots on Metrosideros, some over a meter long, have been photographed.

Four 5-by 5-meter quadrats were established on the southeast side of the cinder fallout area, about 500 feet from its periphery. These, when suitably mapped and checked every six to eight months, should reveal interesting aspects of early succession upon pumice, cinders and spatter substrata. These quadrats urgently need mapping and tests should be run on the pumice, cinders, and spatter for chemical, biotic, and moisture content. The primitive edaphic conditions prevailing now can tell us a lot about pioneer colonizers and their developing associations.

The pumice and cinder field (the area of pyroclastic material fallout) for the plant ecologist is unique because of its geologic composition and geographical position (bisected by a rain shadow). Here both leeward and windward climates are manifested at an elevation of approximately 4000 feet.

In 1960, the photo stations established throughout the area allowed some means of recording vegetative recovery and succession. While these photographs have been very useful in depicting recovery of trees and shrubs (especially their foliage), they are inadequate in recording pioneer colonizers and association. Also they do not permit a quantitative analysis of the life forms present, seral composition, or of populations appearing on tree boles and in tree molds.

The most remarkable aspect of the devastation, plant recovery and succession is that being exhibited by ohia, Metrosideros. Nearly 100% of these mesophytes were killed within 2500 feet downwind (southwest) from the main vent by heat, excoriation, pumice and spatter deposition. Starting at about 75 inches of deposition (downwind), the first survivors appeared and became more numerous toward the southwest as pumice deposition decreased. In the area of complete devastation, Metrosideros seedlings were found growing in the protection of tree molds and at the leeward base of dead trees. Outside the area of complete devastation, sprouts from trunks of covered trees have pushed through the pumice.

Field inspection of each photo station quadrant shows a high number of exotic plants present. At Station #1 of line #1 the lists prepared show over 75% of the pioneer colonizers to be exotic plants. It is difficult to establish which species or taxon first appeared. While the early establishment of photo stations was most desirable, much valuable information was lost by not placing quadrats in each photo quadrant. However, part of the developing sere may be seen at Station #1, line #1 (along the boardwalk). Here Buddleja asiatica, Nephrolepis cordifolia and Rubus rosaefolius, dominated among the initial colonizers. These are (in 1963) being replaced by Setaria geniculata, Paspalum conjugatum, Cyperus rotundus and Holcus lanatus. Following this association endemic and indigenous species appear such as Cibotium chamissoi, Astelia menzessiana, and recovering Metrosideros collina, var. polymorpha.

The pumice and cinder field is revealing many interesting phases of vegetative recovery and succession. More attention has been given to this area than the crater floor. Spatter pumice and cinders, either by physical nature or location, are helping to create numerous habitats, along with tree molds and lee side of dead trees. Remarkable "migration" of some species, though there may be some question as to ecesis, has been made to spatter areas and to those places of low cinder deposition. Most plants appearing on the former substratum have developed from dispersed disseminules. While on the latter buried rooting systems have pushed stems through several inches of cinders and pumice and formed low-lying shrubs. The distribution appears go be correlated with precipitation and the physical nature of the substratum.

Most of the pioneer colonizers (from seed) are exotic types, and along the boardwalk they appear in great quantity. Most represent the families Compositae, Rosaceae, and Gramineae. Analyses of photo quadrants tends to show some of the exotic plants being replaced by endemic and indigenous species.

Ohia (Metrosideros collina var. polymorpha) exhibits some very interesting aspects of recovery and reestablishment. Most noticeable are that branches and branchlets appear on the lee side of devastated trees, while their windward side remains bare. On a few trees all of the conductive tissue was destroyed on the windward side by flying pumice and cinders, thus leaving narrow strips of conductive tissue on the lee side. The majority of recovering trees were not greatly excoriated on their windward side. But their buds were killed there or reduced in number by the blasting by hot cinders, severe desiccation by superheated air, or a combination of these and other physical factors perhaps such as acid or gases.

Ohia trees, approximately 2400 feet (downwind) from the main vent, were stripped of their branches but buds remained alive in the bark. These have given rise to numerous foliated branches that give the trees a fuzzy appearance.

Manifestations of the devastation wrought, especially on live branches on the lee side of trees, tell a story of prevailing trade winds carrying lava from the fountain southwestward.

In areas where burial was 100 inches or more it appears all conductive tissue was destroyed above ground by heat and excoriation. In all probability the rooting system remained alive for an extended period, but died later because of lack of food since there were no leaves.

This hypothesis is supported by one large tree that produced a few leaves on its lee side one year after the eruption. During the following year all the leaves disappeared and since then none has reappeared. It is reasonable to assume that these few leaves were unable to manufacture the amount of food needed.

Some young ohias were completely destroyed above ground; however, the rooting systems apparently were not injured. In several areas the underground parts have pushed stems through four to ten inches of pumice and produced shrubs two to three feet high.

It was reported that within one to two years after the eruption the recovering trees produced a profuse bloom of lehua blossoms. Apparently this indicates more energy available for flower development. Horticulturists often produce a profusion of blooms on shrubs by pruning twigs and branches, a process carried out by the eruption in this case. It is interesting to note that these numerous blooms produced a copious supply of seeds that became dispersed presumably throughout the devastated area.

Most of the seeds that have germinated seem to be in sheltered places and at present appear to have become established.

Another interesting adaptive ability of Metrosideros, after devastation, was the development of aerial roots. Several of these reddish woody appendages have been seen to have taken root. Most of them hang one to two feet from the trunks or limbs and, in allover appearance, resemble witches'-broom formations. By observing trees within and outside the devastated area, it is evident Metrosideros is more likely to develop these appendages after some type of injury. Those trees surviving the devastation exhibit more aerial roots than those outside the fallout area. It is difficult not to believe that these aerial roots are not performing the vital functions of absorption normal to aerial roots. However, Rock (1917) believes their presence is due to "a law of heredity, the reverting to, or the producing of certain characters peculiar to the ancestor." He bases this on observing Metrosideros possessing aerial root in both mesic and xeric habitats.

The dead as well as the live ohia is important to the ecesis of many taxa. Their leeward sides provide suitable habitats for cryptogams and flowering plants. Their presence produces numerous microclimate conditions conducive to germination of seeds and spores, as well as guarding against desiccation and dislodgement by the prevailing trade winds. These microclimatic conditions are also manifest beneath and along side fallen branches and trunks.

At present the sheltered areas are occupied by blackberry (Rubus penetrans), butterfly weed (Buddleja asiatica), hino-hana (Erechtites valerianifolia), pamakani (Eupatorium riparium), sedge, kaluha (Cyperus brevifolius), sword fern (Nephrolepis exaltata), kupaoa (Railliardia scabra), and several mosses and lichens. While their ecesis may be questioned, the ability of these forms to live but a short period will definitely influence the substratum. All but two of the above mentioned are exotics. Certainly these foreign species have their place in the allover plant succession.

On the moist windward side of one dead ohia, near the boardwalk and within 1500 feet of the vent, a colony of snails was located. They tend to put in their appearance during long periods of rain or when suitable moisture is available. Spiders are found on many trees but more often in tree molds.

Absence of fungi throughout the area may indicate high quantities of acid gases at one time. Some fungi are quite susceptible to sulfur poisoning. However, on a dead Acacia koa, about 1200 feet downwind from the main vent, a Basidomycete, Schizophyllum commune, was growing. This fungus is common in temperate regions of the United States.

Phanerophytes are the most obvious of all plant forms appearing since the eruption. The majority of these woody forms are developing from old rooting systems not destroyed by the eruptive events. Their recovery is dramatic especially when the 1- and 3-year differences are compared in photographs. Bisects made approximately 5000 feet from the main vent show that Styphelia tameiameiae, Dodonea viscosa, Vaccinium reticulatum, and Railliardia laxiflora have pushed their stems through four to six inches of pumice. Today, some of these shrubs are over 10 decimeters high.

Most herbaceous plants have developed from seeds. Dissemules dispersed to the lee of trees or into mats of ground runners (Coprosma ernodioides and Commelina diffusa) have found conditions favorable for establishment and in most places it appears that such migrations have been successful.

Some of the leeward spots are colonized by therophytes such as Sonchus oleraceous and Erechtites valerianifolia. Perennials such as Tritonia crocosmaeflora and several grasses have survived from root stocks buried under three to four inches of pumice. It is again interesting to note that most all types of live forms exhibiting recovery from old rooting systems, bulbs, etc., are phanerophytes, hemicryptophytes or ceophytes. Most of the pioneer colonizers fall among the therophytes and chamaephytes.

Some Rubus plants, on spatter substratum, have developed very dark green leaves which probably indicates a copious supply of nitrogen. This is a weak assumption since most vegetation on young volcanic soil looks "nitrogen poor." Is it possible that the dark green condition is attributable to a dense population of bacteria and a related availability of nitrogen? The great sterility of spatter substratum, produced by extremely high temperatures at the time of ash fall, may have favored high bacterial densities prior to the entry of controlling predators. However, no bacterial counts have been made of the spatter to support this hypothesis.

3- SUCCESSION ON NEW SURFACES

By Garrett Smathers

Two principal categories of surface were formed by the 1959-60 Kilauea Iki eruption. These are the consolidated lava surface flooring of Kilauea Iki and the ash or cinder forming Puu Pua'i and the soil cover nearby. For comparative purposes, studies of both the new floors of Kilauca Iki and the nearby similar crater Keanakekoi have been undertaken.

On the floor of Kilauea Iki Crater four transects and 10 quadrats have been established to record and keep check on plant succession. Primarily the quadrats have been located in such a manner as to give proper perspective of recovery determined by physiographic and climatic influences. However, other habitat determining factors, such as substratum and biotic effects, have not been overlooked.

Each quadrat is one meter square, and it has been mapped for every square decimeter. Care was taken to locate the quadrats in respect to cracks and crevices, microphysiographic features that provide a variety of exposures and shelters. Under these conditions some knowledge should be obtained to help correlate early plant forms with insolation, evaporation, air and substratum temperatures. It is now hoped that the remapping of each quadrat every six to eight months will be continued.

To expedite location of quadrats, they were placed on transects related to the present position of the U.S.G.S. rain gauge. The four corners of each quadrat were marked with a spot of yellow paint about two inches in diameter. A map of the crater floor was prepared, and on it the transects and quadrats have been located.

Keanakakoi Crater floor was selected as the control area for seral comparisons. The flora on the floor of this crater now exhibits a composition and in distribution what may appear at a later state in succession on the new floor of Kilauea Iki. It is most interesting to notice the cracks and periphery of this crater floor already lined with ohia and other woody plants. This population is similar to that destroyed by the lava now covering the floor of Kilauea Iki.

The most interesting aspect of the new Kilauea Iki Crater floor is its physiographic significance. As a type of land form this crater, like many others, may play a very important part in the distribution and development of some Hawaiian floral elements. The opportunity for isolation of a taxon and center of dispersal of its disseminules makes these habitats important. Kilauea Iki evidences numerous microclimates, and in no way do they represent to any great extent the local climate. The yet-continuing downward sinking of the floor creates new and various habitats in new cracks and crevices. Many of these have come to shelter mosses and ferns. The sword fern (Nephrolepis cordata) is now found on northern exposed cracks where favorable microhabitat conditions apparently prevail. These latter conditions vary tremendously with the degree of isolation. Several mosses have been collected. In one crack with a northeast exposure, on the northeast side of the crater floor, a spermatophyte (Lythrum maritimum) germinated and survived for a season. Its success is partially attributed to dust and bits of organic materials, dead parts of plants, etc., that were blown by the wind into the crater and later became lodged in vesicles and recesses of the lava cracks.

Ferns and mosses are exhibiting an indicator manifestation. In some places observed, only on the reddish ferric oxide rich part of the lava strata do these early colonizers appear in great numbers.

Since most of the cryptogams are found on northwest to southeast exposed cracks, insolation must be the primary determining climatic factor. However, on the islands or large blocks of lava rising above the crater floor and the crater periphery, these pioneers may be found on all quadrats. A variety of shelter is produced by the numerous cracks, crevices and shelves.

Yet, this is not the complete story because the temperature of air and the surface, the chemical content of the different lava strata, the biotic and moisture content of dust filled vesicles, and other important factors have not been explored. One would think that primary succession characteristics of a xerosere would be exhibited. But such is not the case in every lithosere. One would expect lichens to be the first colonizers followed closely by mosses and other cryptogams. In all quadrats these forms have appeared first or simultaneously with mosses. However, very few lichens have been observed. Probably the vesicles in the lava account for this advanced seral; i.e., they are analogous to lichens in collecting and holding moisture, dust, and disseminules. Winds blow in all directions on the crater floor, thus insuring even distribution of any disseminules that find their way into the crater. While there is no supporting data present, these winds can be very dry, thus causing great desiccation and killing or damaging most plant life present.

Unlike the steam cracks elsewhere throughout Kilauea's summit area, those on the floor of Kilauea Iki fail to provide suitable habitats for plants. It is suspected that the vapors are still too acid to allow even the most physiologically tolerant cryptogams to invade or take hold. The deposition of sulfur and acid salts at these openings lends support to this hypothesis.

The U.S.G.S. has maintained a rain gauge on the crater floor (Number 1 of Fig. 10) since April of 1960. While the data collected (Chapter III, Table VI) may be reliable for some purposes, its use for biological work is highly questionable. It is imperative that maintenance of this gauge must become part of the project. Knowing the annual precipitation of this area is the heart of the research. Without this information vegetative recovery and soil development cannot be correlated with climatic phenomena.

The floor of Kilauea Iki Crater possesses a hostile climate, and only hardy cryptogams have been able to colonize to any extent. It is an area of high air and surface temperatures, extreme evaporation, and very strong light intensities. In many respects it is like a desert climate, though subject to greater fluctuations. The ferns and mosses exhibit a distribution that correlates with their physiological tolerance to the harsh climatic conditions.

In all probability, as previously pointed out, recovery will not entirely follow the xeric to mesic succession pattern because of the small amounts of organic and inorganic debris collecting in cracks and crevices. These shelters can retain their moisture over an extended period and could become suitable habitats for higher plant life, such as ohia (Metrosideros) and other woody and herbaceous plants. Once established these pioneers will further modify habitat conditions and act as centers of dispersal for disseminules. The floor of Keanakakoi Crater, in part, reveals such a sequence. There Metrosideros and other woody plants have lined the cracks and crevices forming a mosaic of vegetation upon the crater floor.

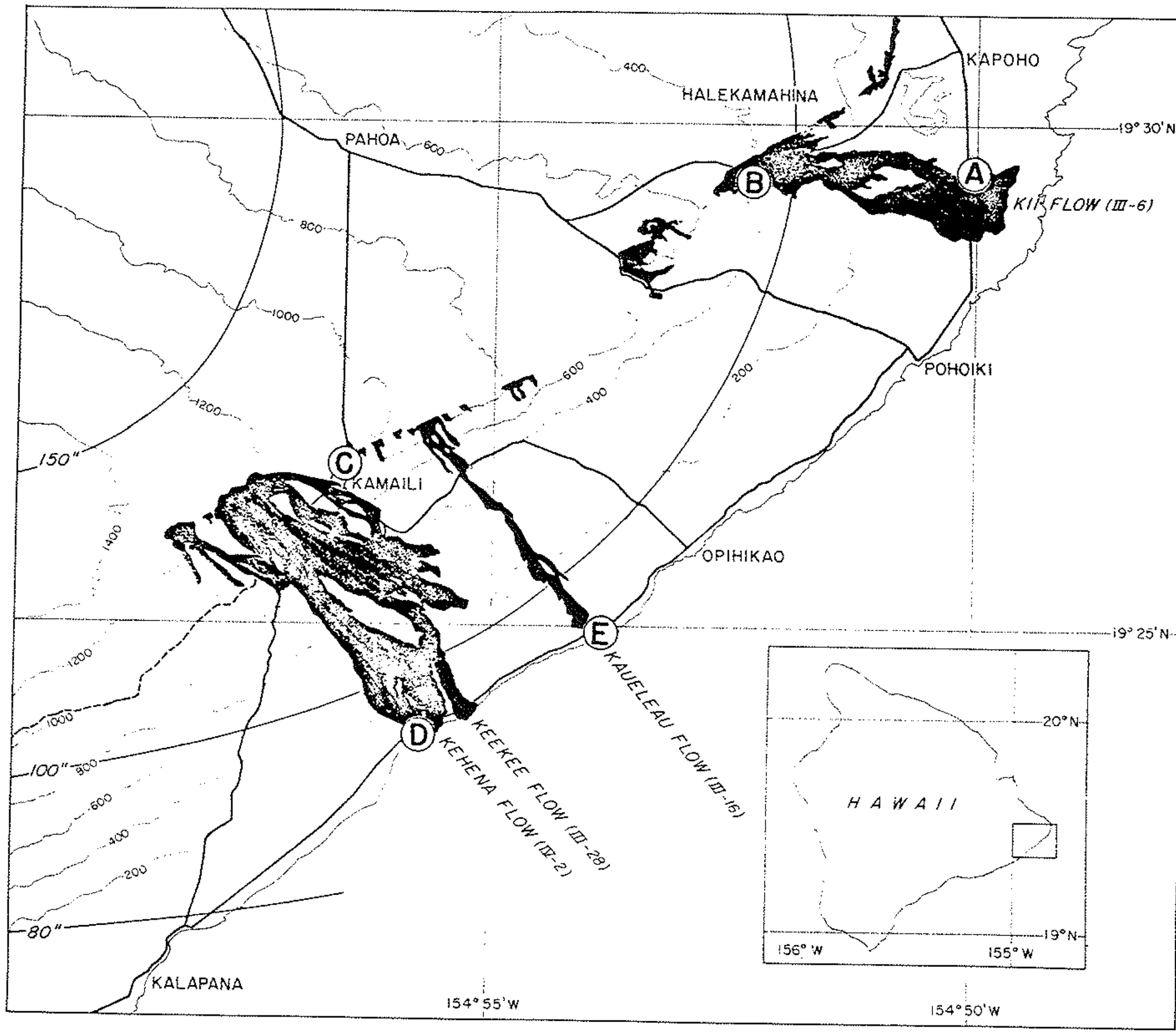
Plant succession on the floor of Kilauea Iki Crater is occurring in the shelter of cracks and crevices. Though this area receives about 73 inches of rain annually, plant distribution is characterized by other climatic factors such as high insolation and the latter in time effecting microhabitat conditions such as moisture and heat. The dark color of the lava substratum also adds to the degree of insolation.

E- THE WETTER LOWLAND VEGETATIONS

Expecting a flow in the Park to extend to the lower elevations sometime in the future, this information from just outside the Park (Fig. 24) is included here for reference to give the reader some orientation as to the nature of the floras that would be removed, covered or passed through by such lava flows. Two are described here cursorily. They are the near-shore forest and that at the 900 foot elevation studied in reference to the 1955 flows. The 1955 flows cover prehistoric lavas that are, nearby, rather uniformly populated, at least qualitatively, regardless of age. That is to say, while it is obvious in many places that one is at the edge of a younger flow where it has passed over an older flow, at such a place there is no marked vegetational change. For the present purposes, which are noting the first steps leading toward the climaxes (i.e., in the sense of their being stable communities) in these different regions, two pairs of adjacent prehistoric and 1955 flows, considered to be uniform in respect to climate, were studied. The prehistoric vegetations are taken up first and then (in the next section F) the 1955 surfaces.

1- The prehistoric lowland forested surfaces alongside the Kii lava flow ("A" in Fig. 24) about 100 meters upwind from the related study sites on 1955 lava is predominated by Metrosideros collina (ohia) running about 6 meters tall and averaging one for every 2.5 square meters of forest floor. The elevation is about 90 meters. The frequency distribution of diameters is given in Figure 25. Elsewhere in the islands this species is not often found at such low elevations. Here it commonly extends to the coastline or about to the 15-meter (50-foot) elevation contour. Perhaps every tenth tree

Fig. 24. Map of the 1955 'a flow just to the east of the Park and on which population events have been followed at the sites labeled A-D. The times indicated at the seaward ends of the major flows are the day the flow stopped moving at its seaward end.



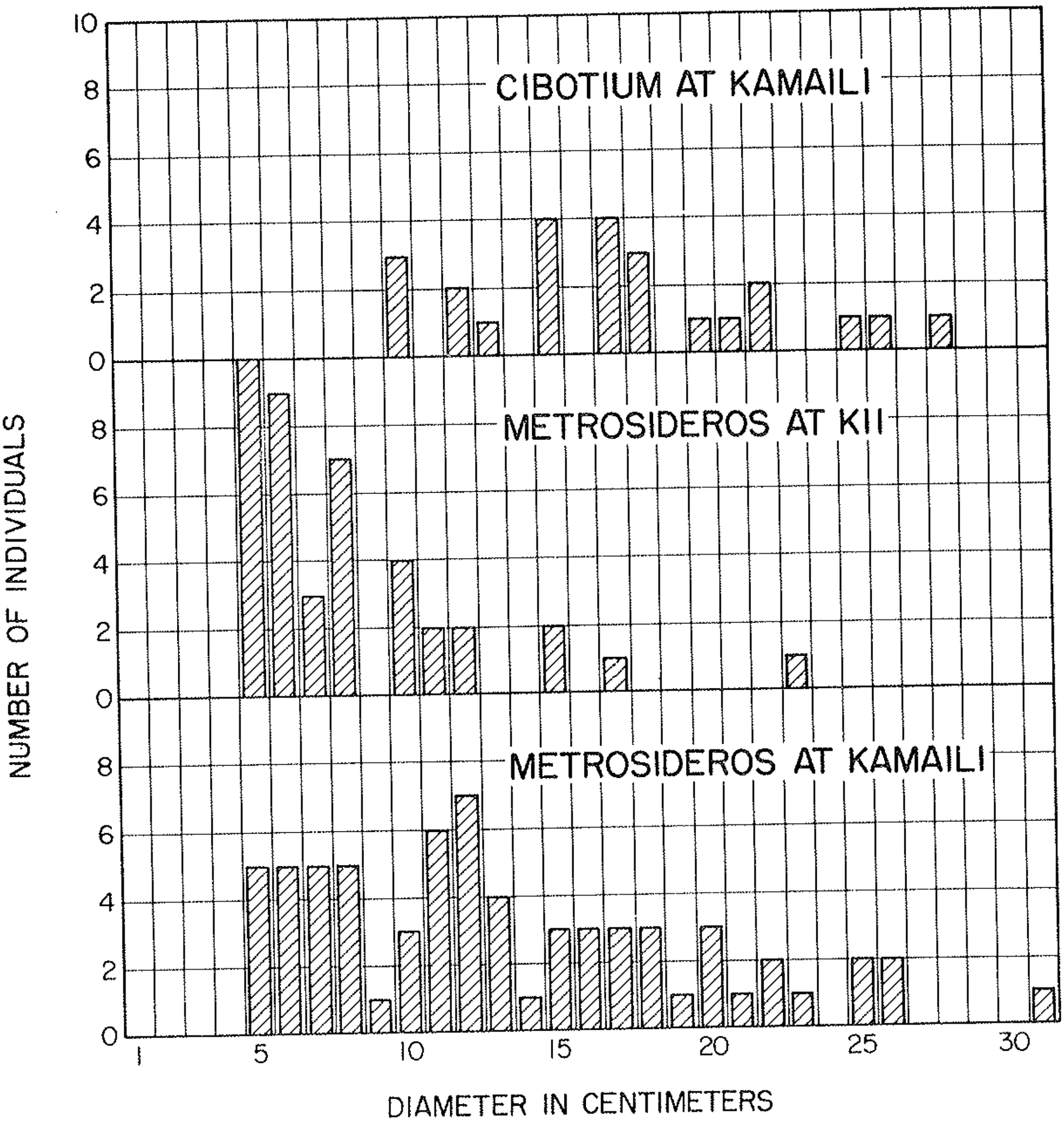


Fig. 25. Histogram to show frequency distribution of trees of different diameters in "control" areas for the Kamaili and Kii study sites on the 1955 lava flows.

is Rhus chinensis var. sandvicensis or Diospyros ferrea, but any other tree is unusual. Every 60 meters or so one can expect to see a spindly seedling of Morinda citrifolia with very broad leaves and perhaps fruiting. A very few guavas, Psidium guajava, and also strawberry guava, Psidium cattleianum, have appeared in the area and near the road mangoes, Mangifera indica. Overhead the forest is perhaps 50 per cent open.

Plants that are secondary in size in the form of shrubs or bushes are not particularly common, and when present are usually small forms of the above species, with the exception that there are but few small plants of ohia. One of the most common shrubs is a species of Wikstroemia and small forms of the above endemic Rhus. There is a small acacia, Cassia leschenaultiana, that is woody but of herb size. An occasional woody bushy plant of Lantana camara can be found.

There are a number of vines which are for the most part herbaceous. Running into the tops of the trees is Cassytha filiformis and climbing on this or on other vegetation are occasional plants of Passiflora foetida and Cocculus ferrandianus.

The herbs with the lichens and mosses cover some ninety per cent of the forest floor on some older pahoehoe areas, but perhaps only 15 per cent of the forest floor in the youngest prehistoric a'a areas. The fern Nephrolepis exaltata is predominant among the herbs. The grass (Paspalum), Stachytarpheta cayennensis, Psilotum nudum, which is often on trees as is Nephrolepis, and the orchid, Spathoglottis plicata, make up about ninety per cent of the remaining herbaceous cover. Here and there other plants, e.g., Peperomia leptostachya or Fimbristylis pycnoephala, are common. They are usually localized in areas a meter or two across or restricted to a ledge or fold in the lava, otherwise they are but occasional isolated plants, as were the scant half dozen thalli seen of the fern, Sadleria cyatheoides.

The tops of the lava chunks otherwise barren of vegetation are for the most part covered with Campylopus exasperatus[3/]. On the rather vertical sides of rocks not covered by higher forms of vegetation such lichens as Cladonia didyma are common. Below these uppermost surfaces occur a number of bryophytes, e.g., Rhacopilum cuspidigerum, Brachiolejeunea sandvicensis and Frullania meyeniana. The latter two occur on trees as well but usually only near the ground. On occasion Weisia viridula and Bryum megalostegium had developed in small heavily shaded upward-facing rock concavities at least three decimeters below the normal ground level. These concavities had in them, beneath the small moss patches, a few millimeters of simple soil. Other bryophytes and lichens are abundant above the ground on the trees. Stereocaulon does not seem to be present.

2- The prehistoric higher-level forested surface studied at Kamaili ("C" in Fig. 24) is not greatly different from that at Kii, other than in degree. The elevation is about 290 meters. The same Metrosideros collina is the dominant tree, quite to the exclusion of others. The individuals are a little more closely spaced (one per 1.5 m^2) than on the older of the two prehistoric flows at Kii. Also at Kamaili they are larger (Fig. 25), often 20 to 35 cm in diameter, breast high, and 12 to 18 meters tall. In a stand nearby occasional specimens were estimated to be 30 meters tall. The forest is nearly closed over above.

[3/] We wish to express our appreciation to Dr. H. A. Miller, who repeatedly assisted us by identifying the bryophytes, and Dr. I. MacKenzie Lamb, who identified the species of Stereocaulon.

At the bush level the space is occupied mostly by Cibotium chamissoi Kaulf., there being about one for each 4 m^2 of forest floor. Though this is a low elevation for this species, it was assumed to be this species for there were stiff blackened prickles on the leaf bases rather than the soft hair, the pulu of C. splendens (Gaud.) Krajina, the common lowland species. It is a low elevation for Metrosideros, too. The trunks of the tree ferns were often 1.25 meters tall with the fronds reaching up another 1.5 meters. Figure 25 shows the distribution of trunk diameters. Guava, Psidium guajava, was the next most frequent small tree or large bush. There were some woody plants of other species up to a meter tall, but these merge into the herbaceous cover on the ground. Of the herbaceous plants on the ground Stachytarpheta cayennensis, Oplismenus hirtellus, a Cyperus sp., probably one of the many forms of the common Cyperus compressus, and the weedy orchid, Spathoglottis plicata, were the prevailing cover along with several grasses and other herbs, including Erechtites valisneriafolia, that were not conspicuous.

The above-mentioned Cyperus was much less conspicuous here than was Fimbristylis at the lowest elevations at Kii. Nephrolepis exaltata and Psilotum nudum were absent and there were none of the rock lichen or moss genera so common at lower elevations to be seen. However, Table V, other genera of mosses and lichens were abundant. No bare rock shows. There was no decomposed rock soil cover but the surface was thoroughly covered with not only the flowering plants but as well by an abundance of the bryophytes (Table V) and a number of small ferns, such as Polypodium lineare.

It is to be noted that where roads have been built through this type of forest the roadsides are usually lined with a dense stand of Nephrolepis exaltata though it may be quite absent in the woods away from this edge

Table V. List of bryophytes found in order of their abundance in the forest at 950 feet elevation adjacent to the Kamaili study area.

Rhizogonium spiniforme	Frullania apiculata
Leucobryum gracile	Odontoschisma cf. sandvicensis
Acroporium fusco-flavum	Brachiolejeunea sandvicensis
Bazzania didericiana	Anastrophyllum esenbeckii
Cephalozia sandvicensis	Radula cordata
Bazzania brighami	

effect. In some places what is taken to be the Cyperus mentioned above dominates the scene rather than the Nephrolepis.

F- POPULATION DEVELOPMENT ON THE LOWLAND 1955-LAVA FLOWS

After preliminary warnings the 1955 eruption began at 08:00 on February 28 (Macdonald & Eaton, 1955) some 5 kilometers (Fig. 19) directly north of Opihikao. The village of Kapoho was evacuated as the eruption extending via cracks opening successively seaward and down the rift zone began exuding lava toward it. As Macdonald describes the event in his detailed account (1959) "efforts to remove all reasonably moveable property" were made. While the village, ultimately, was not destroyed until the 1961 eruption, an immense amount of material was extruded, at times at such rates as 450,000 cubic meters per hour. In all, perhaps 108 x 10^6 cubic meters of material were extruded.

At various intervals during the following month in different places this molten rock flowed down toward the shore, (Fig. 24) reaching it independently in three places (Kaueleau, Keekee and Kehena); two of these coalesced later in part. A fourth flow (Kii) did not quite reach the sea. The extent of these is illustrated in Figure 24 as well as the dates when they are accepted as having become stable surfaces.

About one month after the flows had cooled, a study of several areas was initiated ("A" through "E" of Fig. 24) and continued for ten years through March, 1965. At first, studies of these areas were made at about 2-month intervals. With each visit both quantitative and qualitative observations were made or attempted. Macdonald & Katsura have published studies revealing the rather similar chemical compositions of these flows, and in 1959 Macdonald noted that the entry into and cooling of the lavas in sea water did not alter their chemical nature measurably. Thus, essentially, a set of chemically uniform surfaces of the same age formed the study sites.

The observations inland away from the shoreline were largely to provide a record of what happens up to the four year old stages studied by Skottsberg (1941). Three elevations (Fig. 24) were investigated on dry land initially: "C" 290 meters at Kamaili near Iilewa; "B" about 108 meters at Halekamahina near Kapoho; and "A" at about 90 meters on the Kii flow. These sites have rainfalls (Figs. 11 & 12) estimated, respectively, at 3750 mm, 2500 mm and 2000 mm per year. The temperatures are less well known but the near-ground free air temperatures probably do not vary often as much as 6 degrees from 25 degrees C in vegetated areas. Other factors influencing the biological events observed on these very young 1955 flows are described below.

The area at Kamaili near Iilewa ("C" in Fig. 24) is on the lava of vent area "R" of Macdonald (See his Figs. 12, etc., 1959). Macdonald's illustrations, (See his plates 10-15, 1959) are from a remarkable series of photographs he made before the crack which opened began issuing lava. These illustrations show not only the cucumber plants but the native forests both of which were destroyed as the lava outflow continued. During days after rains there was a great deal of steam in the air during the first two years of this study. This area has Metrosideros forest within about a hundred meters of three sides. This forest was described, above, as the "higher forest." The other two areas have no such moistening influences nearby. For example, the Halekamahina area ("B" in Fig. 24) is 300 meters from the surrounding sugar cane fields, and the Kii area ("A" in Fig. 24) is about 100 meters in the upwind direction, from the Metrosideros forest described, above, as the "lowland forest." In other directions the Kamaili study area is separated by 100 meters and the other two by at least 4-tenths of a kilometer of the same lava flow from the forests and fields, the normal sources of populants.

At the lowest elevation ("A" in Fig. 24) nothing was observed until March, very nearly one year after the flow had ceased moving. At this time along the 99-foot (30.4 meter) base of the Kii area, at least 6 mossy spots were found. In every case the moss area was sharply restricted to one rock even though adjacent rocks were in contact. This moss though immature was just becoming fertile. It appeared to be *Campylopus densifolius*. One of the mossy areas was irregularly about 3 decimeters square. In none of these areas was any spermatophyte seen.

These observations raise three issues. It seems unlikely or even incredible that a microscopic base for colonies 15 to 25 cm across would grow or that such colonies could grow macroscopically to this size in the time between studies; thus, one is led to expect that such colonies arise from a number of disseminules rather than one. The different moss colonies are often ten meters apart. A rock bearing mosses often may bear ten plants per five square centimeters. If these arose from separate disseminules, then by chance, the rocks between those bearing macroscopic mosses must also have caught disseminules. Each plant appears to be an independent, erect individual having no relation to others that could be distinguished with the magnification afforded by the 20x lenses of a dissecting microscope. This leads to the second question and that is, how does it happen that some chunks of surface clinker and not others have moss colonies on them? The chemical differences (Macdonald, 1955; Macdonald & Katsura, 1964) between such clinkers are insignificant insofar as analyzed. The water-holding properties do not seem to differ significantly. A third enigma here is that there is no increase in the frequency of moss colonies with nearness to the forest on the windward side of the flow. In fact, the frequency of colonies fall off when investigated at different times during the first three years of the study. Only one Campylopus, the different species Campylopus exasperatus, was found in the edge of the forest, where this species and four other bryophytes cover a major portion of the old lava and near-ground tree surfaces.

Around steam vents, now inactive, the undersides of some lava cinders were densely green with a coating of an unicellular green alga, which for convenience we call here Chlorococcum humicola. In order to determine whether there was an increase with time in the amount of greenness on the undersides of rocks near the inactive steam vents, a special search was made on July 27, 1956, and September, 1960. There seemed to be no increase in density of these populations; in fact, there were no visible populations below the surface elsewhere on the flow such as those of algae described by Newhouse (1954; 46) and Doty (1954; 17) from atoll island surfaces where moisture conditions must be equally severe. These early green algal populations were on sky-facing surfaces, and they became progressively less conspicuous as the years passed and were no longer visible in 1960.

Some fourteen to sixteen months (July, 1956) from the time of cooling, two widely separated "1.5 by 1.5 meter" boulders were found from the overhanging under surfaces of which were growing ferns. These few sterile fronds were apparently of the common Nephrolepis exaltata. The largest were perhaps 7.5 cm tall but by far the most were about 2 to 3 cm tall. There were many dead dried fronds of these smaller sizes. By November 10, 1956, a few of these Nephrolepis thalli were fertile.

From one of the overhanging surfaces just described there were collected at the same time moss thalli and small bits of greyish-green hard gel. The gel appeared to be a mixture of fungus filaments with Palmogloea protuberans. Moss thalli were wide-spread and identified as juvenile Campylopus. Still there were no evidences of spermatophytes appearing on the study area or other 1955 flow surfaces at this elevation.

An increase in the conspicuousness of algal and moss colonies on the individual rocks was recorded up to November, 1956. The occurrence of these colonies was so irregular, easy to overlook, and infrequent that any count in the study area seemed ridiculous. While the moss colonies were more conspicuous, they seemed to be so through increased density rather than height of thalli or color change. Except near disturbed areas and right at the edges of the flows, a moss colony could perhaps be found in any ten to twenty meters traversed. In December, 1959, only one moss colony could be found. This colony was but a trace of the largest observed several times before, and the thalli were but little more developed, if at all. Many colonies were found in September, 1960. The thalli were of the same size as before, but perhaps the colonies were smaller in diameter. In March, 1965, fewer thalli were present and it is presumed the variation during the past few years is fluctuation rather than periodic or seral change.

The Halekamahina study area at the middle elevation ("B" in Fig. 24), near Kapoho, was first visited in August, 1955, some three months after the lava surface had cooled. At this time there were in evidence a very few dicotyledonous seedlings, estimated at 0.75 per square meter. These were in the folds of blister surfaces and absent on the superficial surfaces of the very rough a'a and loose cinders.

Unfortunately, between the time of the laying out of the transect and the second visit in December, 1955, a road was built right alongside the previously remote study area. Only one small dicotyledonous seedling was seen on the whole study area and nothing else, e.g., there were no mosses, ferns or algae to be seen. However, along the opposite side of the new road there were 4 similar seedlings in one particular square meter area. None of these seedlings was sufficiently large to be identified, most of them being 0.5 to 1.0 cm in their greatest dimension. By March, and in July, 1956, no seedlings could be found anywhere here. While no algae or mosses were to be seen on the undisturbed surfaces or on down-facing surfaces, in crevices there were areas where many small fern thalli could be counted. These ferns in July had become larger but many had become noticeably pale in color.

In November of 1956 ferns had become abundant as small sporophytic thalli on almost all of the red partially-shaded cracked surfaces below the general flow level. Nothing was to be seen growing either on the cinder beds or on the undisturbed blister area, with the exception of ten tiny dicotyledonous seedlings in a deep crack in one blister surface. Some few mosses, a Cyperus, and a few dicotyledonous seedlings were seen on disturbed blister material near the road.

Yearly into 1965 Nephrolepis has been progressively less evident. Since December, 1958, such as the following have grown on the site: Plumeria, Musa, Vanda, Aleurites, Drymaria, Emilia, Pipturus, Nicotiana, Canavalia, Leucaena, Pueraria and Cyperus compressus. Various plantings have been made since then in this disturbed area, and thus attempting to observe natural events in this area was discontinued.

The casual observation was made at the Kamaili site that after sitting on the sun-warmed dry rocks, one would find cameras and notebooks and pants wet on the underside. Furthermore, the undersurfaces of cave rooves were usually dripping water[4/] though perhaps only 6 to 15 cm thick and warm and dry on the upper surface. This seems to indicate the rock porosity is such that the rain water is both caught in abundance and runs through without most of it being held by capillarity. Several large gas vents were formed near this middle elevation study area at Halekamahina when the flows were active. These produced steam each time there was rain during the first year or two of the observation period. As time went on steaming was less frequent and finally steam was to be seen only after periods of very heavy rain.

Apparently the heat in a new lava bed, at least, at first prevents the water from percolating through and becoming lost to the pioneer colonizers. One would expect that ordinarily the water is driven to the surface so slowly that when the sun is out and the humidity low, e.g., only 60 to 75 per cent, the vapor is not noticeable and most of the vapor condenses in the rock, and the water not held by capillarity percolates back down again to the hot lava. At first even a light rain with its accompanying high humidity brings clouds of water vapor to the observer's attention. With time the effect is less and the depth to rock as hot as 100° C greater.

While the hot rock may repeatedly redistill the water and this may promote the more rapid transfer of heat toward the surface, clouds of water vapor arising from the surface come to notice only when the humidity is high and there has been enough rain either to fill much of the rock to field capacity above the hot layer leaving little space in which the vapors

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[4/] Such drippings collected in leaves and shells were a major source of drinking water for the Polynesians in this district.

can expand, cool and condense or enough rain to provide more steam than there is space for it in the rock.[5/] Water especially from light showers must be merely recycled repeatedly, but when the flow cools throughout to temperatures below 100°C., then the rainwater in excess of field capacity would percolate through to the fresh water lens or any existing water table below, and perhaps be lost to the pioneer plants on the surface.

Thus, while at first there is water enough for plants on the relatively barren surface and pioneer colonizers are abundant, with time the surface is exposed to increasing dryness and to such an extent that quite possibly such plants as the Erechtites, which was an early colonizer and shed seeds, could not persist or reproduce, especially during the rainless periods of two or three days to be expected (Fig. 8) about once a month. Such edaphic changes in water or chemical availability may act as screening mechanisms determining ecesis and, thus, separating mere pioneer colonizers from those pioneers that succeed themselves and form a pioneer community.

In the immediate vicinity of vents near Halekamahina, but not at all affecting the middle elevation study area ("B" of Fig. 24) at Halekamahina, the air and less so the rock surfaces were, thus, very humid, and it was here a pioneer community was first manifest on the 1955 flow. On the outer slopes of these vents ferns developed in the folds of some blisters to the stage where the primary sporophyte leaves were fully developed August 15,

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[5/] Another factor would be the steam driving the air out of the surface layers of the cooling flow and the re-entry of the air as the water vapor decreased, an aeration process that would be repeated to differing degrees with each greater or lesser wet period.

1955, four and a half months after volcanic activity had ceased. No mosses or other plants were in evidence there at that time. In July, 1956, this same fern, Nephrolepis exaltata, was an incomplete sward 30 cm tall and abundantly fertile. There were also present many patches of the moss Campylopus introflexus (Hedw.) Bridel. Since this time there have always been Nephrolepis thalli reproducing and in various stages of growth. Thus, we feel a community of ferns in simple form was established 14 months after the flow.

Further development has been along two lines actually followed in greater detail at the other two terrestrial elevations studied and, respectively, described above and below. These two lines are 1) toward more complete cover by the pioneer community to where there is in places a sward of fern except on the protruding rocks, and 2) the production of a more complicated community a) species-wise, b) with zonation or storying, but c) without the physical and perhaps close physiological interrelationships between the components to be found in a stable mature population such as found on the prehistoric flows.

The highest area elevationally, at Kamaili near Iilewa ("C" in Fig. 24), was first studied closely 9 months after the cessation of activities. At this time (December, 1955) a study area was laid out covering some of the same area as shown in Macdonald's (1959) Plate 15. In the restricted part of this Kamaili area selected for rather close observation, there were at this time 124 ferns and 21 dicotyledonous seedlings in 10 square meters. One seedling of Spathoglottis plicata Blume with three leaves was seen. No mosses or algae were seen in this study area, but in lava blister folds nearby and downhill on a random walk of perhaps a hundred meters, three dark green dense tufts of moss, Campylopus boswelli, with an undeterminable very juvenile leafy liverwort were seen and collected.

By February, 1956, the fern Nephrolepis exaltata was much larger but none of the thalli was fertile. There were only 3 flowering plants of Erechtites valisneriafolia left in the study area. Here and there, mostly in the crack-like folds of lava blisters, there were small low dense moss mats of the very common Campylopus densifolius Angstrom and a few algal spots.

In March, 1956, no new flowering plants or fern thalli were found, however, one fertile frond of Nephrolepis exaltata was collected. Mosses were much more in evidence and seemed to be entirely Campylopus densifolius, the same species appearing later on the lowest and driest study area. The only specimen of Erechtites valisneriafolia remaining was small but blooming. Other plants were flowering on the edge of the lava near the forest. The more conspicuous of these were Coleus blumei, Commelina diffusa Buym., Pluchea odorata and larger specimens of the same Erechtites. On the study area the one small felt-like algal patch found, turned out to be the nearly ubiquitous Scytonema hofmannii.

A visit here in May, 1956, revealed the disappearance of the last of the flowering plants from the study area, though they were covering over the edges of the flow nearby. There were fewer clusters of ferns. The individuals were larger and were producing sporangia. There was more moss and an abundance of what we took to be the same Scytonema hofmannii. At the time of this visit the rock surfaces even on that particularly dull and cloudy day were dry and warm to the hand. The Scytonema felt was, however, cool and sufficiently wet that water ran out of it when it was pressed with a finger.

In July of 1956 there were ten small seedlings taken to be of the same

Erechtites valisneriafolia in shaded (Temp. 26° C) blister folds. The same fern plants were larger than before and producing many prostrate rhizomes, some 20 cm long, as Holttum (1960) emphasizes as characteristic of Nephrolepis hirsutula and other Nephrolepis species. The Scytonema hofmannii on the broken blister edges had become differentiated in some places either into dark more gelatinous areas or into browner areas. The browner, as opposed to the dark, areas covered were of apparently more actively growing filaments with more hyaline sheaths.[6/] The sunny surface of the browner Scytonema was about 28.3° C, two degrees cooler than the non-algal covered surfaces adjacent. Campylopus exasperatus Bridel had spread and the thalli were much taller. Where water drips through the rooves of open blisters onto their floors gelatinous algal scums, largely mixtures of Scytonema hofmannii and Stichococcus subtilis, were found as well as green whefts of unidentifiable moss protonemata. There were also isolated branched strands of the moss Rhacopilum cuspidigerum (Schwaegr.) Mitt. on the floors of these small "blister caves."

In November, 1956, the Erechtites was all dead and, indeed, only a single dead stalk about 30 cm tall was to be found in the study area. The floor of the blister cave had a number of brown and blackish patches not unlike crusts of paint. These were taken to be the same Scytonema hofmannii

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[6/] The browner drier material had some fungi in the sheaths. Dr. Francis Drouet tells us this was not noticeable in the former collection from the same place. That this difference noted after 14 months might be incipient lichenization or, in view of their disappearance by November (see below in text), a suffering from fungus disease are appealing hypotheses.

collected before on the broken edges of the roof above. These broken edges were now populated by only the black form of colony first noted in July, 1956. Nephrolepis had become conspicuous, protruding above the general surface of the flow and lining the folds in the surface. However, few were over 10 cm tall and none of those in the small intensive study area was fertile. In a small kipuka about two meters across and 3 meters long near the study site, Colsus blumei Benth., Stachytarpheta cayennensis (L. Rich.) Vahl, Commelina diffusa Burm. and Pipturus brighamii Skotts. were blooming. In March, 1965, Pluchea odorata was blooming in this kipuka and there was no Coleus and little Commelina, as though the site were drier.

In the spring of 1962, seven years after the lava first covered this site, a restudy was made. At this time it was interesting to note the shifts away from the pioneer communities and the establishment of what we take to be the full development of the pioneer communities on the surface of the flow. The latter seems to be indicated by the appearance in some places of mature yellowish brown tufts of Campylopus exasperatus appearing as tufts dominating areas but a few centimeters across in the general field of grey Stereocaulon vulcani[3 & 7/] covering the flow surface. Secondary invaders were beginning to appear. Insofar as they were flowering plants they were the non-native orchids Arundina bambusifolia Lindl. and Spathoglottis plicata, or the native Metrosideros colina.

Metrosideros presents an interesting picture for while on the study area there were only small plants, perhaps 6 to 9 cm tall, unbranched and

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7/ Stereocaulon vulcani (Bory) Ach. is accepted as synonymous with S. flavireagens Guilnik.

with one plant visible per 9 square meters on the average, near the study area where there had been more disturbance of the lava a number of plants 20 to 30 cm tall were to be found. These larger plants almost all show dead shoots and some "runners" as well as "adventitious" shoots from the base; as though the tops had died back during unfavorable weather and the plants had shot up from a crown again during more favorable conditions. Indeed, most of the Metrosideros on the even drier regions along the shore in this area that seem young are, in essence, several irregular trunks arising from the ground level as though they had arisen from separate shoots engendered by a common base. We, thus, presume the small unbranched seedlings will die-back and sprout up from the base on the study site and give rise to such bushy trees as described.

This pioneer form should not be the unbranched tall form of tree that occupies the mature forest in the immediate vicinity of the Kamaili study area. Therefore, we assume that the original forest at the study area, removed by the lava flow or in the land clearing process, was of trees that had grown in soil formed from prehistoric lava and that they were not merely old trees formed under different climatic conditions, probably as secondary growth.

Interestingly enough on the study area and nearby the Nephrolepis similarly shows dead stalks as though it had died back from time to time. These stalks often 18 cm tall may, however, in the case of this fern represent merely the remains of fronds which were fertile and from which the pinnules were eventually shed. The living fronds in 1962 were often only about 12 cm tall and, thus, shorter than the dead stalks. Whether this indicates seasonality or a decline in the fern population, we cannot tell at this time.

While the first community to become established was algal and of Scytonema hofmannii, blackened areas of Stigonema eventually became conspicuous. Sometimes low dense coatings on the pahoehoe are formed among the podetia of the predominant surface organism, Sterocaulon vulcani, and formed so extensively that for areas a decimeter or so in extent, 30 to 50 per cent of the rock surface is black. This, it would seem, would be a replacement of the primary blue-green pioneer colonizer, Scytonema, by a secondary and morphologically more complex colonizer, Stigonema.

The hypothetical explanation that currently seems to fit these observations from all three areas is that there is seral development of a rather classical nature, with the addition that there are conspicuous early populants which may be ephemeral accidents. To put it briefly in more formal terms, there is colonization by a wide variety of forms but ecesis of only the cryptogams that come thus to establish the pioneer communities. For example, the dicotyledonous seedlings that first appeared on the Halekamahina tract were an ephemeral population as was Erechtites on the higher area. We would suppose that the substratum is unable to support these organisms except during exceptionally favorable conditions, largely of moisture.

Since these same organisms are common and consistently present on older surfaces, we must presume that the sere leads to conditions such that a population of them can live all the year around, reproduce and thus be recognizable as a community. It appears that the same accidents (perhaps wind, largely) deposit dissminules of both these flowering plants and the cryptogams. While the ferns appeared on wet areas early like the flowering plants, they, too, tended to drop out. However, some have matured under arches of rock where one would presume the evaporation was at a lower rate than on the open surface. The mosses, algae and especially the lichen, Stereocaulon, did not form obvious macroscopic growths so soon nor so often on surfaces exposed to wind and sun. With time these have been steadily increasing in prominence so that in the wettest places they cover the surface.

It would seem the first cryptogamic communities function in reducing surface temperatures and altering other conditions such as moisture and the chemistry of the substratum in such ways that the more advanced seral elements, for example the flowering plants, may come to form a secondary community rather than continue to be present as mere ephemerals.

It is to be noted that near the 460 meter elevation on the 1952 flows in South Kona a different moss, Rhacomitrium lanuginosum, and the tree Metrosideros collina became well established in addition to Nephrolepis within two years after the flow had ceased its movement. Perhaps the more rapid development in the South Kona district, a region having convectional showers, was due to the more regular occurrence of rain.

G- THE SEASIDE OR MARINE VEGETATIONS

Three situations from the rocks between the plant-covered areas along the shore and the open sea provide us with three categories of mature or climax habitat for descriptive and study purposes. A fourth category is the events in the development of these populations as they take place on new shores provided when a lava flow flows into the ocean. These we take up in turn below under these four titles:

(1) Littoral shores of the Park
  (a) The black zone
  (b) Marine caves
(2) Pools in the shores of the Park
(3) Intertidal shores of the Park
(4) Population development on new lava shores

Unfortunately, there has been little study of the organisms, the algae, that dominate these habitats nor of the communities themselves. For the Island of Oahu, a hundred and fifty miles away, beginnings have been made, but there are no studies published on algae for the Park area. The algae which dominate them belong for the most part to various botanical phyla, but to their serious modern students mostly they are not plants and botanists rarely recognize them. Of course,if one was brought up to believe in the dualistic system of good-bad, day-night, black-white, etc., there are only plants and animals. At that academic level these habitats are dominated by plants, but such strange plants. The Park does provide a splendid opportunity for algal study. Scientifically, it is almost an unknown area except for the preliminary surveys carried out in preparing this Atlas.

Though not in reference to the Park the marine ecological treatise edited by Hedgpeth (1957) would be the single publication of most use to a student of the ecology of this part of the Park. However knowing the marine algae would be an essential too, just as knowing the birds or insects would be an essential to studying them.

(1) Littoral shores of the Park

(a) The black zone is a community covering the occasionally wave-swept rocks and those kept free of soil by spray. In the rain or during prolonged high surf and spray periods, the black dry rocks take on a greenish sheen and may become very slick. The individuals in this community are inconspicuous and mocroscopic and in abundance usually appear black or grey when dry. Developed on the soil and sand which accumulates in low places among the rocks or just inshore of them this extensive community traces the shoreline on aerial photographs (*e.g.*, Aerial Photo 8-0024) with an irregular black line. Ideal places to study this community exist readily accessible to the Kalapana road at Kamoamoa and, as it is quite insensitive to rainfall, westward throughout Puna.

On less wave-swept rocks, but perhaps most developed in areas protected from erosion, Calothrix crustacea Thuret may develop so as to be the predominating member of the community. It can form a dense, usually greenish, layer of hair-tipped filaments on rocks and with or on other algae. This is a very widely distributed species on all sorts of littoral substrata. Sometimes it is difficult to distinguish it from the usually-coarser C. pilosa Harvey which forms mats of erect fascicles of filaments each of which terminates in a hemispherical cell. Fan (1956) has produced the most recent comprehensive taxonomic study of this genus; though the older work by Tilden (1910) is more often used.

Calothrix pilosa Thuret forms a felt of erect fascicles of filaments. While the dimensions are variable at their centers, the filaments are often about 20 microns in diameter. The trichomes within the sheaths, which together make up the filaments, are usually but little, if at all, tapered and many have a heterocyst at the middle. Since the heterocysts stick to the sheaths and are formed at irregular distances along the trichome, Scytonema-like branches are often found as a result of the force from growth in length pushing the trichome through the sheath material. This species has often been identified as a Scytonema for this reason. The felts may be a few millimeters thick and the individual fascicles of filaments visible to the naked eye. Within its gamut of habitats this alga largely comes to predominate where not exposed to the sun all day, even appearing in caves where it forms a dark bright green coating. C. pilosa is black when growing on directly sun-lit surfaces. Actually, under the microscope these colors can be seen to be the greenish color of the cytoplast masked by the color of the sheath which becomes beautifully golden. It is the presence of this color in the sheath that makes the filaments black to the naked eye. C. pilosa may appear a quarter of a mile inland from the shore as it does as an inhabitant of 10-year old 1955 lava surfaces at Kii to the east of the Park proper. At Kamoamoa, C. pilosa seems to be an ever less conspicuous element in the community inland to where it appears only occasionally on sand trapped in crevices with the first grass. It is, perhaps more than anything else, in the above habitat and as well as the morphology that this species is distinguished from C. crustacea.

A turf of Calothrix pilosa dominates some almost constantly wet, very-high tide rocks at Kamoamoa and is to be found at many places along the shores of the Park. It is common almost everywhere the sea's splash keeps the rocks wet except during calm weather and the lowest tide periods.

The seaward edge of the soil and sand caught in low places among the barren rocks is most often likely to be dominated by a mat of Microcoleus chthonoplastes (Mert.) Zanardini, as is any area which is exposed to strong desiccation by being immersed in sea water for a few days or exposed occasionally to strong sunlight for a few days between immersions in water. Drouet (1964) has published an excellently detailed study of the morphological variations, i.e., ecophenes, of this very widely distributed species. Actually the species is also reported from desert conditions where freezing and 125 degree Fahrenheit temperatures must both have been tolerated. On rather vertical rocks many places elsewhere in Hawaii and in the Park where Calothrix pilosa is well developed, Microcoleus chthonoplastes (or Oscillatoria laetevirens) appears or can be expected.

At the landward edge of the barren rock along the shore there are sometimes flat soil areas presumably in response to erosional material being deposited. Perhaps it is wind that then becomes functional and erodes the fine material so that in dry weather raised black algal crusts are left on the otherwise rather flat surface. In such cases Oscillatoria chalybea Mert. has been found to predominate with Microcoleus chthonoplastes and Calothrix crustacea as minor elements, the latter a depauperate ecophene. Perhaps this is a final level in leaving the sea and the typically-marine Calothrix is at the landward extreme of its distribution.

In crevices far above the sea, crevices that may be floored with sand bound by algal filaments, dark red to brown cushions of Polysiphonia howei Hollenberg are often found. The sand-binding algal filaments in such places are usually Microcoleus chthonoplastes at Kamoamoa but may have Rhizoclonium hookeri in with them. Actually this Rhizoclonium is more typically found in small green tufts or whisps in rock crevices holding a little sand and exposed to brighter light. A very interesting alga, Boodleopsis hawaiiensis, Gilbert has been found with the above Polysiphonia near McKenzie Park to the east of Hawaii Volcanoes National Park. A diligent search in Polysiphonia howei habitats within the Park might provide a rewarding find of this rare species.

Rock tops near the sea that are black when dry in the sun often develop a green sheen when wet for a few hours in the rain by the spray from large waves. This green sheen is usually Entophysalis deusta. While very commonly mixed in with the other algae of the littoral community it is most conspicuous as a widespread nearly-unialgal cover on smooth igneous rock surfaces. Enthophysalis deusta is the most widely spread of all algae on tropical rock shores. Often it covers much of the near-high-tide land, i.e., the calcareous or limestone materials, of an atoll island with a brownish coating at the levels regularly immersed in sea water or with a black coating at those levels normally out of water.

Further inland a smaller coccoid alga with smaller Anacystis-like cells appears which actually may be Anacystis montana (Lightfoot) Drouet & Daily. Again Kamoamoa is a desirable place to study this change in predominence among these organisms which crowd the rocks that are otherwise barren in appearance. Also inland Scytonema hofmannii predominates in any pioneer situation as, for example, on a recent lava flow. On old flows this species can be expected to be replaced in time by such algae as Stigonema. On a low flat place in the lava in the inshore half of the barren shoreside rocks at Kamoamoa, black somewhat dendritic excrescenses one to one and a half centimeters tall and with lobes a millimeter in diameter can be found. These may be Schizothrix thelepheroides with a few multicellular "eggs" of Anacystis-Entophysalis in them. Chunks boiled will come apart, when teased, into fan-shaped branching systems of sheaths in which one or more trichomes can be seen.

(b) In marine caves, where only rarely can one see without becoming very closely associated with the sea, the walls are lined with a pink crust. This is coralline algal material, the material principally responsible for the major features of Central Pacific atolls and reefs. Here in the shade and where often exposed to the air, rarely is it sufficiently developed that one can confidently identify the species. Sometimes in high tide pools in such caves as one finds at Kamoamoa, the corallines will be present on rocks that are otherwise quite devoid of other algal or marine life of any macroscopic kind. As a rule, one expects that these are crusts of Porolithon onkodes (Heydrich) Foslie for this is the widely spread pioneer coralline crustose alga of recent lava surfaces as well as being the principal builder of the ridge at the sea edge of reefs. The surface of a Porolithon crust is, like finely frosted glass, not glazed or shiny. Sometimes other coralline crusts found here have a glazed surface when dry and are probably of the genus Goniolithon.

At the highest levels during low or calm water periods the corallines in the pools or on air-exposed open rocks die, lose their color and become white. Often extensive patches of this material cover offshore rocks where, without noting their ecological relationships or biological origin, one may be inclined to think of them as evidence of a sea bird colony.

(2) Pools in the shores of the Park

In such cave pools as mentioned above there are traces of the algal communities of intertidal non-cave locations. The species are usually sterile or juvenile thalli and so unidentifiable. Lynbya aestuarii (Mertens) Liebmann is perhaps the most recognizable. It forms somewhat gelatinous tangles in which juvenile thalli of Sphacelaria, Cladophora, and various filamentous, sometimes Achrochaetium-like red algae, appear. Perhaps the gelatinous nature is provided by a Phormidium, the very slender trichomes of which are common, present with the above Lyngbya.

At Kaena, a pleasant 30-minute hike from the place where the Kalapana road turns inland for the last time, there is a delightful series of tide-pools and ponds with varying degrees of salinity. Most of them are closely surrounded by the flowering plant Sesuvium portulacastrum L. and, in turn, by flat sandy spots of soil dominated by Portulacca or planted Messerschmidea and Cocos or bush-like small trees of Morinda citrifolia. Just inland where a conventional flowering plant vegetation can be recognized, one is in the summer-drought climate and, often, a Heteropogon grassland.

In the smallest and most inland of the ponds at Kaena the bottoms may be covered with a suspended mass of fine material that is yellowish-brown on its surface. Small fishes, frightened by the shadows of an approaching man, dart into this and in stirring it a bit reveal its below-surface greenness. It is a combination of, largely, the blue-green algae and diatoms that are also to be found in the plankton above. Though many algae are present, only in individual granules of the material was any given species dominant. Among the blue-greens Gomphosphaeria aponina Kuetz., Anacystis dimidiata (Kuetz.) Dr. & Daily, Anacystis marina (Hansgirg) Dr. & Daily, and representatives of Calothrix, Lyngbya, Oscillatoria, Hydrocoleum, and Phormidium are present. None of these is typical of other than a brackish pond. A similar nondescript list of diatoms could be presented but among which some are distinctive; perhaps the most distinctive elements are Melosira, Surirella and a huge Campylodiscus.

Not to be overlooked in this habitat is the abundance of protozoans such as Arcella and an abundance of ciliates and flagellates, many of these latter actually members of algal phyla.

In the ponds at the seaward end of the series, i.e., the more saline, the bottom is covered by a generally gelatinous crust. Nearer the sea it is more nearly a plain continuous browner layer. Nearer the fresher ponds the material is an irregular reticulum of rounded lumps that are greener on the surface. In this material the gelatinous matter is mostly of Microcoleus chthonoplastes. Oscillatoria and slender Calothrix-like filaments are common as are Hormidium-like green algal filaments. Schizothrix-like trichomes of the Microcoleus are less common as are Gomphospheria aponia and Anacystis dimidiata, but the host of diatoms mentioned above is yet present. What we interpret as Anacystis marina is abundant. Occasionally thalli of what seems to be Mastigocoleus testarum Lagerheim, normally a dweller in dead calcareous material, can be found.

Brownish scums may be found wrinkled against the shores, protruding rocks and in the narrow passageways between ponds or against the Sesuvium portulacastrum which closely surrounds the shores. This scum, pushed by the wind, would seem, from the detritus in it and the non-planktonic organisms, to be matter stranded on the intertidal sandy shore surfaces and picked up from them as the tide rises.

(3) Intertidal shores of the Park

The intertidal communities vary with the degree of water turbulance, substratum and tide level. Three community variants have been recognized as those likely to be found in the Park by Mr. Roy Tsuda as 1) protected coves or areas not affected by wave action; 2) areas which are moderately wave-washed, and 3) areas which are affected by strong wave action, below the high sea cliffs. A good complement of these types is available between Kaimu and Kalapana outside the Park. Such areas are often not safely accessible within the Park.

One can expect the rocks of protected, or calm, areas to be dominated by Amansia glomerata C. Ag., Asparagopsis taxiformis (Delile) Coll. & Harv., Chnoospora implexa J. Ag., Microdictyon japonicum Setchell, Polysiphonia sphaerocarpa Boerg. and Valonia aegagropila C. Ag. Especially these can be expected to be found growing in tidepools. Looking down from overhanging cliffs one sees behind the dark background of the basalt rocks young pink patches of colorful crustose coralline algae with two articulated corallines, Jania capillacea Harvey and Jania ungulata Yendo.

In habitat type 2 of moderate exposure to waves, Ahnfeltia concinna J. Ag. with its long yellow and maroon thalli is found associated with thick green and red mats of Gelidium sp., Pterocladia sp., Hypnea pannosa

J. Ag., and Centroceras clavulatum (C. Ag.) Montagne. These species comprise the majority of the marine population in such places. High in the intertidal region, however, short brown tufts of Ectocarpus breviarticulatus J. Ag. predominate. They are about three centimeters in length and are most often seen attached on large basalt boulders. Occasional thalli of Chaetomorpha antennina (Bory) Kützing and Chnoospora minima (Hering) Papnefuss are also to be found in association with this Ectocarpus. Juvenile forms of Ulva fasciata Delile and a species of Enteromorpha, appearing as green blades and filaments respectively, are usually present on the lower portion of any wave-washed bench. Along the edge of a wave-washed bench, erect greenish thalli of Polyopes clarionensis S. & G. are often seen. A slippery black film of Lyngbya and other blue-green algae is often present on smooth basalt rocks making walking very difficult.

Short stubby forms of Sargassum echinocarpum J. Ag., juvenile forms of Turbinaria ornata (Turner) J. Ag., prostrate forms of Zonaria variegata (Lamx.) C. Agardh and Ralfsia pangoensis Setchell are conspicuous in tidepools on wave-washed benches. Small entangled thalli of Polysiphonia are also found in the smaller tidepools. The only epiphyte found thus far is a small Ectocarpus, probably E. indicus Sonder, found on Sargassum. Epiphytes are, however, abundant on these algae in most habitats.

Although collections have not been made from the third habitat situation in the Park, the predominant flora below the high sea cliffs is easily recognized to be the colorful thalli of Ahnfeltia concinna J. Ag. above stunted Sargassum scattered over a pinkish crustose coralline algal coating covering of the rocks. Below this, species of Gelidium occur as a redish turf.

Actually, in reference to tide or wave level little precise study within the Park has been feasible. A tide level or vertical distribution study does not seem likely to be rewarding for the reason that the generally heavy wave action seems to dwarf the effects of the tides. There are all degrees of basalt substrata, consolidated shores as cliffs or non-consolidated huge and relatively permanent boulders, or gravels, or even finer material. The smaller sizes are so mobile they do not remain in one position long enough for much in the way of a population to develop on them unless they are on rather flat bottoms as are present between the island of Kaoi and the Halape shore or between the near-shore bilsters of lava and the shore at Kaena.

Without going into the possible tide level relationships of the different, apparently dominant species, the highest-growing macroscopic alga may be taken as Ahnfeltia concinna. This species (Fig. 26) forms a yellow bunchy cover on the rocks with individual fronds often 25 centimeters long but varying greatly from place to place. At a distance a zone of it (Figs. 27 & 28) reminds one[8/] very much of the similarly located yellow-brown strands of Fucus or Pelvetia on North Temperate shores. Note (Fig. 26) the variation in standing crop with elevation indicated in the "blow up" of the intertidal part of the shore.

The zone just below the Ahnfeltia is generally of about the same width as the Ahnfeltia zone. It is usually (Fig. 27) one of several sorts: merely for the most part black rock; populated with Ulva or Enteromorpha; populated with Ralfsia above and Ulva below, or largely dominated by crustose corallines. Of course there are times when there are mixtures of all three or other species. Caulacanthus ustulatus occurs here, too. Sometimes this zone is

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[8/] Dickie (1876) in writing of the algae collected at Hilo by H. N. Moseley on the Challenger Expedition also mentions this resemblance.

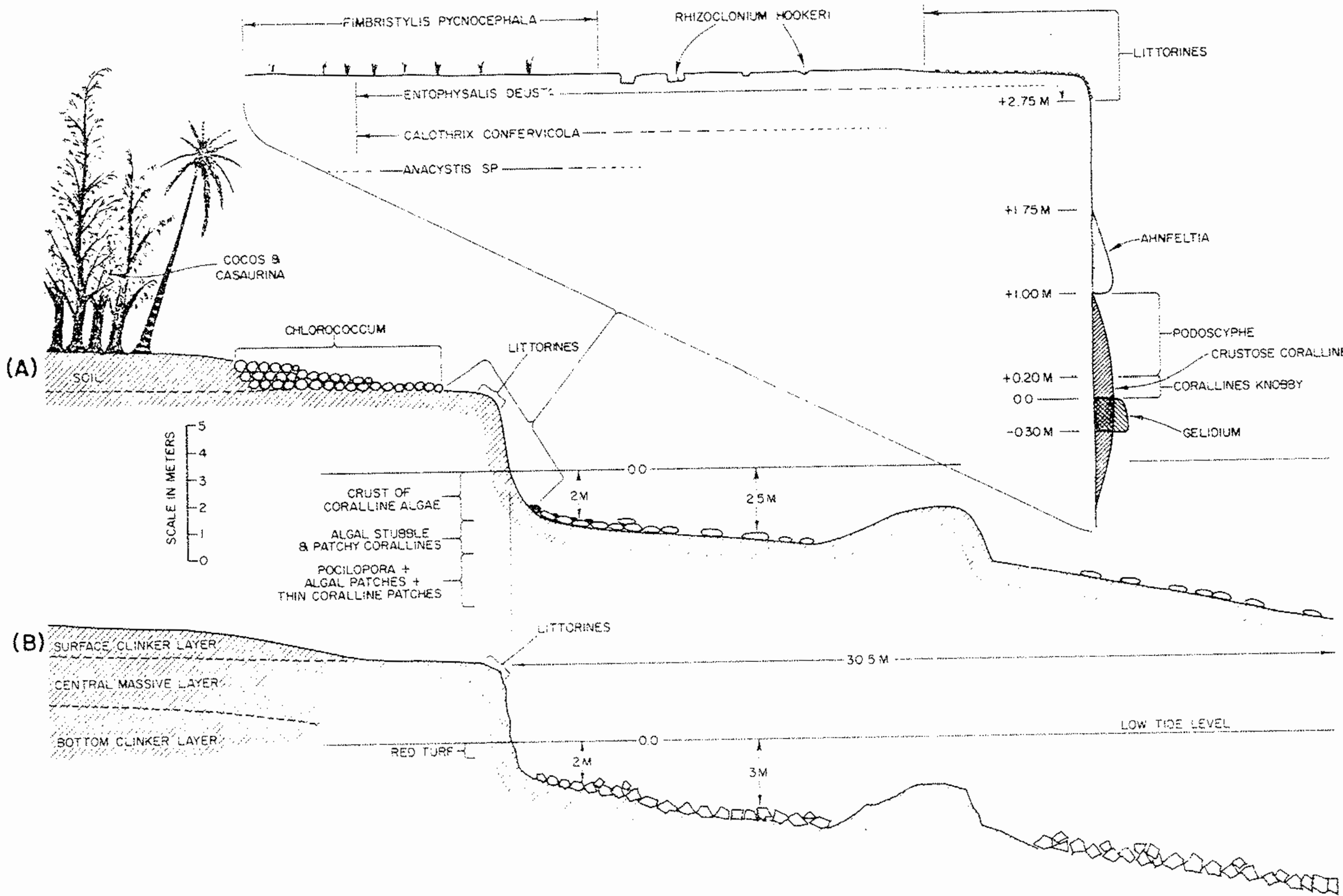


Fig. 26. Comparison of old (A) and recent (B) igneous shores by a diagrammatic presentation of the horizontal and vertical distributional features of the populations and some geological details.

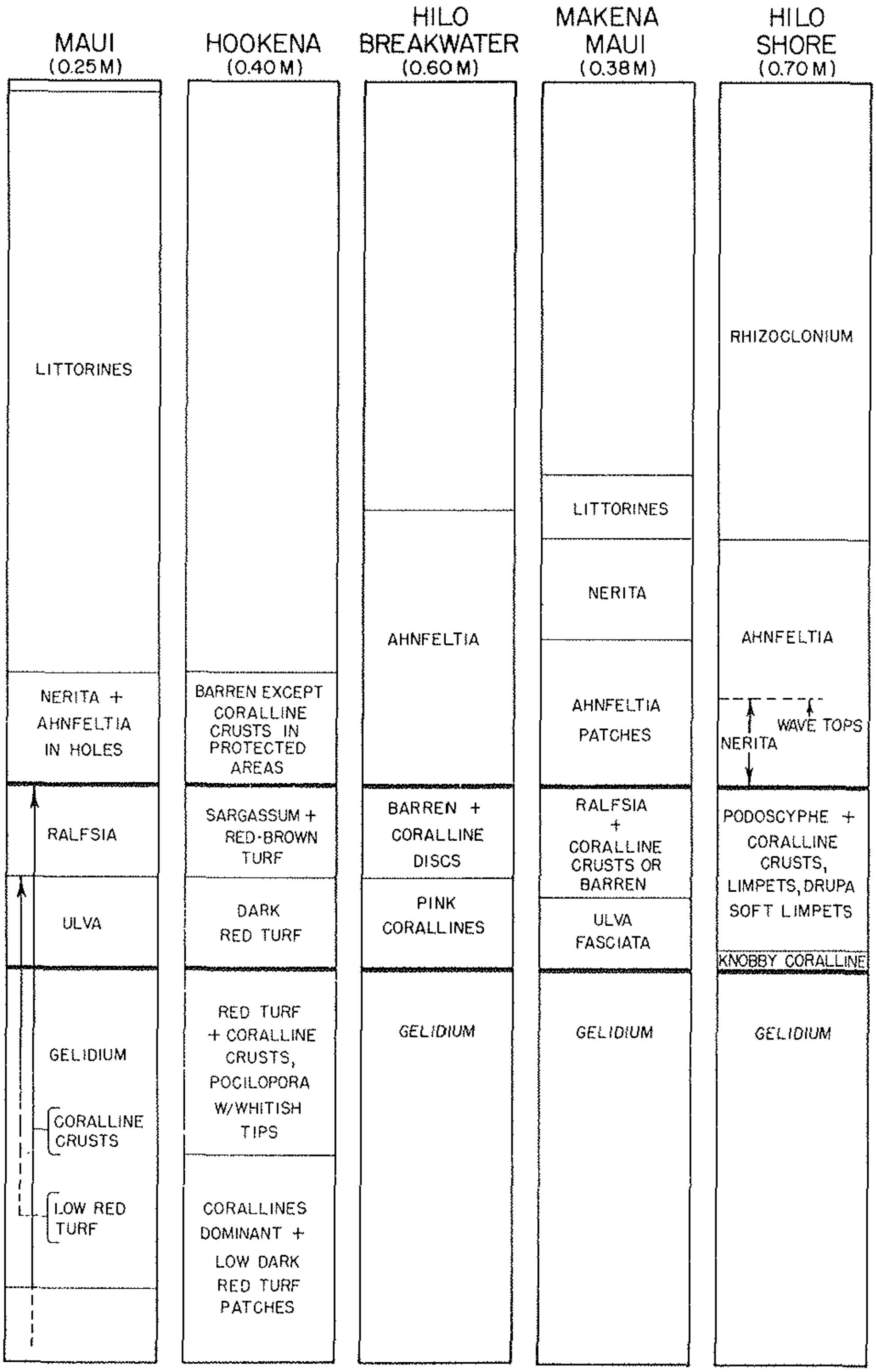


Fig. 27. The vertical distribution patterns common to Hawaiian shore areas similar to those to be expected within the Park. The distance between the two horizontal dark lines in meters is given at the top of each strip as well as the location of the two on Maui island and three on the island of Hawaii. This provides the scale for the whole diagram.

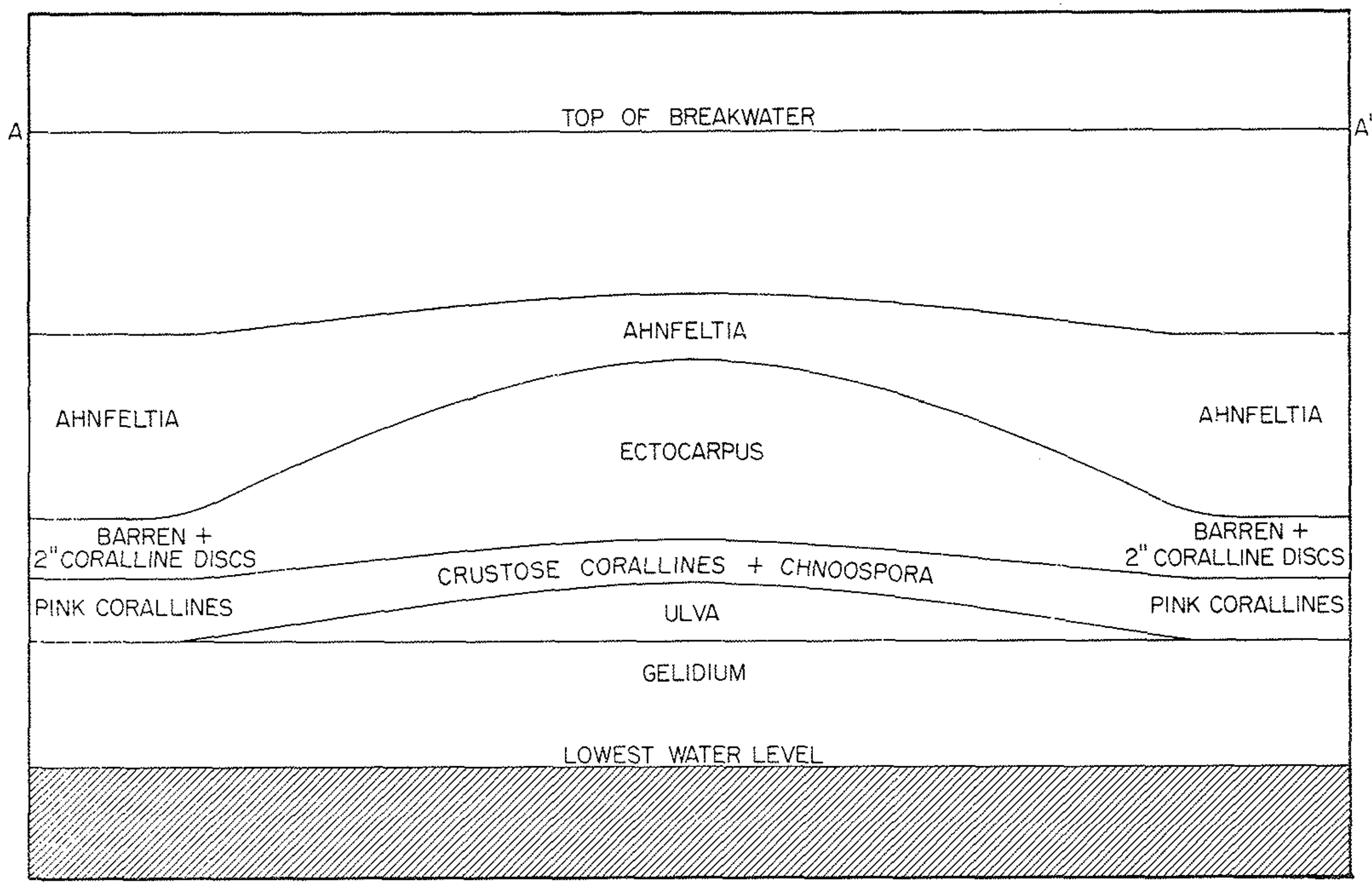


Fig. 28. Diagram of algal vertical distribution on a wave-exposed projecting angle of the Hilo Breakwater in relation to the adjacent less wave-exposed portions of the same breakwater. The diagram is essentially without scale.

subdivided with the rock of the lower part coated with crustose coralline algae, the upper part with non-coralline algae. The corallines, low in this zone (Fig. 27), may be rough-surfaced or produce small Porolithon-type heads. Podoscyphe, Drupa and limpets, when present, are here.

The next zone down is comparatively as broad or even broader than the two above together. It is underlain by smooth crustose coralline algae, often covered with Gelidium or other closely related genera. In the upper part of this zone the brownish genus, Sargassum, is common. If in a place where the water has a consistent direction of motion, the fronds will be a foot long, but as the water is more turbulent the fronds are shorter and may be merely irregular patches of stubble. At the lowest common level of the waves, the Gelidium cover rather abruptly terminates. When working on shore the abrupt upper limit of this alga ("A" in Fig. 26) can be used as zero datum level in measuring vertical distribution: when under water the abrupt lower edge can be used as a convenient zero. The dense Gelidium cover probably represents a zone between mean sea level and the lowest low tide level.

The shallow water communities are dominated by the crustose corallines extending on below the Gelidium-covered zone (Figs. 26 & 27), often completely covering all consolidated rock surfaces down to a depth of 1 to 1.5 meters below low tide line. They extend much further down (certainly to at least 7 meters) but as a thin cover gradually becoming yet thinner and covering the surface less completely as greater depths are reached. Of Oahu, crustose algae are still present at depths of 525 feet as determined from diving in a research submarine. About 2 meters below the bottom of the Gelidium, an algal stubble becomes dominant and is conspicuous for at least 5 meters on down. Conspicuous elements in this stubble are Dictyota friabilis and Griffithsia as well as the small algae commonly found in the Gelidium-levels and especially well developed in intertidal pools.

While pink coralline algae, the principal builders of reefs in the Pacific, are everywhere to be seen, the animal corals are but very few. Pocillopora, the only conspicuous coelenterate coral, often appears about 3 meters below low tide level with the individual heads being, perhaps, 3 meters apart down to the -8 meter level. No really sharp limits below the bottom of the Gelidium have been observed in Hawaii. From the results of dredging it appears that the algal standing crop may actually increase once depths below those affected by wave action are reached.

The vertical range of levels at which algae are found changes with the degree of wave action and the actual algae present may be there in relation to the degree of population (seral) development or seasonal progression. This latter is an unknown for the Park communities. In Figure 28 there is diagrammed a class of events which is useful in formulating an explanation of the change of elevation of communities with wave action and some events in their development. As an example of use in explaining phenomena in the Park: over the center of the basalt breakwater of Hilo Harbor there passes at times a lot of gravel as evidenced by a large pile of fresh appearance on the inner side and the growth of this pile with time. Wave action has been seen to be definitely less to the right and left of the center of the area. The upward shifting of horizons or zones illustrated (Fig. 28) is apparently in relation to the greater wave action at this place along the breakwater. The characteristics of the population indicated at the right and left ends of the diagram are consistent, respectively, toward shore and the sea. These conditions, shoreward and seaward, are thought to represent the stable community, or climax, conditions relative to the central region.

The Ulva and Ectocarpus populations at the center of the diagram would seem to represent disclimax or subclimax conditions depending upon their origin. Subsequent examinations of this place lead us to prefer the term disclimax as applicable in this and some other situations where the same algae have been observed to appear after a disturbance of the climax population. In another connection Randall (1958) has indicated phenomena possibly of this sort in connection with an hypothetical explanation for some poison fish occurrences.

(4) Population development on new lava shores.

Sooner or later it can be expected that within the Park a lava flow will reach the sea. In order to provide information to be used in interpreting the events that will follow and provide a guide for studies of these events an extract of the results of a study made on the 1955 lava where it went into the sea a few miles to the east of the Park is included here. It is also hoped this will be useful in interpreting phenomena concerning the present mature populations on prehistoric surfaces in the Park.

In the Hawaiian Islands there are historic lava flows in the intertidal regions dated from about 1750 down to the present. None of these has quite the same population on it as is to be found on the adjacent probably much older undated or prehistoric lava shores. This is a problem for in studies elsewhere observations in the intertidal region have led to the expectation only about five or six years are required for the "climax" situation to become established. Indeed some have said that in the case of intertidal populations there was "direct development" of the mature or "climax" populations. Fahey (1953) reviews this situation briefly.

Observations on the 1955 lava flow in the sea, itself, were made not only to provide a record of events but to provide a series of special observations to test certain hypotheses concerning the development of intertidal populations on them. These hypotheses are, largely, the separation and distinction of succession, seasonal progression, the events of zonation, the regulation of climax formation, and classification of the different algae and other organisms according to the part they plan in the populating process. Testing, observation and experimentation elsewhere (Northcraft, 1948; Fahey & Doty, 1949; Fahey, 1953) have been concerned with surfaces such as concrete, old rock or wood brought to the sea for the first time, with denuded surfaces, or (e.g., for review of subject, Williams, 1965) glass slides.

The initial hypotheses were that this phenomenon of slow development of a climax situation was related to the geographic position in the islands or the chemical or physical composition of the lava. These hypotheses were destroyed by a few simple experiments and measurements. For example, chunks from recent and old lava flows of different dates, composition and physical surface were seated in concrete blocks, sometimes enclosed in wooden forms and exposed in the sea. It was found that the pioneer and secondary populations developed about the same on all surfaces exposed, including the wood and concrete. This is a quite different result from that obtained in experiments with terrestrial forms on different substrata.

The 1955 lava flows ran into the sea along a shore (Fig. 24) where there was very little sand. Shortly after the flows had cooled, extensive beaches of black sand were seen extending along the shores to the left and right of the new lava flows. With time, as determined by successive observations, this sand moved off or away (often moving inland) from these first formed beaches.

Uniform samples of the water washing the intertidal surfaces taken from near the 1955 flows and from near the much older undated flows revealed a measurably larger amount of sand and sediment in the water from the new flow areas. Erosion of these 1955 shores has been high and, in some cases, several meters of the new lava surface have been removed in but a few months. In passing, it may be noted that the Honokua 1950 lava flow at Hookena, Hawaii, was so worn back by late 1955 that in many places the prehistoric flow under it was again exposed to the sea.

A different hypothesis finally arose after following the populations on these 1955 intertidal lava flow surfaces for some time. This is to the effect that the surface would have to become so stabilized that it would remain effectively constant for at least the five or six years one can expect it takes a climax population to appear. It seems true that wherever a dated flow is not yet worn back to the general coast line, it does not bear a sere-wise advanced population.

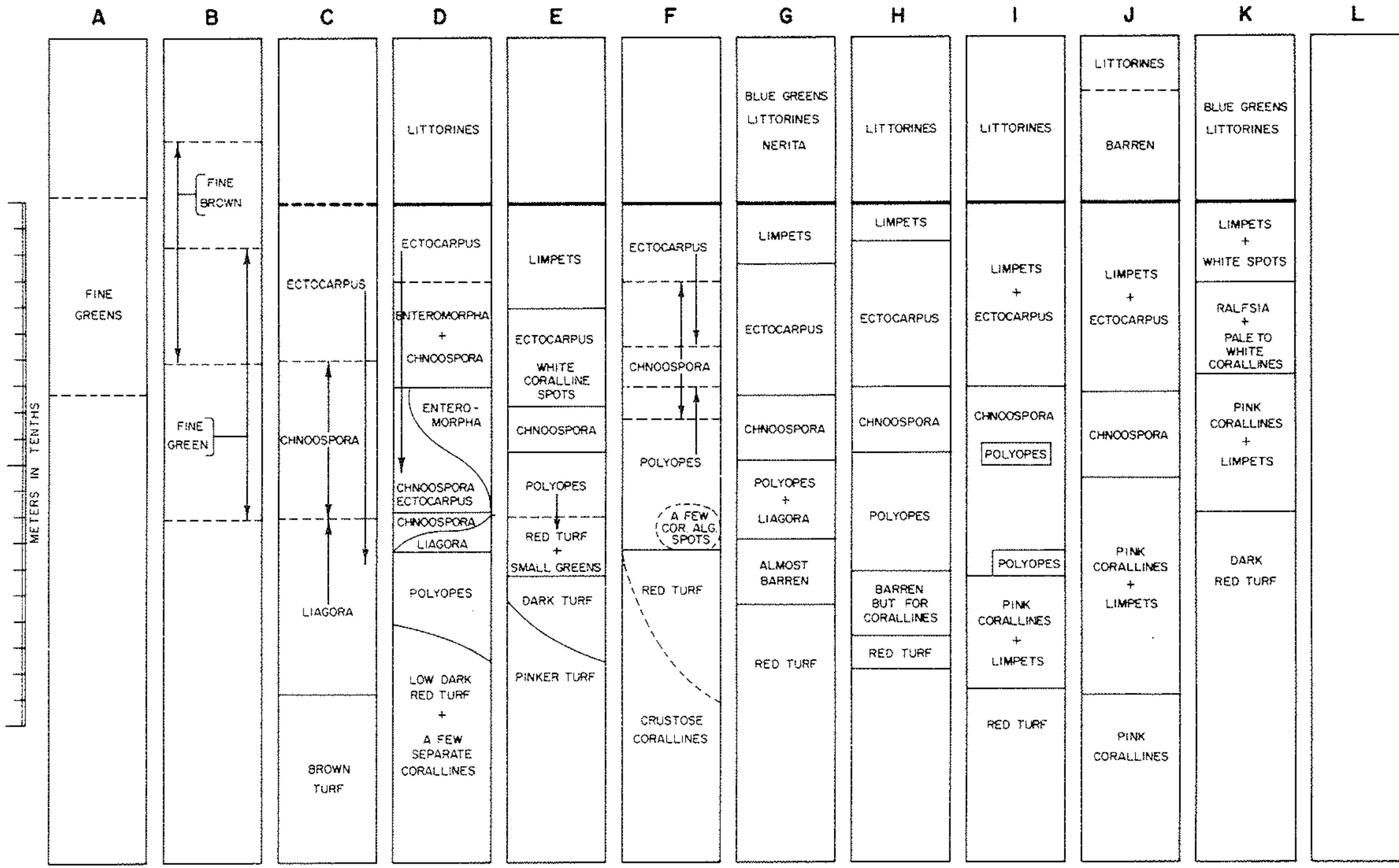
Somewhat similar statements can be made in regard to the presence of black sand. Where black sand is present nearby in quantity, the populations tend to be immature. Rigg (1914) and Dawson (1954: 10) both comment on the denuding action of such volcanic pumice and sand on nearby populations. In our case, no such observation of the removal of old nearby populations has been made. We do note that, as indicated by the contrast in Figure 26, there is a change in the rocks on the bottom. Not only with time have the rocks in the sea off the Kehena flow become smaller, more closely packed and more rounded, they have also become more completely populated, largely by crustose algae. Early visits to the area were marked by notes of the frequency stones were seen thrown by wave action higher and beyond the splash of the water itself. Likewise in skin and SCUBA diving, moving stones were often seen. The author observed stones, adjudged to be of 7 to 12 centimeter dimensions, in the turbulent water .3 to .7 meters off the bottom during a period of unusually rough seas while swimming under the large waves after having been washed off the study area. The author has not been in the water at this place under such rough sea conditions during the last few years, but the impression is that the bottom, which is of closely packed stones, is of fewer and more uniformly dense boulders not moving as freely as they did during the first two years of the study.

At the time of our observations in June, 1955, one of the dominant algae on the 1955 lavas was Liagora maxima. It was present both on prehistoric lava near the 1955 Keekee flow and on the 1955 Kehena flow. This alga was much less evident in December (1955) than it had been earlier in June and August, and by February and March (1956) none was seen at all. However, in May and in July (1956) it was again abundant. This we regard as a manifestation of seasonal progression or periodicity rather than as pioneer colonization without ecesis.

Our study has been rewarding in connection with the obtaining of observations that bear on the problem of distinguishing seral progression. As illustrated for the Kaueleau study site ("E" in Fig. 24) at "A" in Figure 29 the first macroscopic populant on the newly cooled lava was fine green strands of Enteromorpha. Specifically this green algal material is not identifiable further than to genus at this time. These populations were very hard to reach consistently for measurement or collection.

Subsequent more consistent study was possible when portions of the flow surface broke away and disappeared. In these cases regardless of time of year or vertical position in the intertidal region, the same Enteromorpha appears as a fine hair-like rather uniform coating on such "fresh" surfaces. Certainly this particular phenomenon is one of disclimax in consideration of the whole area, yet on the particular fresh lava surfaces the Enteromorpha

Fig. 29. Population changes in time on a vertical 1955 lava surface extruded into the sea and observed as follows: A at Kaueleau, VI-21-1955; B at Kehena, XII-30-1958; at Kaueleau respectively--- C, VIII-15-1958; D, XII-21-1955; E, III-24-1956; F, V-16-1956; G, VII-14-1956; H, VIII-18-1956; I, XI-10-1956; J, IV-20-1957; K, XII-30-1958.



is a pioneer. In time the Enteromorpha matures into isolated tufts of mature thalli that may eventually become somewhat brownish with the development of epiphytic diatoms and then disappears as succession takes place.

Ectocarpus breviarticulatus can be expected to appear ("B" and "C" in Fig. 29) shortly after the Enteromorpha has appeared and with it distributionally but also alone at still higher intertidal levels as well. While the Ectocarpus at first may be diffusely spread over the surfaces, intermixed with the hair-like coating of Enteromorpha, it too first becomes restricted to small tufts and these become fewer and larger as time goes on. In age the lower tufts of Ectocarpus may become intermixed with a Cladophora, the tufts of which other than for color are quite similar macroscopically.

As time goes on, the pioneers become replaced by other algae and zonation (Fig. 29) becomes evident and more stable as longer-lived organisms appear. While the Ectocarpus, all the time it remains, is the highest macroscopic algae, a blue-green coating began to appear ("D" in Fig. 29) conspicuously on the rocks above the Ectocarpus in December, 1955, six months after the flows had cooled here. We have gained the impression that with excessive abrasion during storms, many of the zoned organisms are removed. In fact, so many may be removed irregularly and replaced by pioneers (e.g., the Enteromorpha in "D" of Fig. 29) that zonation becomes obscured. It would seem this disclimatic process is related to that which holds some areas (Fig. 28) in subclimax condition semipermanently.

The series of events illustrated in Figure 29 was progressive. The blue-green population gradually became more dense so that it could be readily detected in its lower reaches even when dry. At first it was seen as a blue-green sheen only when wet. Littorina pintado became progressively more abundant as this happened. Lower down the same events were true for the high-growing limpets, Helcioniscus exaratus. Ralfsia and the crustose corallines appeared as small spots over a wide vertical range, became larger, tended to completely cover the surface in a smaller vertical range, and became fertile. The corallines often developed erumpent edges where adjacent crusts closed together. The early populants Estocarpus, Chnoospora and the various Chlorophyta by March, 1965, were no longer obvious except in an occasional spot where a chunk of lava had broken away. While not actually measured, it seems clear that the bottom depth adjacent to the Kehena and Kaueleau flows has increased.

The finger-shaped point of rock at Kehena ("D" in Figure 24) some 7 meters broad, perhaps 4 meters thick which jutted into the sea some 20 meters and bore the surface repeatedly studied, photographed and measured completely disappeared early in 1961. Perhaps this is related in part to its being undermined as the depth alongside increased. Even before that time disclimatic events had disrupted the study and such climax genera as Sargassum never did develop there. Other sizeable protrussions and seaward faces of the 1955 lava flows were noted to have disappeared between visits. As a result in 1965 these flows are hardly irregularities in the outline of the shore. Undoubtedly, this rapid wearing back of the flows to the general island contour is a major reason for the lack of bays in this younger part of Hawaii.

In the series of phenomena observed, we feel there was demonstrated seral progression as Sargassum echinocarpus, S. obtusifolium and the crustose coralline algae became well established only during the second year of observation of the 1955 flow surfaces. Similarly in time Corallina sandwicensis became present as dense fertile hemispheres at Kehena, as did occasional tufts of Alsidium sp. and Lophosiphonia villum at their characteristic high elevations. This seral progression, while it has resulted in populations having some of the more conspicuous algae and animals of the climax situation, has not yet progressed very far either qualitatively or quantitatively. On more protected less abraided areas and in pools the populations are much more advanced toward the climax situation and the standing crop is higher.

No one has yet been successful in determining the precise quantities of algae on a rough nearly perpendicular intertidal shore exposed to the full sweep of the surf, but comparative observations show that though forms conspicuous in climax populations are present and fertile, for example, crustose coralline algae, the cover was still (March, 1965) not as dense as it was on the prehistoric shores. It does seem likely that as the sere moves toward the climax situation a higher standing crop is maintained, though productivity may be lowered.

Certain qualities, e.g., the red algal species Ahnfeltia concinna, coelenterate corals, and the brown algal genus Ralfsia, were absent during the first year of observation at Kehena and Kaueleau. Of these during the second year small patches of Ralfsia appeared. Ahnfeltia was first noted in December, 1959, about four and a half years after the surface had cooled. Earlier, these two qualities had been found sparsely developed on the surfaces of flows five years old elsewhere (the 1950 flows). By April, 1962, 7 to 8 cm tall tufts of Ahnfeltia concinna were conspicuous on the 1955 Kaueleau lava flow study point. This alga while not forming a band was quite abundant, though not frequent elsewhere. Much of the flow surface inland from the study point was gone by March, 1965. It was largely loose clinker material, but some of the clinkers or chunks removed must have weighed at least a metric ton. This removal is slight in comparison to the complete removal of most of the study point at the Kehena site. There between two visits the whole small solid rock peninsula disappeared except for the tip which remains as an isolated islet perhaps 2 meters in diameter and constantly washed over by the waves at high tide.

It can be stated here that the idea of Fahey, Northcraft, and others, that the pioneer organisms, e.g., Enteromorpha and Ectocarpus, may be occasional organisms in climax situations seems to be borne out by our observations. To this group we would add Polysiphonia. Enteromorpha, which was the principal macroscopic pioneer, has become restricted to but a few spots on some of the population-wise most advanced surfaces. It appears in abundance, however, as a pioneer coating over any new surface such as is formed when a piece of the flow is broken away by the waves. Ectocarpus breviarticulatus, on the other hand, may remain as a rather regularly predictable populant of the highest intertidal regions for at least a year. It is much less conspicuous on older surfaces and absent for the most part where Ahnfeltia concinna is abundant on prehistoric flows.

It is to be noted that the more permanent crustose colonizers, e.g., Ralfsia and the crustose corallines, appear as small spots and grow so as to occupy most of the surface. In doing so, they leave less and less space free on which the frondose earlier more conspicuous or dominant and short-lived populants can grow.

Should a lava flow enter the sea within the Park a photo series, including vertical aerial views, should be made at intervals such as one week for the first few months and a biological study begun at once that can be carried on intensively for at least five years. Planning for such a study should be done in advance for such a study could become a biological classic.

Chapter VIII- The Vegetation Map and Vegetation Profiles

By Dieter Mueller-Dombois

Utilizing the aerial photographs discussed above in Chapter I a vegetation map has been prepared for the Park area on a scale of approximately 1:12,000, the scale of the aerial photographs themselves. The mapping was done on transparent plastic overlays in the form of 53 sheets each 27 x 27 inches in size with the details in a polygonal area selected so that the 53 provide complete coverage of the Park.

In preliminary form the different types of vegetation were first outlined by F. R. Fosberg utilizing, indoors, the field knowledge he had accumulated through his years of experience with vegetations. The preliminary vegetation units so mapped were studied and checked out in the field by the writer and modified as necessary. From the 53 finished maps a revised, partially new, classification of the vegetation units was developed. Abbreviations of the names of the predominant plants in these units provided (Table I) the symbols used on the maps and in the text below. Table II reviews the classification. Perhaps even more usefully, a series of vegetation profiles (Figs. 30-34) related to climate, topography and soils was prepared. Figure 18 shows the locations of the profiles which are referred to as Transects 1 through 5 in the text below.

Field mapping involved correlating ground conditions with the patterns found on the photographs. This was done by exploring all unknown photographic patterns in the field and by running transects through those areas that showed a maximum of variation in pattern on the photographs. The vegetation types were defined by physiognomic and floristic critera and in some instances in relation to topographic and substrate features. Extrapolation was kept to a minimum in the more accessible areas, where all

Table I. Symbols used in the vegetation map for Hawaii Volcanoes National Park. The symbols are largely abbreviations of the generic names of species. For example, a front symbol "oM," indicating open Metrosideros forest might be combined with an attribute symbol, such as "(Sa)" indicating a scattering of Sapindus occurred with the Metrosideros. Often more than one front or attribute symbol is combined. In use and in the following alphabetic list the attribute symbols are enclosed in parentheses. These symbols were recorded on the transparent overlays made to correspond to the aerial photographs described in Chapter I.

(Ac)-	Scattered *Acacia koa*.
AcSaM-	Mixed *Acacia koa*—*Sapindus*—*Metrosideros* forest.
(ad)-	Admixed trees in lower story (*Myrsine lessertiana*, *Myoporum*, *Coprosma rhynchocarpa*, *Cheirodendron*, *Pelea*, etc.) and arborescent shrubs (*Pipturus*, etc.).
Al-	Forest dominated by *Aleurites moluccana*.
(Al)-	Scattered *Aleurites*.
An-	*Andropogon* grassland (includes *A. virginicus* and *A. glomeratus*).
(An)-	*Andropogon*.
ash-	Ash deposits with little or no vegetation.
(ash)-	Much barren ash.
C-	*Cibotium* forest.
(C)-	*Cibotium*.
Ch-	Dense *Chrysopogon*—*Cynodon* grassland on loess-like, yellow ash (Puu Kaone).
clf-	Closed mixed lowland forest, mostly fragmented by urbanization and strongly modified and variable from tree planting (*Mangifera*, *Samanea*, *Aleurites*, *Cocos*, *Pandanus*, *Psidium guajava*, *Thespesia*, *Schinus*, etc.).

Table I. (continued).

cls-	Closed lowland scrub, mostly low-growing.
cM-	Closed *Metrosideros* forest.
E-	*Eragrostis tenella* grassland.
(E)-	Abundant annuals, *Eragrostis tenella* and *Bulbostylis capillaris.*
(e)-	Abundant epiphytes (*Astelia*, *Freycinetia*, *Cheirodendron*, mosses and liverworts).
fu-	Fumarole areas with dwarf shrubs, *Andropogon virginicus*, *Nephrolepis*, *Gleichenia*, and barren ground.
(G)-	*Gleichenia*.
H-	*Heteropogon* grassland.
(H)-	*Heteropogon contortus*.
(i)-	Introduced shrub (*Psidium guajava*, *Stachytarpheta jamaicensis*, *Lantana*, *Cassia* spp., *Solanum* spp., etc.).
it-	Stand composed of introduced trees.
(it)-	Introduced trees (*Eucalyptus*, *Jacaranda*, etc.).
(L)	Lichens (*Cladonia* spp., *Stereocaulon*, etc.).
(ls)-	Sprawling or short lowland scrub (*Waltheria*, *Osteomeles*, *Cassia leschenaultiana*, *Indigofera*, *Psilorhegma*, etc.).
lsi-	Mixed lowland scrub composed largely of introduced species.
(M)-	Scattered, old *Metrosideros*.

Table I. (continued).

MAc-	Mixed *Metrosideros*—*Acacia koa* forest.
MAl-	Mixed *Metrosideros*—*Aleurites* forest (the latter scattered) with other mesophytic forest tree species (*Myrsine lessertiana*, *Santalum*, etc.).
MD-	Mixed *Metrosideros*—*Diospyros* forest, almost always open, with other dryland forest species (*Antidesma*, *Canthium*, etc.).
(Me)-	Abundant *Melinis* patches.
mx-	Mixed grassland (mxg = grazed).
(mx)-	Mixed grass (above 4000 feet elevation).
(N)-	*Nephrolepis* patch communities on a'a lava.
ns-	Native shrubs (includes *Styphelia*, *Vaccinium*, *Dodonaea*, *Dubautia*, *Coprosma ernodeoides*, *Metrosideros*, *Myoporum*, *Wikstroemia*, *Sophora*, etc.).
(ns)-	Native shrub (*Styphelia*, *Dodonaea*, etc.).
o-	Open (only used in combinations).
olf-	Open mixed lowland forest, mostly fragmented by urbanization and strongly modified and variable from tree planting (*Mangifera*, *Samanea*, *Aleurites*, *Cocos*, *Pandanus*, *Psidium guajava*, *Thespesia*, *Schinus*, etc.).
ols-	Open lowland scrub, mostly low-growing.
oM-	Open *Metrosideros* forest.
P-	*Prosopis* forest.
(poik)-	Poikilophydrous (*i.e.*, xerophytic) plants and annuals (Kau Desert).

Table I. (continued)

r-	Lava flows with little or no vegetation (r for rockland).
(R)-	Scattered *Rhacomitrium* moss.
(r)-	Much barren lava.
rb-	Lava flows, completely barren (summit of Mauna Loa down to 11,000 feet, and further down where indicated).
(Sa)-	Scattered *Sapindus*.
scM-	*Metrosideros* scrub.
(scM)-	*Metrosideros* scrub.
(So)-	Scattered *Sophora*.
spr-	Salt-spray and other shore communities.
(spr)-	Salt-spray and other shore communities.
(T)-	*Tricholaena repens*.
x-	Cleared or strongly disturbed areas that have not been left for long enough to establish a recognizable vegetation types.
(x)-	Much modified by man.

major variations were investigated. In the less accessible areas, which involved about 20% of the total, vegetation was determined by matching photographic patterns. Indirect mapping was necessary for the higher altitude vegetation on Mauna Loa, where vegetation cover is not dense enough to show on the photos. Here topographic lines and substrate types were matched to approximate the correct vegetation limits.

The symbols used (Table I) on the vegetation maps prepared as overlays of the aerial photographs (Chapter I, above) are derived from the names of genera or other predominant surface cover. They are usually in two parts, a front symbol of letters indicating the more obvious stand or surface features and an attribute symbol added in parentheses after the front symbol. The attribute symbol denotes a finer variation. More systematically, a front symbol indicates a major cover type, an attribute symbol, a breakdown within the cover type, commonly recognized by a change in the subdominant species. For example, oM(C) stands for open *Metrosideros* forest with *Cibotium*, and oM(G) stands for open *Metrosideros* forest with *Gleichenia*. There are 29 front symbols. The 28 attribute symbols provide further characterization. Symbols denoting a species are capitalized abbreviations of the generic name. Symbols denoting other vegetational or surface features are also similar simple abbreviations, but in lower case.

TOPOGRAPHIC VEGETATION PROFILES

The vegetation profile diagrams (Figs. 30-34) are intended for map interpretation as well as for a classification of the vegetation in the Park. The diagrams follow the transect lines 1-5 shown on the orientation map (Fig. 18) in the chapter on climate. Their location was selected to give the maximum of information about the arrangement of the vegetation cover in the Park as permitted by the chosen geographic scale.

The segments shown by sequential numbers and vertical separation lines on each profile diagram portray the more important vegetation types in the Park. However, several of the separately numbered profile segments represent the same vegetation type. For example, segment 12 on Figure 30, segment 8 on Figure 32, and segment 7 on Figure 33 represent the closed Metrosideros-Cibotium forest type. The same applies to other geographically widely distributed or frequently recurring types, e.g., to the Heteropogon grassland type, which recurs on three profiles (segment 2, Fig. 32, segment 2, Fig. 33, segments 1 and 3, Fig. 34) and even twice on one profile (Fig. 34). Therefore, the total number of profile segments, 47, is greater than the number of vegetation types recognized, 31.

The profile segments coincide closely to the vegetation units recognized on the map sheets. However, the degree of abstraction has been carried a little further on the profile diagrams to eliminate unnecessary detail. For example, the mixed Acacia koa—Sapindus forest (segment 9 on Fig. 30 and segment 8 on Fig. 31), which here represents the vegetation type of Kipuka Puaulu (Bird Park), shows as two types on the map sheet, a closed mixed Acacia koa—Sapindus forest [map symbol AcSaM(ad)] and an open mixed Acacia koa—Sapindus forest (or savannah) with Metrosideros [map symbol mx-AcSaM]. Both types appear on aerial photo 8-0079. Another example may be illustrated by referring to the profile diagram Figure 34, segment 5. Here the diagram refers to only one type, the mixed lowland scrub, map symbol ls(i). On aerial photos 14-0016 and 6-16 the type is further subdivided into open lowland scrub [symbol ols(i)] and closed lowland scrub [symbol cls(i)]. There are numerous other examples. The finer variations recognized by finer type designations on the vegetation overlays would not add any relevant information to the profile diagrams. Therefore, they are omitted.

The numbered segments shown on the profile diagrams and the vegetation types that they represent are related primarily to significant variations in macroclimate, but in part also to variations in substrate and stand development. The latter two variations occur wherever there is more than one vegetation type within a climate type.

The climate, substrate and stand structure relationships are presented as simple, factual relationships. They do not imply any causal relationship. The establishment of cause and effect relationships requires further study.

In order to facilitate map interpretation each vegetation type name will be supplied with the map symbol in the following discussion of the profile diagrams. They are arranged alphabetically in Table I and systematically in Table II.

Vegetation types along the east slope of Mauna Loa. Transect 1 (Fig. 18). Profile diagram Figure 30.

The vegetation was explored on a two-day field trip (August 17/18, 1965) that began from the summit of Mauna Loa. Transect 1 follows the approximate course of the Mauna Loa Park Trail from 12,000 to 6600 feet elevation. From the 6600 foot elevation on down it follows a straight-line course independent of any road or trail to 3900 feet. The area is covered by aerial photos 4-0015, 6-0124, 2-0081, 4-0038, 5-0014, 4-0066 and 8-0079.

The vegetation types are portrayed on the profile diagram Figure 30, segments 1-12. The vegetation type limits and floristic records were checked with an altimeter. The discussion follows the number sequence of the profile segments on Figure 30.

Segment 1 (Fig. 30). Unvegetated stone desert; map symbol rb; aerial

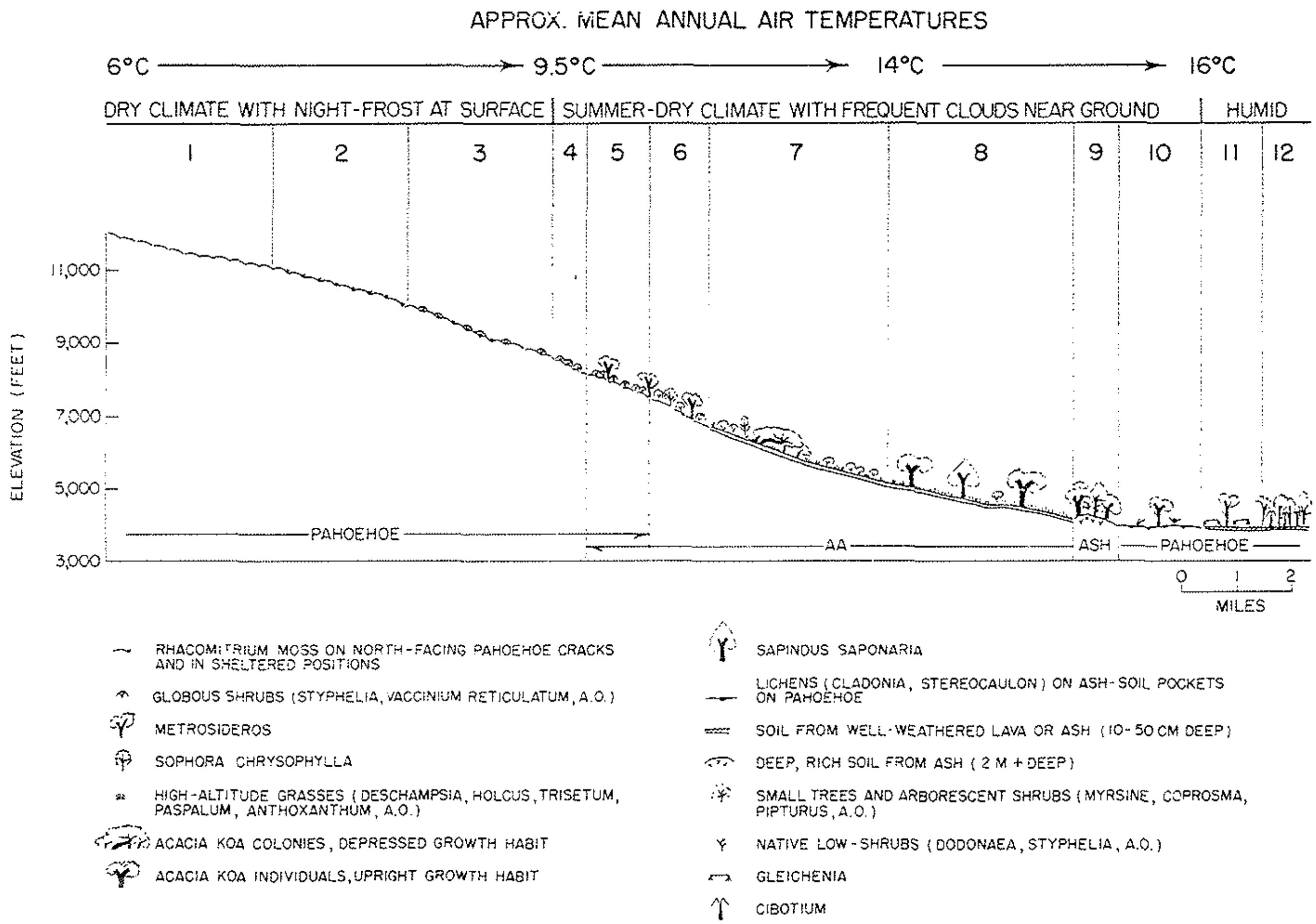


Fig. 30. Profile of vegetation types on the east slope of Mauna Loa from 12,000 feet down to 3900 feet on prehistoric and dominant substrates, 22 miles from Ohaku O Hanalei over Puu Ulaula, Kipuka Puaulu (segment 9) to Kilauea Iki surroundings. This is Transect 1 of the text and Figure 18.

photos 1-0090, 1-0092, 1-0094, 4-0015, 4-0017, 4-0019.

The upper east slope of Mauna Loa, from its summit at 13,676 down to 11,000 feet, can be classified as unvegetated stone desert. Only a single bunch grass of Deschampsia nubigena was noted on the trail at 11,400 feet. Here it was thriving, apparently with good vigor, on an area strewn with olive-black pumice consisting of 0.5 to 3 cm diameter fragments. The air temperature at noon (12:30 p.m.) was 12.5^{o} C, the soil temperature (1 cm in the olive-black pumice) was 28^{o} C on a bright, sunny day (August 17, 1965). In spite of its complete bareness of vegetation, the stone desert area is rather colorful—glistening, greenish-black pahoehoe (smooth, ropy lava) interchanges with steel-gray, older pahoehoe and with buff-colored, more weathered old prehistoric pahoehoe that appears as white fields on the aerial photos (e.g., photos 4-0015, 4-0017 & 6-0124). Also, black and dark-brown a'a (coarse, clinker-like) lava occurs here and there. In addition, one finds local areas of reddish pumice and cinder (that also appear as white flecks on the aerial photos) and areas of olive-black pumice and ash. Other signs of life besides that one clump of grass were the occasional Epilobium seeds that drifted in the afternoon upwinds within 10 m height across the barren lava fields and here and there old horse droppings along the trail. These were completely bleached and straw-like showing no signs of decomposition through microorganisms. (No old horse droppings were sighted below 10,000 feet.)

Segment 2 (Fig. 30). Rhacomitrium moss type; map symbol r(R); aerial photos 6-0124, 6-0126, 6-0128, 7-0014, 11-0007.

The type is composed of small (4 x 10 cm), whitish-gray cushions of Rhacomitrium lanuginosum var. pruinosum that are not readily noticed as they are found only on north-facing cracks of the buff-colored, prehistoric pahoehoe lava and in sheltered blister-holes. The cushions are extremely scattered. Many north-facing lava cracks are barren. Occasionally denser colonies can be observed in association with gypsum crystals. The first cushion-colony was observed at 11,000 feet just below Dewey's cone (aerial photo 11-0007, where overlooking a larger area, Rhacomitrium could be seen here and there clinging to the north-facing cracks. Apparently, this moss has been observed right on the summit of Mauna Loa (Bartram, 1933). This is a noteworthy record that would indicate its distribution continues through the stone desert. However, if it does, it certainly cannot be considered as forming a vegetation type above 11,000 feet, where the writer did not see any specimens. It is important to note that Rhacomitrium was found only in the cracks of the old, buff-colored pahoehoe at 11,000 feet. From 10,500 feet on down it was noted also in the cracks of more recent, dark-gray pahoehoe and on dark-brown a'a.

At 3:30 p.m. a sudden fog appeared from the north that reduced the visibility to 10 m distance. It lasted only for half an hour. It is possible that a short afternoon fog is a rather regular phenomenon in the Rhacomitrium moss type, which seems probable from the discussion of wind movements at the Mauna Loa Observatory by Price & Pales (1963).

Fosberg (1959) found at this elevational range along the Kulani Mauka Road in the somewhat moister northeast slope area two other plants in isolated deep cracks, the fern Pellaea ternifolia, and the grass Trisetum glomeratum.

Segment 3 (Fig. 30). Scattered, low globous scrub type; map symbol r(ns); aerial photos 2-0081, 4-0038, 11-0007.

This type starts at 10,000 feet and extends down to 8500 feet. It consists of only two shrubs, Vaccinium reticulatum and Styphelia douglasii. These shrubs occur first as small (up to 30 cm tall), gnarled individuals with loose, cushion-like crowns. The term cushion applies here and in the following unit descriptions only to the semi-globose crown shape of the shrubs and does not imply a tightness or density feature of the crown habit. The distribution of the shrubs, from 10,000 to 9400 feet, is extremely scattered.

They occur at distances of about 50 to 100 m apart only in the cracks of the buff-colored and steel-gray pahoehoe lava and on red pumice. The latter substrate is only of very restricted distribution. The older a'a flows at this elevation are still barren, except for the presence of Rhacomitrium lanuginosum var. pruinosum that continues also through this shrub type in the north-facing pahoehoe cracks. Trisetum glomeratum dominates as a scattered thin bunch grass on the few small areas strewn with cinder and red pumice. However, these areas are too small for recognition as a separate type on this scale.

Other components in the scattered scrub type include the grass, Deschampsia nubigena (only where there is an accumulation of fine materials), the ferns, Pellaea ternifolia and Asplenium trichomanes, the composites, Tetramolopium humile, Gnaphalium sandwicensium var. kilaueanum, Hypochaeris radicata, and Carex wahuensis var. rubiginosa (in a sheltered blister-hole). All of these are extremely sparsely distributed in the cracks of the old, buff-colored pahoehoe.

Soil temperature (1 cm deep in red pumice) at 10,000 feet was 0° C at 7:30 a.m. on a warm, sunny, summer morning(August 18,1965).

Segment 4 (Fig. 30). Open to closed cushion scrub type; map symbol ns; aerial photos 2-0081, 4-0036, 4-0038, 5-0035.

At 8500 feet shrubs began rather suddenly to grow taller (up to 75 cm) and to be more densely distributed, i.e., at every 5-10 m. They also tended to occur in clumps of several (about 3 or more) individuals with combined crown coverages of 1-3 m^2. This change occurred on the same substrate, i.e., the prehistoric, buff-colored pahoehoe, while on the older a'a lava, at parallel elevations, shrub growth appeared to be as sparse as in the previous type (segment 3, Fig. 30) on pahoehoe. In addition new shrub species appeared, Dodonaea viscosa, at 8400 feet, Coprosma ernodeoides at 8250 feet, Dubautia ciliolata var. laxiflora at 8150 feet. At 8400 feet, the writer noted the first lichens, an Usnea clinging to the branches of a shrub and a minute specimen of a green Cladonia. This observation differs from that made on the north slope of Mauna Loa, where a few colonies of Stereocaulon were noted on lava at this elevational range. However, the absence of lichens above this area is remarkable as the upper vegetation has been described formerly as a moss-lichen type (Robyns & Lamb, 1939). Another noteworthy feature in this type was the occurrence of Trisetum glomeratum in association with the shrub colonies, commonly forming a thin fringe around these, where apparently wind-borne finer soil particles and litter had accumulated.

The sudden change in shrub size and density on the same substrate seems to indicate a rather sudden change in climate beginning with this type. From calculations of daily temperature fluctuations, combined with the small annual range, it is quite conceivable that the effect of nocturnal ground frost suddenly disappears at about this elevational range (e.g., 8100 feet). Thus, a change in climate type has been indicated at this point on Figure 30.

Segment 5 (Fig. 30). Cushion shrubs with scattered Metrosideros; map symbol ns(M); aerial photos 4-0038, 5-0012, 5-0035.

This can also be called the timber line type which extends from 8100 down to 7500 feet. Metrosideros collina appears suddenly as a full-grown tree (3-5 m tall) at 8100 feet. Metrosideros was not seen among the shrubs of the previous type, which would indicate that it does not form an alpine "krummholz." Instead it stands out as a distinct tree occurring in a widely scattered formation of one individual at every 100 to 200 m. The trees showed a slight up-slope lean and shrub growth was distinctly denser and taller beneath the trees indicating a fog drip effect. Metrosideros appeared to be correlated in this type with old, brown a'a lava, rather than with pahoehoe. However, this observation needs further checking. A'a lava became distinctly more dominant at 8100 feet and prevailed from here on down to 3900 feet. At the same time a more advanced degree of surface weathering was noted, as evidenced by the somewhat smoother edges of the a'a chunks and the presence of shallow pockets with finer soil. The strong white-black color contrast on the aerial photos, so characteristic for the upper slope area, also disappears abruptly at about the 8100 feet elevation.

Other new components in this type were the shrubs, Coprosma montana and Dubautia scabra, and the ferns, Pteridium aquilinum var. decompositum and Asplenium adiantum-nigrum. An interesting associate observed at 8100 feet was Argyroxyphium sandwicense (silversword) that occurred here in a local depression with three or four individuals. One of these was flowering and 170 cm tall. While these appeared to be of natural distribution, only one other specimen planted at 10,035 feet was observed along the transect. Thus, silversword has a wide altitudinal range as was noted already by Hartt & Neal (1941) and thus can hardly be used for a fine distinction of the altitudinal vegetation types on Mauna Loa, except in a negative way due to its extreme rareness.

Segment 6 (Fig. 30). Open Metrosideros—Sophora forest; map symbol oM(So-ns);

aerial photos 5-0012, 5-0035.

This upper subalpine forest extends from 7500 down to 6600 feet elevation. It has been observed only on a'a lava showing a reasonable degree of surface weathering. The pockets between the a'a chunks were filled with soil and the rock itself could be broken apart by kicking with the foot. In contrast to the preceding two types, however, the type boundary is less sharp. This type is particularly characterized by relatively denser tree growth, with the individuals from 10 to 50 m apart as opposed to a density of 100 to 200 m/individual in the preceding timberline type. Tree height increase was not so pronounced, but tree height averaged 5 m. Sophora chrysophylla occurred here as a scattered tree, first noticed at 6900 feet. Coprosma montana assumed tree stature, growing up to 3 m tall, but occasionally these shrubs were taller (up to 1.5 or occasionally 2 m) and tended to fill-in, forming the main matrix instead of the barren rock matrix of the preceding types. Thus the tendency of shrub clumping beneath individual trees, so characteristic for the timber line type (segment 5), appeared lost. Pteridium became denser and Deschampsia nubigena more common. Noteworthy new components besides Sophora were the shrub, Geranium cuneatum var. hypoleucum (at 7500 feet) and an occasional Luzula hawaiiensis.

Segment 7 (Fig. 30). Tall cushion scrub savannah with scattered Acacia koa colonies; map symbol mx-ns (AcSoM); aerial photos 4-0066, 5-0014.

This type occurs from 6600 down to about 5000, or in places to 4200 feet. It occurs on soil varying from about 10-50 cm deep and which appears to be in part derived in situ from weathered a'a lava and in part from ash. A significant difference from the preceding type is the abundance of mixed high-altitude grasses that form the matrix. These are composed largely of Deschampsia nubigena, Trisetum glomeratum, Holcus lanatus, Anthoxantum odoratum, Festuca ernoides, Eragrostis atropioides and Paspalum urvillei.

They commonly exhibit a tussock-like habit where not too dense. Their general height is about 75 cm to 1 m. A dominant component in the herb layer is Pteridium aquilinum var. decompositum. Other common herbaceous plants are Luzula hawaiiensis and Hypochaeris radicata. There appears to be no ground exposed. The type transition is very abrupt, which may be correlated with the sudden difference in substrate. The same shrubs of the preceding unit continue to form a major element in the vegetation. However, they occur in patch-communities from but a few meters square to several 100 m^2 in size. The dominant shrubs are Styphelia and Dodonaea which are commonly 1.5 to 2 m tall, with dense globular crowns. A third major element is Acacia koa that grows here in circular or eliptic colonies of 30-100 m in diameter. These colonies usually consist of one or two central trees with relatively large trunk diameters of 70-100 cm and maximum crown heights of 15 m. The trunks are commonly gnarled at about breast height and the upper trunk part may then spread like a branch. Smaller koa trees are associated with the fringe area of the colonies. The crown-outline of these koa colonies is umbrella-shaped. Occasional dead branches are heavily covered with Usnea. In addition widely-scattered single trees of Metrosideros and Sophora occur that are usually not taller than 5 to 10 m. This type, which appears to correspond to the mountain parkland formation of Robyns & Lamb (1939), can be viewed as a complex of three types, grassland, shrubland, and forest. However, their pattern is rather diffuse and the communities are generally too small for separate mapping on the scale of 1:12,000 used.

Segment 8 (Fig. 30). Mixed Acacia koa—Sapindus tree savannah; map symbol mx-AcSaM; aerial photos 4-0066, 8-0079.

This type begins at about 5000 and extends down to 4000 feet. It occurs on the same well-weathered substratum and soil. The main difference from the preceding type is the absence of the tall cushion shrub communities. Instead relatively tall (15-25 m), scattered and rather isolated trees are found growing among tall grasses, largely composed of the same species as of the preceding type. The tussock-habit is absent and Pteridium aquilinum appears to be even more abundant. Occasional shrubs, a 2-3 m tall Dodonaea or even a Pipturus may be found, but they are rather insignificant components. A new tree component is Sapindus saponaria growing with beautiful, high, umbrella-shaped crowns. Acacia koa individuals dominate and seem to find their ecological optimum in this type together with the Sapindus. Scattered, tall Metrosideros is present as well as Sophora, which never seems to get as tall as the other three.

Segment 9 (Fig. 30). Mixed Acacia koa—Sapindus forest with lower-story trees and arborescent shrubs; map symbol AcSaM (ad); aerial photo 8-0079.

This is the closed forest type of Kipuka Puaulu (Bird Park), which is however also represented by Kipuka Ki and others in the summer-dry climate on deeply weathered soil. The soil here is composed of deep (up to 6 m) volcanic ash, probably of dune origin (Mueller-Dombois & Lamoureux, 1964), and it is much enriched with organic colloids. These closed forest types occur usually as islands (kipukas) throughout the same elevational range as the preceding savannah type, i.e., between 5000 and 4000 feet. However, this particular kipuka (Puaulu) ranges from about 4200 to 3900 feet exhibiting a broadly undulating secondary topography. All preceding types occurred on the typically smooth, gently-sloping east-flank of Mauna Loa showing no pronounced secondary topography. The taller trees (20-30 m) are dominantly of Acacia koa, Sapindus and Metrosideros. A well-developed lower tree layer (of 2-10 m height) comprises a number of tree species among which Myrsine lessertiana, Coprosma rhynchocarpa, Myoporum sandwicense, Psychotria hawaiiensis, Osmanthus sandwicensis and Sophora chrysophylla are the most common. Several species of Pelea are also present. An abundant arborescent shrub, which dominates this stratum locally, is Pipturus albidus. The understory in the less dense parts of the forest is comprised largely of a native fern, Microlepia setosa. There are several noteworthy patch communities beneath the tree canopy. Of particular interest are the Peperomia cookiana patches on pig-scarified ground, and the introduced plants now forming communities such as the two shrubs, Rubus penetrans and Solanum pseudocapsicum, and the herb, Commelina diffusa. The oldest trees are partly covered with epiphytic mosses.

An open forest (Acacia koa, Sapindus, Metrosideros) or savannah occurring in a tall-grass-Pteridium matrix occurs within this kipuka. It corresponds closely to the preceding type, but here it also grows on the deep ash soil. The kipuka is surrounded in its upper part by a Metrosideros forest belt on more recent a'a.

Segment 10 (Fig. 30). Open Metrosideros—lichen forest with native low shrubs; map symbol oM (L-ns); aerial photo 8-0079.

An abrupt change occurs from the kipuka forest to this open forest on old, but little-weathered, pahoehoe. Here Metrosideros grows in the old pahoehoe cracks, that appear to largely control the density of stocking. The trees, though appearing old, are rather short (3-10 m). The depressions between the outcropping convex pahoehoe blocks are covered with finer soil and ash, about 10-30 cm deep. This finer material is still relatively coarse textured and supports only a poor growth of lichens (Cladonia spp. and Stereocaulon) grasses and herbs (e.g., scattered, short Pteridium, Bulbostylis capillaris). Also, mostly in association with the cracks, low (up to 1 m tall) shrubs grow, such as Dodonaea viscosa, Styphelia tamaiamaia, Dubautia scabra and Coprosma ernodeoides (creeping habit).

Segment 11 (Fig. 30). Open Metrosideros—Gleichenia forest; map symbol oM(G); aerial photo 8-0079.

This forest appears just east of the previous type, and at the same elevation (3900 feet), but where the climate changes rather suddenly from summer-dry to humid (near the Military Camp). There is a broader transition zone than between the two preceding types. This is, however, somewhat obscured by a large fumarole area (fu) west of Park headquarters and much modification by man. However, the type is evident in less disturbed areas. It consists of a stand of pure Metrosideros similar to the preceding type, but instead of lichens and scattered herbs and shrubs the associated vegetation is largely formed by matted thickets of the fern, Gleichenia linearis. In places not dominated by this creeping fern one can find Dianella, Hedyotis centranthoides, Lycopodium cernuum and the tall grass, Andropogon virginicus.

This forest type is considered to be a developmental variation of the montane rain forest, which is exemplified by the next type.

Segment 12 (Fig. 30). Closed Metrosideros—Cibotium forest; map symbol cM(C); aerial photo 8-0106.

This is the dominant montane rain forest type in the Park. It is characterized by a pure stand of relatively even-sized Metrosideros trees, with diameters at breast height of 40-65 cm and uniform crown-canopy heights ranging between 14 and 20 m. The branches are more crowded on the upper one-third of the bole and grow at steep angles upward into a somewhat umbel-shaped crown. Tree boles are rather naked and rarely covered with epiphytes. A distinct second tree layer is formed by the tree fern

(Cibotium spp.) that grows here to a relatively uniform crown height of about 2-5 m. The Cibotium understory is characteristically rather dense and, in this area (i.e., near Kilauea Iki), commonly mixed with the other tall fern, Sadleria cyatheoides (which is however not a tree fern). Where there is an interruption in the Cibotium canopy, there is usually some tree fern regeneration, but a variety of less dominant species can be found. These include the small and extremely scattered trees Myrsine lessertiana, Ilex anomala, Coprosma montana and Gouldia terminalis, the shrubs Wikstroemia, Vaccinium calycinum, Pipturus albidus, Cyrtandra platyphylla, the herbs Gahnia gahniaeformis, Briza minor, Isachne distichophylla, Lycopodium cernuum, Hedyotis centranthoides and Peperomia spp. Epiphytic mosses and ferns, such as Acroporium fusco-flavum and Elaphoglossum reticulatum can be found on the lower trunks of Metrosideros.

Vegetation types along south-north transects through the Park. Transects 2, 3 and 4 (Fig. 18). Profile diagrams Figures 31, 32 and 33.

Three roughly parallel south-north transects (for location see Fig. 13, in chapter on climate) are represented as topographic vegetation profiles (Figs. 31-33). These can be used in categorizing the vegetation from sea level to mid-altitudes of, e.g., 5000 feet. They also serve to illustrate the variations from west to east across the main area of the Park along the south and southeast slopes of Kilauea.

Transect 2, from sea level to 5000 feet through Kau Desert. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 31. Of the eleven profile segments shown, only seven (numbers 1-6 and 11) represent new vegetation types that have not already been described before in the discussion of Transect 1. The discussion follows in sequence of the profile segments shown on Figure 31.

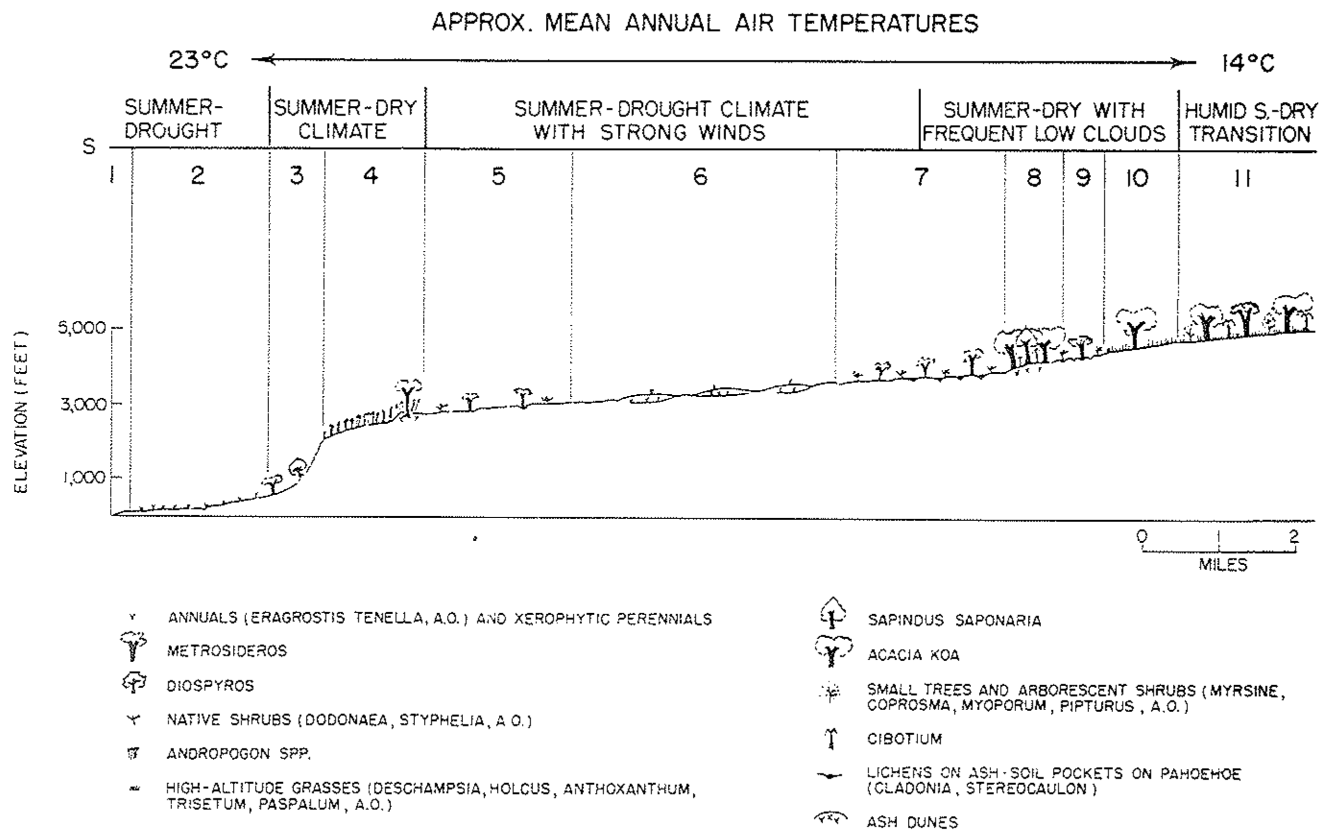
Segment 1 (Fig. 31). Salt spray and other shore communities; map symbol r(spr) and spr; all aerial photos showing shoreline (see Chapt. I, Fig. 6).

This type encompasses several distinct communities that occur on the narrow strip of land along the coastline that marks the seaward boundary of the Park. They are described in detail in Chapter VII, above. The reason for treating this zone as one type is simply a matter of convenience for the vegetation patterning is too small for the scale of mapping used. The predominantly coastal salt-spray zone is comprised of lava barren of macroscopic vegetation and often ending in cliffs vertical to the water line. These cliffs extend above sea level from a few feet to about 50 feet and bear only a few higher plants. These as found on the salt-swept cliff faces or in the extremely scattered, soil-filled cracks are, for example, Portulaca cyanosperma and Fimbristylis cymosa. However, this area is densely covered by a thin coating of algae.

In a few places, where the lava surface is right at sea level or even somewhat submerged and covered with sand of coral and lava origin, there are a few scattered strand communities with the trailing Ipomoea pes-caprae and occasional individuals of the tree, Tournefortia argentea. These occur on somewhat elevated sand, whereas a few halophytic communities, dominated by Sesuvium portulacastrum, are found on patchy sand flats that are periodically inundated with the incoming tide. These more densely vegetated communities are designated by the symbol spr on the map sheets. (The only Prosopis pallida stand in the Park is at Keauhou Landing aerial photo 8-0102 . It has been mapped separately and designated by the symbol P.)

Segment 2 (Fig. 31). Eragrostis tenella grassland; map symbol E(r); aerial photos covering the shore (see Fig. 6 in Chapt. I).

Fig. 31. South-north profile of vegetation types in the west-central area of the Park from sea level to 5000 feet, i.e., for 17 miles from the shore (segment 1) through Hilina Pali (segment 3), the Kau Desert (segment 6) and Kipuka Puaulu (segment 8) to the Kilauea Forest Reserve (segment 11). This is Transect 2 of the text and Figure 18.



This is one of the two dominant dry grass types of the coastal lowland area. The other is Heteropogon contortus, shown on the remaining profile diagrams, Figures 32-34. Most of the area between the salt-spray zone and the foot of Hilina Pali is segment 2 in Figure 31, Eragrostis tenella grassland. It gives a straw-yellow hue to this area during the summer-drought season. However, its cover is relatively thin. The grass is confined to the ash-filled depressions that occur as patchy flats between the outcropping pahoehoe mounds. An equally abundant, but less conspicuous associate is the annual Bulbostylis capillaris. The very similar Fimbristylis hawaiiensis is less common. A poikilohydrous liverwort, that in dried-up condition during the summer-drought season looks like spotty crustations of salt, grows in small patches beneath these two annuals. Another associate is a tiny legume, Desmodium triflorum, which forms small rosettes at the surface that remain green during the summer. The density of the Eragrostis tenella grassland is related to the availability of ash pockets or depressions. In the very rarely exposed soil-filled pahoehoe cracks (which constitute a different habitat type), one finds occasionally the grasses Chrysopogon aciculatus, Chloris inflata and Heteropogon contortus.

A small area of especially dense grass cover occurs east of this transect on Puu Kaone (aerial photos 8-0073, 8-0102), which remains green during the summer-drought season. It occurs on deep, yellow, loess-like ash and is comprised largely of Chrysopogon aciculatus and Cynodon dactylon. In certain areas it is heavily mixed with the small legume shrub, Indigofera suffruticosa. This grassland has been mapped separately with the symbol Ch. It is the central gathering place for the goat herds that roam particularly through segments 2-5 on Figure 31 and segments 2-4 on Figure 32.

Segment 3 (Fig. 31). Very open Metrosideros—Diospyros forest; map symbol MD(r); aerial photos 8-0073, 8-0102, 8-0070.

This extremely open forest type occurs on the steep slope of the Hilina Pali where the trees grow singly or in small groups on almost barren, colluvial a'a. Both tree species have distinctly sclerophyllous foliage and rather broad and open crowns. The trees are relatively short (5-8 m), branchy and have thick trunks (30-50 cm) and a somewhat corky and scaly bark. Native shrubs are conspicuously rare, a few scattered small introduced shrubs are found near the lower end of the slope, such as Waltheria indica var. americana and Pluchea odorata. Widely scattered herbaceous plants are found throughout the type. These include the two ferns, Doryopteris decora and Pityrogramma calomelanos, and the composite Ageratum conyzoides, etc.

Segment 4 (Fig. 31). Andropogon grassland; map symbol An(M); aerial photos 4-0060, 4-0068, 8-0075.

This dense tall-grass type extends from the top of Hilina Pali (at about 2000 feet elevation) to the southern edge of the Kau Desert (segment 5). The name-giving grass includes two species, Andropogon glomerata and A. virginicus. The first is the more dominant. An additional dominant component is Pteridium aquilinum var. decompositum. Occasionally patches of the creeping molasses grass (Melinis minutiflora) have gained local dominance. A few scattered native shrubs of Dodonaea and Styphelia are also present. Metrosideros trees are conspicuous, but they are of very irregular distribution. They occur as widely scattered single trees and in form of larger north-south oriented, open tree colonies. The latter may, in some cases, represent kipukas (islands of remnant vegetation). However, the species composition in these open tree colonies differs but little from the rest of the area. The main undergrowth is the Andropogon.

Of particular interest is the abrupt boundary of this grassland to the north, where it is fringed by a series of ash dunes. Also here one finds little difference in species composition, but the vegetation differs considerably in structure. The dunes are occupied by more or less open Metrosideros patch forests with Andropogon undergrowth and a few scattered native shrubs. Some of the dunes are up to 10 m high. Here one can find snags of Metrosideros that may have been killed as a result of the eolian sand-like ash deposits increasing in depth rapidly. Fallen trees, in places where the dunes have been ripped open by winds from the Kau Desert, show layers of adventious roots from the base of the stem upwards; as though they had formed as a result of locally increasing depths of the dune deposits. The dune fringe is correlated also with a change in slope (Fig. 31). It is conceivable that the southwest blowing winds from the Kau Desert lost velocity rather suddenly at the point of slope increase. Thus, the dune fringe can be considered as conditioned primarily through topography, rather than vegetation. The three described cover variations, open Andropogon grassland, Andropogon—Metrosideros savannah and Metrosideros—Andropogon patch forests that are here treated as one type have been mapped as separate entities wherever possible.

Segment 5 (Fig. 31). Metrosideros scrub forest; map symbol scM(r); aerial photos 4-0062, 4-0064, 8-0075, 8-0077.

This open scrub forest forms a broad fringe at the south, east and north sides of the Kau Desert and can be considered as semi-desert vegetation. It occurs only on old pahoehoe. The western fringe area of the Kau Desert is formed by a similar Metrosideros scrub forest, which however occurs on a'a lava. Though not shown separately on Figure 31, its distribution is very much like segment 9. The major difference is in the stocking density of Metrosideros, which on pahoehoe is extremely open (varying from 20-60 m distance between individuals). Here the trees are found only in the broader and deeper pahoehoe cracks. Shallower cracks are vegetated with native shrubs of predominantly Styphelia tameiameiae and Dodonaea viscosa, occasionally also with small Metrosideros of shrub stature. Most of the surface matrix is barren exposed pahoehoe lava. Stabilized, flat ash pockets in depressions here and there are covered with a sparse cover of Bulbostylis capillaris. The southern boundary of this stand is formed by the fringe of dunes discussed before, which causes an abrupt change in vegetation. The boundary to the north is more gradual and a transitory native scrub type has been recognized on the map sheets in which Metrosideros, if present at all, has lost its tree stature entirely.

Segment 6 (Fig. 31). Extremely sparse desert vegetation; map symbol r-ash(poik); aerial photos 4-0064, 8-0077.

This type represents the central area of the Kau Desert which consists of almost barren lava with shifting ash dunes that are extremely sparingly vegetated with annuals and mostly poikilohydrous perennials. Dwarfed woody plants of Styphelia and Dodonaea are found occasionally in lava cracks. The poikilohydrous perennials on shifting ash dunes include Cyperus polystachyos, Eragrostis variabilis, Gnaphalium sandwicense var. kilaueanum, Euphorbia hirta, Cenchrus echinatus var. hillebrandii, Silene struthioloides and Cynodon dactylon. Only one annual was noted, Agrostis avenacea. The absence of Bulbostylis capillaris was rather striking as this annual is otherwise distinctly associated with ash deposits in summer-dry and -drought climates (e.g., segment 2, Fig. 31). However, it seems to occur only when ash deposits are well stabilized. Many of these plants were partly buried in the sand-like, shifting ash. This fact may provide an explanation for the bareness of this area. Not necessarily the young age of the substrate (much of the sand-like ash was deposited as a result of the 1924 Kilauea explosion), but the instability of the substrate appears to be a major factor in this desert formation, which here is correlated with a pronounced summer-drought during which desiccation by the trade winds appear to have a strong effect. They apparently unload their moisture before reaching the Kau Desert, where they sweep across with unimpeded velocity as evidenced particularly by the frequency of dunes found at the southwest side of the Kau Desert. Sulfur fumes from Halemaumau, at the north end of Kau Desert, may be a contributing factor. Killing of plants occurs only a relatively short distance downwind from other constantly fuming areas in the Park.

Segment 7 (Fig. 31). Open Metrosideros—lichen forest with native low shrubs; map symbol oM (L-ns); aerial photos 4-0064, 8-0077.

This type has already been described as segment 10 on Figure 30. At its southern connection to the Kau Desert, it coincides more closely with the Metrosideros scrub forest described as segment 5 of Figure 31. On the map sheet, the two variations have been mapped as such. However, the transition is very gradual. The boundary between summer-drought and summer-dry climate seems to approximately coincide with the points of departure in structural and floristic variation. The structural variation is shown mainly by a gradual decrease in tree height and wider spacing of trees and shrubs and the floristic variation by the gradual disappearance of lichens in the southern variation.

Segment 8 (Fig. 31). Mixed Acacia koa—Sapindus forest with lower-story trees and arborescent shrubs; map symbol AcSaM (ad); aerial photo 8-0079.

This is the major vegetation type of Kipuka Puaulu shown as segment 9 on Figure 30, and described above.

Segment 9 (Fig. 31). Open Metrosideros—native shrub forest; map symbol oM (ns); aerial photo 8-0079.

This forest occurs on a'a lava that forms the north wall around Kipuka Puaulu. The tree layer is comprised only of Metrosideros and the associated shrubs are mainly Styphelia and Dodonaea. The forest is very similar to segment 7 (Fig. 31) on pahoehoe, however it lacks the lichen and grass-covered ash pockets and shows denser stocking in parts. The same type marks also the western border of the Kau Desert, where it extends on the late prehistoric Keamoku a'a flow along the Kona Highway. Here Metrosideros is, however, more of a shrub in stature.

Segment 10 (Fig. 31). Open Acacia koa grazing savannah; map symbol mxg-AcM; aerial photo 8-0079.

This is a variation of the type represented by segment 8, Figure 30, described above. The area lies outside the Park boundary, where it is used for cattle grazing. The grass composition is depauperated and here dominated by Anthoxantum odoratum. Several snagged and fallen Acacia koa trees were noted. A subdominant tree component is Metrosideros and possibly, elsewhere but not on this profile, Sapindus.

Segment 11 (Fig. 31). Mixed Acacia koa—Metrosideros forest with arborescnet shrubs and Cibotium; map symbol AcM (ad-C); aerial photo 8-0081.

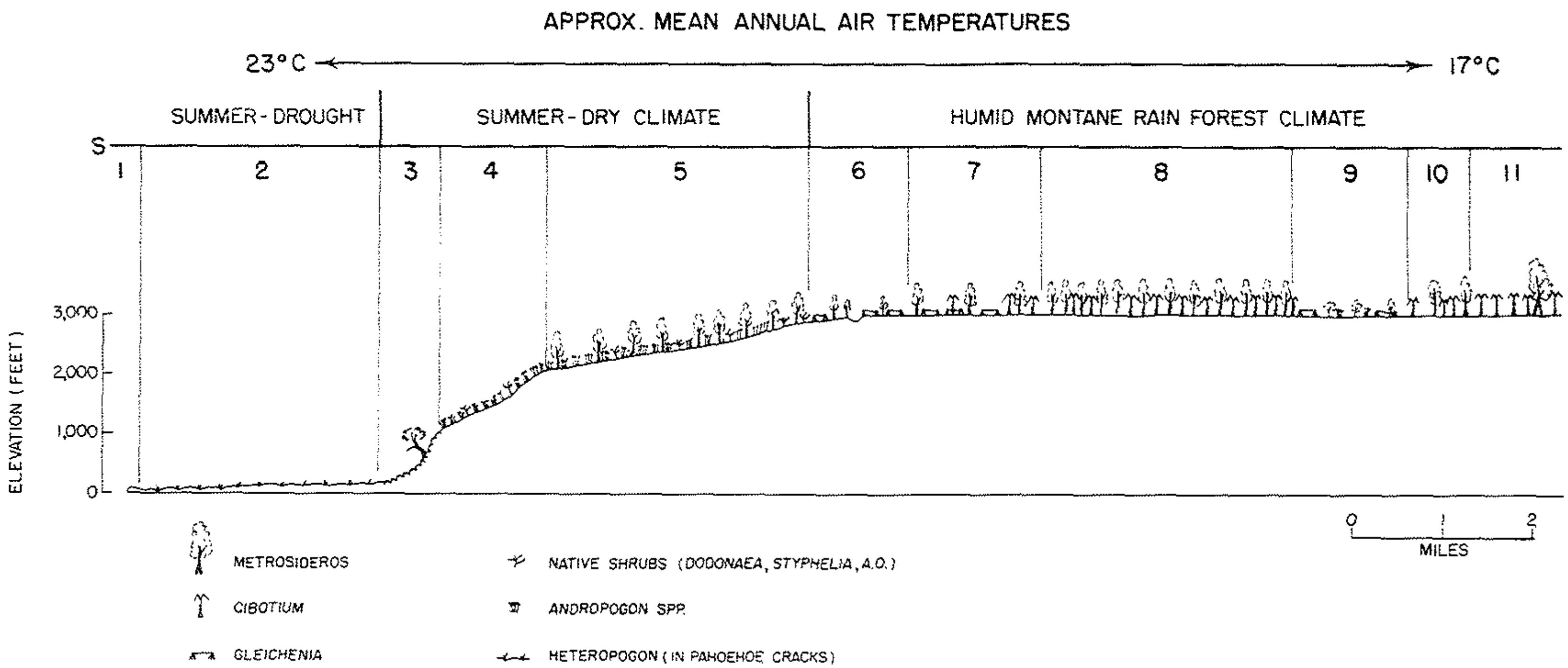
This type represents a transition form between the typical Acacia koa forest and the Metrosideros rain forest. Neither of these latter is shown on this profile because the typical Acacia koa forest (without Cibotium) occurs above this zone (i.e., from about 5000 to 6000 feet, upper Kilauea Forest Reserve and outside the Reserve), and the typical Metrosideros rain forest occurs below this zone (from about 4500 feet downward). This Acacia koa--Metrosideros forest with Cibotium is well represented south of Kulani Prison Camp. It occurs on relatively deep, well-weathered soil. The upper tree canopy is dominated by tall (20-30 m), full-crowned Acacia koa trees with large (80-150 cm) trunk diameters. Metrosideros, though not so large in crown diameter is similarly tall. A second tree layer is dominated by tree ferns (Cibotium spp.), but contains also a number of other smaller trees, such as Myrsine lessertiana, Myoporum sandwicense and Coprosma spp. Occasional openings in the tree canopy are covered with mixed grasses.

Transect 3, from sea level at Apua Point to 3000 feet through Alae crater. The transect covers most of the east-central area of the Park north and south of the Chain-of-Craters Road. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 32. The lower left side of this profile diagram (segments 1-4) shows similarity to the lower left-hand side (segments 1-4) of Figure 31 (Transect 2). Also, the humid montane rain forest on the upper right-hand side of Figure 32 has already been introduced by two types (segments 11 and 12) on Figure 30 (Transect 1). Therefore, in spite of the 11 divisions shown on Figure 32, the profile introduces only three entirely new types. These are represented by segments 2, 5 and 11. The discussion follows again the sequence indicated by the segment numbers on the profile diagram Figure 32.

Segment 1 (Fig. 32). Salt spray and other shore communities; map symbol r(spr) and spr; aerial photo 8-0070.

For description see above under Transect 2. It may be noted that an unusually broad strand community (spr) can be seen near Apua Point, the start of this profile.

Fig. 32. South-north profile of vegetation types in east-central area of the Park from sea level to 3000 feet, 16 miles (from Apua Point through Alae Crater to Olaa Forest Reserve). This is Transect 3 of the text and Figure 18.



Segment 2 (Fig. 32). Heteropogon grassland; map symbol H(r); aerial photo 8-0070.

This is not a homogeneous vegetation type, but it is distinct from the other coastal lowland dry-grass types, the Eragrostis tenella grassland (Fig. 31, segment 2). The main ecological difference is the absence of ash pockets on the pahoehoe, which in this type exposes more soil-filled cracks that are the particular habitat of Heteropogon contortus. But several other grasses are found here as well, such as Chrysopogon aciculatus, Sporobolus diander, Chloris inflata, Tricholaena repens, Dactyloctenium aegyptium, and other herbs such as Fimbristylis cymosa, Emilia javanica and Portulaca cyanosperma. Various low shrubs may be found in association with the herbs, such as Waltheria indica var. americana, Pluchea odorata, Cassia leschenaultiana, C. bicapsularis, Osteomeles anthyllidifolia and Indigofera suffruticosa. Depending on the number of available cracks, age of pahoehoe and various other factors, which include the goat browsing pressure in this area, the Heteropogon grassland may vary from extremely thin cover, where most of the surface is barren lava [map symbol r(H)] to a relatively dense cover, in which the introduced, thin-stemmed and low-growing leguminous shrubs (Cassia and Indigofera) may become rather dense [map symbol H(lsi)].

Segment 3 (Fig. 32). Very open Metrosideros—Diospyros forest; map symbol MD(r); aerial photo 8-0070.

See previous description under Transect 2. Here, the area of this slope type is locally not as large as that on Hilina Pali (Fig. 31, segment 3). Thus it is symbolized only by one sclerophyllous tree, Metrosideros, on the colluvial a'a slope. The relative abundance of Diospyros varies from place to place within the type and there are areas where it is difficult to locate an individual.

Segment 4 (Fig. 32). Andropogon grassland; map symbol An(ns-i); aerial photos 8-0068, 8-0070.

See description above under Transect 2. In this area of the Park the Andropogon grassland varies in that there is no dune fringe at its northern border. Also, Metrosideros, as trees, is almost absent, instead shrubs are more prevalent. It is interesting that introduced shrubs have penetrated into this type, apparently from the lowland areas, while they are rarely found higher up in the next types. The introduced shrubs include Lantana camara, Psidium guajava and Stachytarpheta jamaicensis. The native shrubs are mostly represented by Dodonaea, Wikstroemia, Styphelia and Myoporum. The thick-mat forming grass, Melinis, is particularly "advancing" in this area of the type. Where this type is grazed by cattle (Ainahou Ranch) Sporobolus africanus becomes dominant in place of Andropogon.

Segment 5 (Fig. 32). Open Metrosideros—Andropogon forest with native shrubs; map symbol oM(ns-An); aerial photo 8-0068.

This type can also be called the seasonal evergreen forest, since it occurs in the summer-dry climate. It is, next to the montane rain forest, the most dominant forest type in the Park that extends, with some structural variations from the Andropogon-grassland at 2000 feet to the Metrosideros—Gleichenia rain forest at about 3000 feet, near the Chain-of-Craters Road. From west to east it extends from the fringe forest around Kau Desert (segments 5 and 7 on Fig. 31) to near the southward sloping part of the Kalapana Road (south of Makaopuhi Crater).

The forest is composed of pure Metrosideros in the tree layer, which varies in size and density with degree of weathering of the substrate. On more strongly weathered pahoehoe, the trees are as tall as in the adjacent rain forest to the north and they form, occasionally, relatively closed stands. More dominant is an open growth pattern, where the spaces between the trees (about 5-10 m apart) are occupied by a loose growth of native shrubs, such as Styphelia tameiameiae, Dodonaea viscosa, Wikstroemia sandwicensis and Dubautia scabra. The herb layer is distinctly dominated by Andropogon spp., where here the more prevalent species is A. virginicus rather than A. glomeratus. Other, commonly associated herbs are Gahnia gahniaeformis, Silene gallica and Sporobolus africanus.

In all places visited, pahoehoe lava was found to crop out at the surface, thus fine soil occurs only in cracks and the more or less deep (20-40 cm) depressions between the outcropping mounds. In these pockets the soil is formed primarily from coarse, sand-grained ash. Such ash pockets are often occupied by Bulbostylis capillaris, and occasionally by lichens in very open places.

In spite of a similar tree stand the type is well distinguishable from the rain forest by the complete absence of Gleichenia and Cibotium and the prevalence of Andropogon.

Segment 6 (Fig. 32). Disturbed Metrosideros scrub forest with Gleichenia and Andropogon patches; map symbol scM(G-An); aerial photos 8-0068, 8-0066.

This forest occurs along the Chain-of-Craters Road around Alae Crater (the crater is indicated by a depression of Fig. 32). The disturbed condition is caused in part by a fire that went through this particular area about 30 years ago, in part by the proximity of fumarole areas and scattered, individual steam vents and in part by relatively recent lava flows. The type recurs as segment 9 (Fig. 32) far within the humid montane rain forest climate, where the disturbance is primarily due to the recency of the underlying substrate. From extrapolation of relatively undisturbed types in the vicinity it became clear that this type (segment 6, Fig. 32) can be considered a seral form of the humid montane rain forest. It is characterized by scattered small (1-5 m) Metrosideros trees, some of which are sprouts from stumps. Also, smaller seedlings may be present. The ground cover is dominated by thickets of the creeping fern, Gleichenia linearis, and by patches of Andropogon virginicus. Other common plants are Lycopodium cernuum, Machaerina angustifolia, Carex wahuensis var. rubiginosa, Isachne distichophylla and Briza minor. The Gleichenia cover in this type is somewhat similar to the Gleichenia mats found at mid-slope on the windward ridges of Oahu. However, ecologically the two Gleichenia areas are quite different, with the main physiognomic difference being the much greater frequency of Metrosideros trees in the Hawaii Volcanoes National Park type (segments 6 and 9, Fig. 32). The Gleichenia itself is different in the Park, being G. linearis var. tomentosa.

Segment 7 (Fig. 32). Open Metrosideros—Cibotium—Gleichenia forest; map symbol oM(C-G); aerial photo 8-0066.

This type is of wide-spread occurrence in the continuously humid montane rain forest climate and it can be considered an intermediate developmental form between the disturbed Metrosideros—Gleichenia scrub forest type (segment 6) and the closed Metrosideros—Cibotium forest (segment 8). Its major characteristics are the open growth of Metrosideros trees (5-15 m apart), the dense patch formations of Gleichenia in the openings, and the abundance of tree ferns (Cibotium spp.). The taller Cibotium individuals (1.5-3 m) are roughly equal in number to the Metrosideros tree individuals. In this type Gleichenia can often be seen to have grown into the lower crowns of the Metrosideros trees (up to heights of 3-5 m). Other common associates include Vaccinium calycinum, Wikstroemia sp., and Sadleria cyatheoides in the shrub layer, and Lycopodium cernuum, Isachne distichophylla and Hedyotis centhranthoides in the herb layer together with the dominant Gleichenia.

Segment 8 (Fig. 32). Closed Metrosideros—Cibotium forest; map symbol cM(C); aerial photos 8-0064, 8-0066.

This is the same as segment 12 on Figure 30. For description see discussion under Transect 2, above.

Segment 9 (Fig. 32). Disturbed Metrosideros scrub forest with Gleichenia and Andropogon patches; map symbol ScM(G-An); aerial photo 8-0066.

This type is the same as represented by segment 6 on Figure 26. However, steam vents are absent in this area near the Volcano Road. Instead the disturbed condition is primarily caused by the recency of the lava substrate and, in part, locally aggravated by the clearing of vegetation for land development. Andropogon virginicus cover dominates locally over Gleichenia in the most recently disturbed areas.

Segment 10 (Fig. 32). Open Metrosideros—Cibotium forest; map symbol oM(C); aerial photos 8-0062, 8-0064.

The spacing of Metrosideros compares very closely to the open growth described for segment 7 (Fig. 32). However, the intervening spaces between the trees are filled with dense growths of Cibotium, while Gleichenia is very rare or absent. Other occasional components in the tree fern layer are Pipturus, Cyrtandra and Myoporum. The herb layer is very poorly represented because of the dense shade beneath the Cibotium fronds. This type occurs on shallow soil pockets on pahoehoe as well as on deeper soil formed from well-weathered ash. It seems to represent a later developmental form of segment 8, in which several Metrosideros trees have died, broken down and been replaced by Cibotium. This type is found only north of the Volcano Road, i.e., outside the Park boundary.

Segment 11 (Fig. 32). Cibotium forest with scattered old Metrosideros trees that are covered with epiphytes; map symbol C(M^e); aerial photos 8-0062, 8-0064.

This type is characterized by a distinct cover-dominance of Cibotium, which here attain occasionally a height of 4-8 m, and by the presence of scattered, often very tall (20-25 m), Metrosideros trees. These have commonly a split lower "trunk," which indicates that they germinated on higher objects (usually tree ferns) and then sent their roots downward into the soil. The tree-fern substrates are still alive in many cases, as Metrosideros collina does not form an anastomozing root system around the substrate-host as does Metrosideros robusta in New Zealand (Walter, 1964). There are also many trees in this type that germinated in the soil, and even smaller trees can be found in this same category. The latter may have germinated in open places created by the breakdown of over-mature Metrosideros, which gave the seedlings a chance to grow through the Cibotium layer before the tree canopy overhead closed. Germination on higher objects that provide sufficient light for growth for the obviously shade-intolerant Metrosideros, shows a remarkable adaptation to survival in densely vegetated, old stands. Another important characteristic is the abundance of vascular epiphytes, such as Astelia menziesiana, Freycinetia arborea, Peperomia spp. and Cheirodendron trigynum. The latter is also found as a soil-rooted tree in more open places. In addition, trunks and branches of the old, tall Metrosideros trees are often covered with epiphytic ferns and bryophytes, the latter may often provide suitable habitat conditions for the vascular epiphytes. Even a tree fern and, in several cases, a small Metrosideros tree were observed to have grown epiphytically on old Metrosideros trees. Such old trees typically have rather rough, scaly bark, aerial roots along the trunk, and often enormous branches that though crooked have some horizontal segments which are particularly crowded with epiphytes. There are many other small trees and arborescent shrub species in this type, but they are not dominant. Among these are Myrsine lessertiana, Coprosma rhynchocarpa, Pipturus albidus, Pittosporum sp., Myoporum sandwicense, Pelea sp. and Cyrtandra. Occasional patches or individuals of the native palm, Pritchardia, can be found. Wherever this stand was observed, it occurred on deep, melanized soil from well-weathered ash.

Transect 4, from sea level to 2500 feet through Naulu Forest to Napau Crater. For location see map, Figure 18. The transect is portrayed by profile diagram Figure 33. The diagram shows seven profile segments. Segments 1 and 2 represent the same vegetation type as segments 1 and 2 on Figure 32 (Transect 3) and segment 7 represents the same humid rain forest type as segment 8 on Figure 32 and segment 12 on Figure 30 (Transect 1). Segments 3-6 (Fig. 33) represent new type variations found in this, more eastern part of the Park. The discussion follows the segment number indicated on the profile diagram Figure 33.

Segment 1 (Fig. 33). Salt spray and other shore communities; map symbol r(spr); aerial photo 8-0024.

For description see Transect 2, above.

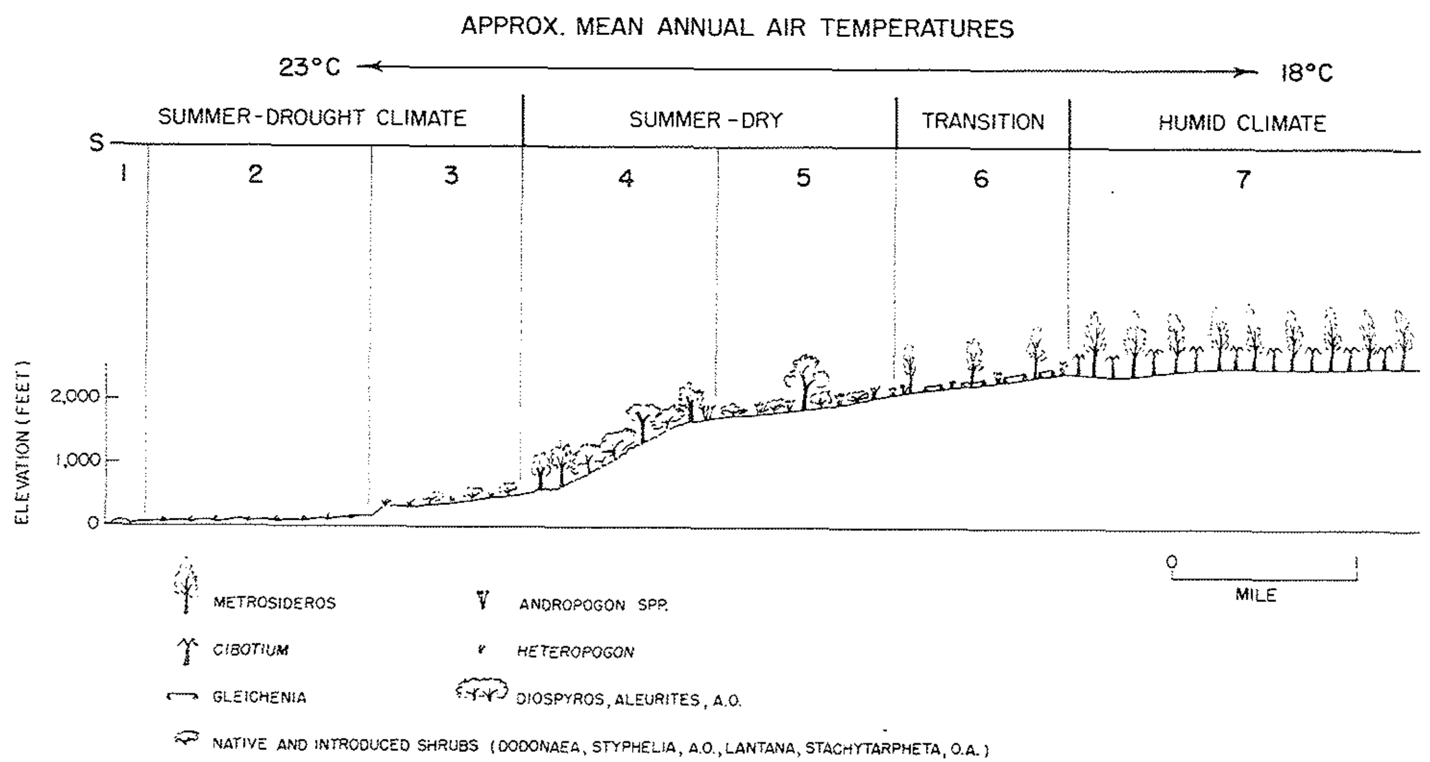
Segment 2 (Fig. 33). Heteropogon grassland; map symbol H(r): aerial photo 8-0024.

For description see Transect 2, above.

Segment 3 (Fig. 33). Heteropogon grassland with low shrubs; map symbol H(ls-i); aerial photo 8-0024.

This type differs from the previous type particularly in the prevalence of low, spreading shrubs that occur together here with the grasses, including Heteropogon contortus and others, such as Chrysopogon aciculatus,

Fig. 33. South-north profile of vegetation types in the eastern area of the Park from sea level to 2500 feet, an area 7 miles long extending from Kealakomo through the Naulu Forest to Napau Crater. This is Transect 4 of Figure 18 and the text.



Sporobolus diander, Tricholaena repens, Chloris inflata. The shrubs consist of such native species as Osteomeles anthyllidifolia, Canthium odoratum, Styphelia and Dodonaea. The first two are typical lowland species, whereas the other two are distributed over a wide range of altitude. Most of the shrubs are, however, introduced species that have their range dominantly in the hot lowland. These include Waltheria indica var. americana, Pluchea odorata, Indigofera suffruticosa and Cassia leschenaultiana. Another characteristic of this type, apart from the presence of a scattered shrub component, is a closer vegetative cover. The outcropping barren pahoehoe mounds, so conspicuous in the Heteropogon grassland type, are mostly hidden here beneath the vegetative cover. The ecological difference is attributable primarily to a higher degree of weathering giving rise to larger soil pockets that can store more rain water. The somewhat higher rainfall may also contribute to the difference, as this type is transitional to more heavily vegetated types (segment 4, Fig. 33, and segment 5, Fig. 34) in the summer-dry climate. This type is found only on pahoehoe lava and not on a'a.

Segment 4 (Fig. 33). Metrosideros—Diospyros mixed forest with patchy stands of Aleurites; map symbol MD(Al-ns-i-An-N); aerial photo 8-0024.

This type is quite variable, forming open to scattered Metrosideros—Diospyros ferrea stands with either grassy undergrowth dominated by Andropogon virginicus (symbol An) and mixtures of native (ns, i.e., Styphelia, Dodonaea) and introduced shrubs (i, i.e., Lantana camara, Stachytarpheta jamaicensis, and small Psidium guajava, or occurring on almost barren colluvial a'a lava surfaces with patch colonies of the fern, Nephrolepis exalta (symbol N), or thirdly, forming closed patch-forests dominated by Aleurites moluccana (symbol Al). Wherever permitted by the scale, these variations were mapped separately. The profile diagram emphasizes particularly the latter variation (Aleurites patch forest), as this represents the more obvious variation. The area is known as Naulu Forest. The type represents the eastward continuation of the pali vegetation type on colluvial a'a lava shown first as segment 3 on Figures 31 & 32.

Here Aleurites occurs (segment 4, Fig. 33) as a new element, which becomes still more abundant further east in the more humid climate (not shown on profile diagrams). The most westerly Aleurites tree was spotted near Transect 3 (in the east-central part of the Park). A few scattered individuals and groups occur between Transects 3 and 4. Comparison of the habitats of Aleurites with those on Oahu may be in order. On Oahu pure patch communities of Aleurites are found around the island from mid-altitudes (about 1800 feet) downward in deep ravines. They form larger stands on the windward than on the leeward side, but they are always restricted to ravines. Here, on the more recent surfaces in the Park there are no such ravines. However, both habitats have three things in common, the upper altitudinal limit, the slope, and the coarse, stony surface. While the stones as such do not appear to have any causative relation to Aleurites, the seepage water occurring in these habitats appears to be significant. A solid core of lava is always found beneath the coarse a'a rubble surface at about 1 m depth. While in the gulches on Oahu most seepage water may run superficially, here (segment 4, Fig. 33) it is probably providing subsurface-irrigation. A closer investigation of these relationships would be desirable. Obviously, the increasing abundance of Aleurites towards the more humid climate eastward shows another moisture relationship (which may act through more abundant seepage) and the altitudinal relation, from about 1800 feet downward, indicates a relation to a mean air temperature of about 20^{o} C upwards. Aleurites can hardly be expected to eventually form a climax formation as was suggested by Robyns & Lamb (1939).

Beside the three main tree components, Metrosideros, Diospyros and Aleurites, there are several other woody species found here. These include Canthium odoratum, Myoporum sandwicense, Bobea timonioides, Alphitonia ponderosa, Antidesma pulvinatum, Myrsine lessertiana and M. sandwicensis. A more complete list is shown in "Guide to the Kalapana-Chain-of-Craters Road," a mimeographed publication of Hawaii Volcanoes National Park.

Segment 5 (Fig. 33). Shrubland with Andropogon and scattered old Metrosideros; map symbol ns(i-An-M); aerial photos 8-0024, 8-0026.

This type is related to the Andropogon grassland (segment 4 on Fig. 32 & 33). However, the shrub component is dominant over the grass in this type. The shrubs are comprised mainly of Dodonaea and Styphelia, but individuals of the introduced shrubs, Lantana, Stachytarpheta and Psidium guajava are here found to reach their upper altitudinal invasion limits except for some locally disturbed places higher up, e.g., near fumaroles. The shrub layer forms locally-impenetrable thickets. A third component is represented by scattered old Metrosideros trees (20 m tall) with large globose crowns (10-15 m in diameter) that were in full bloom throughout the summer-dry season of 1965. Many of these trees have died and occur as snags in this type, and there seems to be no seedling reproduction of Metrosideros here.

Segment 6 (Fig. 33). Open Metrosideros—Gleichenia—Andropogon forest; map symbol oM(G-An); aerial photo 8-0026.

This forest occurs a little north but particularly south of the old Kalapana Trail. It has the characteristics of a transition forest between the humid montane rain forest (segment 7 of Figs. 32 & 33) and the evergreen seasonal forest (segment 5, Fig. 32). In spite of the fact that its dominant components (Metrosideros, Gleichenia and Andropogon) are the same as in the disturbed rain forest (segments 6 & 9, Fig. 32), its character is quite different.

The grass, Andropogon virginicus, forms pure patch communities up to 10 x 20 m across and the same applies to the Gleichenia mats beneath the trees, which sometimes may even be larger. Pig scarification was observed to be particularly prevalent in this area and it is possible that the two herbaceous patch communities form a pattern that is related to pig damage. Where the same degree of pig scarification occurs in the true humid montane rain forest, the scarified ground is soon invaded by either Peperomia in shaded places or by Gleichenia in more open places. Andropogon is not found upon such small-scale disturbances. However, in this type (segment 6, Fig. 33) Andropogon takes a strong foothold. This appears to be related to a certain reduction in summer-rainfall in this zone.

In addition to Metrosideros occasionally one can find an individual of Santalum ellipticum var. paniculatum in this type, which may be of tree or shrub stature. Other common shrubs are Vaccinium calycinum, Coprosma menziesii, Dodonaea viscosa and Styphelia tameiameiae. Common herbs in addition to Andropogon and Gleichenia are Machaerina angustifolia, Rhynchospora scleroides and Gahnia gahniaeformis.

Segment 7 (Fig. 33). Closed Metrosideros--Cibotium forest; map symbol cM(C); aerial photo 8-0026.

This is the same as segment 8 on Figure 32 and segment 12 on Figure 30. For description see above under discussion of Transect 2.

Vegetation types in the coastal lowland, east-part of the Park. Transect 5 (Fig. 18). Profile diagram Figure 34.

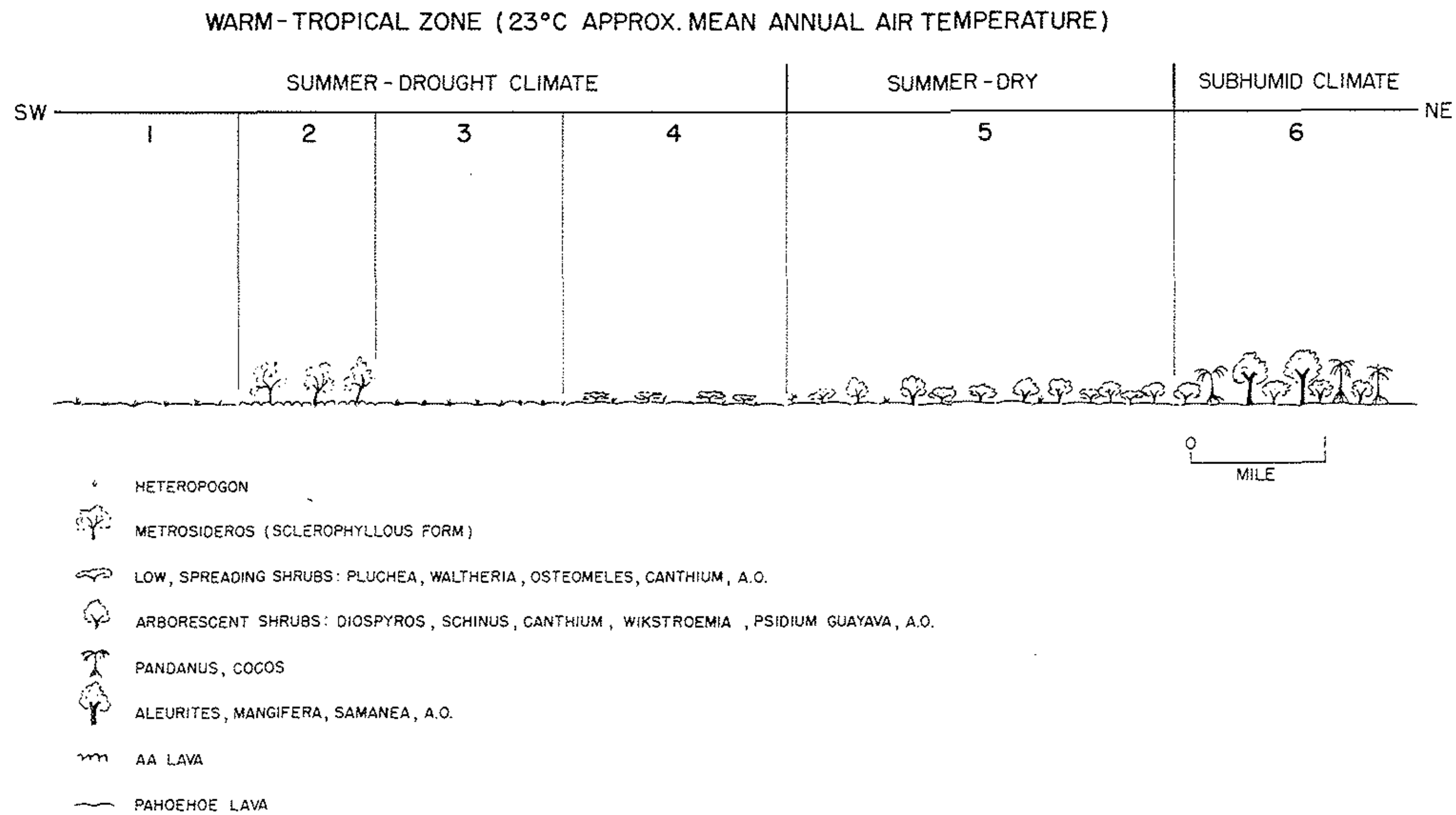


Fig. 34. Profile of vegetation types inland of the salt-spray zone in the eastern lowland area of the Park from Kaena (SW) to Kalapana (NE), a distance of 10 miles at elevations of between 30-60 feet. This is Transect 5 of Figure 18 and the text.

Transect 5 extends along the coastal lowland from Kaena to Kalapana (for location see map, Fig. 18). The profile diagram on Figure 34 portrays the lowland vegetation types as they occur along this transect in relation to a change in climate from summer-drought to humid. There are no significant variations in elevation, and the mean annual air temperature is thus likewise rather constant.

The major lowland types in the west-central (Eragrostis tenella grassland, segment 2 on Fig. 31) and the east-central area (Heteropogon grassland, segment 2 on Figs. 32 & 33) of the Park have already been described in the discussion of Transects 2 and 3. These two grassland types occur in a distinctly warm, tropical summer-drought climate. A more interesting variation in the same climate is the scattered Metrosideros stand which is shown on Figure 34 as segment 2. Therefore, Transect 5, though only short (10 miles) encompasses the major vegetation variations in the coastal lowland inland of the seashore communities.

The discussion follows in order of the six profile segments shown on Figure 34.

Segment 1 (Fig. 34). Heteropogon grassland; map symbol H(r); aerial photos including the shore.

For description see discussion of Transect 2, above.

Segment 2 (Fig. 34). Scattered old Metrosideros on nearly barren a'a lava; map symbol r(M); aerial photos including the shore.

This type represents a remarkable variation in the lowland vegetations of the summer-drought climate. It shows a close relationship to the pali type (segment 3, Figs. 31 & 32). It is quite possible that Diospyros ferrea may be present as well, but Metrosideros is definitely by far the more prevalent tree. Here it has extremely sclerophyllous leaves. The type is found wherever old a'a lava extends, often in finger-like patterns, into the coastal lowland area which is otherwise dominated by pahoehoe. Thus, the type occurs also, for example, below Hilina Pali (near Transect 2) and between Transects 3 and 4.

Tree growth on a'a can be explained by the fact that a solid lava core is always associated with and under the coarse, clinker-like a'a rubble at a depth of about 1 m or so. This soild lava core acts as an impervious base on which rain water collects and does not evaporate. Metrosideros seedlings may become established in moist years, when rapid extension of its roots into the moist zone above the impervious layer is permitted.

Grasses do not get established on this material as their fibrous root system is not adapted to growth in such coarse material. Their typically intensive root system does not extend very deep and it would rapidly be desiccated on this substrate. Grasses are better adapted to growth in shallow soil-filled cracks on pahoehoe, which cracks are much too small a habitat for Metrosideros trees. Seedlings that do appear soon perish because of lack of soil water. However, one can observe Metrosideros trees widely scattered on pahoehoe outside the a'a areas, particularly along the summer-drought climate of this transect. This is related to a distinct variation in the pahoehoe lava, which seems to be only local. Here the pahoehoe surface forms a very uneven microtopography. Surface rock plates have been pushed together resulting in small hills (2 m or so high) that have cracked open at the apex. On these small hills, Metrosideros trees are sometimes found that have extended their roots into those deep cracks, at the bottom of which rain water is held by a solid lava core similar to that beneath the a'a surface.

Segment 3 (Fig. 34). Heteropogon grassland; map symbol H(r); aerial photos 8-0020, 8-0024.

This is a recurrence of segment 1 on the very same substrate. For description see discussion under Transect 2, above.

Segment 4 (Fig. 34). Heteropogon grassland with low shrubs; map symbol H(ls-i); aerial photos 8-0020, 8-0024.

This is the same as segment 3 on Figure 33. For description see discussion under Transect 2, above.

Segment 5 (Fig. 34). Mixed lowland scrub; map symbol ls(i); aerial photos 8-0020, 8-0024, 14-0016, 6-16.

This type is formed on much the same well-weathered pahoehoe substrate as segment 4. The increase in density and shrub size is obviously related to an increase in rainfall from a summer-drought to a summer-dry climate.

The dominant native shrubs are Canthium odoratum, Wikstroemia phillyraefolia(?) and Diospyros ferrea (shrub stature). In addition there are many introduced shrubs such as Schinus terebinthifolius, Eugenia cumini, Psidium guajava and Pluchea odorata. Also, several of the smaller shrubs of the preceding type are present. The taller shrubs are from 2-5 m tall, usually showing globose crowns. Grasses are rare, but Chrysopogon, Trichloaena and Sporobolus diander can be found in openings between the shrubs. However, shrub density throughout most of the type is such that the crowns are just touching each other. Thus, there are no thickets and the type is easily accessible.

Segment 6 (Fig. 34). Mixed lowland forest; map symbol lf; aerial photos 14-0016, 6-16.

This type occurs near the eastern Park border and mostly outside the

Park near the village of Kalapana. It occurs in the humid to subhumid rain-forest climate, but the forest is much interrupted and restricted to stand fragments as a result of urban development. With few exceptions the forest is comprised of introduced, probably, mostly planted trees. These are distributed in patch forests so that the dominant trees vary from patch to patch. The more common trees are Mangifera indica, Samanea saman, Aleurites moluccana, Cocos nucifera, Pandanus and Thespesia.

6- Summary. The vegetation types of Hawaii Volcanoes National Park have been described on the basis of five vegetation profiles (Figs. 30-34) intended as an interpretation of the vegetation map that was prepared from plastic overlays on 53 aerial photos at an approximate scale of 1:12,000. There is some overlap of vegetation types on the five profile diagrams. As reviewed in tabular summaries (Tables I & II), the map symbols are explained in the form of a legend, and each type is shown as one or more segments along the profile diagrams and identified by the appropriate map symbol in the text. References to aerial photographs are provided to facilitate their ordering and use.

Table II. The vegetation types of Hawaii Volcanoes National Park as these units are distinguished on the five vegetation profiles (Figs. 30-34) and discussed in the text.

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Dry climate with night-frost near surface. Vegetation types on upper east slope of Mauna Loa. Elev. 8500-11,000 feet. Figure 30.	*Rhacomitrium* moss type	r(R)	Fig. 30, Seg. 2
	Scattered, low globous scrub	r(ns)	Fig. 30, Seg. 3
Summer-dry climate with frequent clouds near ground. Downslope continuation on east slope of Mauna Loa. Elev. 3900-8500 feet. Figures 30 & 31.	Open to closed globous scrub	ns	Fig. 30, Seg. 4
	Globous shrub with scattered *Metrosideros*	ns(M)	Fig. 30, Seg. 5
	Open *Metrosideros*—*Sophora* forest	oM(So-ns)	Fig. 30, Seg. 6
	Tall globous shrub savannah with scattered *Acacia koa* colonies	mx-ns(AcSoM)	Fig. 30, Seg. 7
	Mixed *Acacia* koa—*Sapindus* tree savannah	mx-AcSaM	Fig. 30, Seg. 8; Fig. 31, Seg. 10
	Mixed *Acacia koa*—*Sapindus* forest with lower-story trees and arborescent shrubs	AcSaM(ad)	Fig. 30, Seg. 9; Fig. 31, Seg. 8
	Open *Metrosideros*—lichen forest with native low shrubs	oM(L-ns)	Fig. 30, Seg. 10; Fig. 31, Seg. 7
	Open *Metrosideros*—native shrub forest	oM(ns)	Fig. 31, Seg. 9

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Humid to summer-dry transition climate above montane rain forest in Kilauea Forest Reserve, lower east slope of Mauna Loa. Elev. 5000 feet. Figure 31.	Mixed *Acacia koa*—*Metrosideros* forest with arborescent shrubs and *Cibotium*	AcM(ad-C)	Fig. 31, Seg. 11
Humid montane rain forest climate in northern part of Park, from Chain-of-Craters Road in north and beyond northern Park boundary. Elev. from below 5000 feet at lower east slope on Mauna Loa to 2500 feet at Napau crater. Figures 30, 32 & 33.	Closed *Metrosideros*—*Cibotium* forest	cM(C)	Fig. 30 Seg. 12; Fig. 32, Seg. 8; Fig. 33, Seg. 7
	Open *Metrosideros*—*Gleichenia* forest	oM(G)	Fig. 30 Seg. 11
	Open *Metrosideros*—*Cibotium*—*Gleichenia* forest	oM(C-G)	Fig. 32 Seg. 7
	Disturbed *Metrosideros* scrub forest with *Gleichenia* and *Andropogon* patches	scM(G-An)	Fig. 32, Segs. 6 & 9
	Open *Metrosideros*—*Cibotium* forest	oM(C)	Fig. 32 Seg. 10
	Cibotium forest with scattered old *Metrosideros* that are covered with epiphytes	C(M^{e})	Fig. 32 Seg. 11
Humid to summer-dry transition climate below montane rain forest in eastern part of Park. Elev. about 2000 feet. Figure 33.	Open *Metrosideros*—*Gleichenia*—*Andropogon* forest	oM(G-An)	Fig. 33 Seg. 6

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
Summer-dry climate of mid-altitudes on south slope of Kilauea. Elev. 1000-3000 feet. Figures 31, 32 & 33.	Open *Metrosideros*—*Andropogon* forest with native shrubs	oM(ns-An)	Fig. 32, Seg. 5
	Andropogon grassland	An(M) and An(ns-i)	Fig. 31, Seg. 4; Fig. 32, Seg. 4
	Shrubland with *Andropogon* and scattered old *Metrosideros*	ns(i-An-M)	Fig. 33 Seg. 5
	Metrosideros—*Diospyros* mixed forest with patchy stands of *Aleurites*	MD(Al-ns-i-An-N)	Fig. 33 Seg. 4
	Very open *Metrosideros*—*Diospyros* forest	MD(r)	Fig. 31, Seg. 3; Fig. 32 Seg. 3
Summer-drought climate at mid-altitudes with strong winds in west-central part of Park. Elev. 2500-3500 feet. Figure 31.	Extremely sparse desert vegetation	r-ash(poik)	Fig. 31 Seg. 6
Warm-tropical climate in coastal lowland from summer-drought (west) to subhumid (east). Figures 31, 32, 33, & 34.	*Eragrostis tenella* grassland	E(r)	Fig. 31 Seg. 2
	Heteropogon grassland	H(r); r(H); and H(lsi)	Fig. 32, Seg. 2; Fig. 33, Seg. 2; Fig. 34, Segs. 1 & 3
	Heteropogon grassland with low shrubs	H(ls-i)	Fig. 33, Seg. 3;
	Scattered old *Metrosideros* on nearly barren a'a lava	r(M)	Fig. 34, Seg. 2

Table II. (continued)

CLIMATE	VEGETATION TYPE	MAP SYMBOL	PROFILE & SEGMENT
	Mixed lowland scrub	ls(i)	Fig. 34, Seg. 5
	Mixed lowland forest	lf	Fig. 34, Seg. 6
	Salt spray and other shore communities	r(spr) and spr	Fig. 31, Seg. 1; Fig. 32 Seg. 1; Fig. 33, Seg. 1

Chapter IX- Bibliography

The following list of literature has been prepared as a guide. The user will find it short in entries concerning the geological aspects of the Park. The splendid annotated bibliography by Macdonald (1947) covers this subject for the island up into 1946. The lists of literature in the papers on the Park's more recent geology which are cited should satisfy most of the biologist's needs. Natural History Bulletin No. 5 issued by the Hawaii National Park and Western Museum Laboratories in 1940 is another extensive source of useful bibliographic information. Miss Margaret Titcomb of the B. P. Bishop Museum and Dr. Dieter Mueller-Dombois both have contributed further useful lists of bibliographic material for which we are thankful.

An effort has been made to include some of the less well known minor publications as a matter of record and at the same time a number of the very early and the more generally informative or basic publications even though not specifically biological but referred to in the text. In some fields it has not been possible to be thorough, *e.g.*, in the fields of invertebrate zoology and cryptogamic botany, but in such fields the principal works for the Park or the islands are given with the hope that interested individuals will find it easier to begin the work of determining the status of the Park's biota in such fields from the particular few starting points given.

Actually the hope is that through the stimulus of this Atlas, or data assemblage, scientific work in the different fields of biology and ecology will be encouraged and that, as a result, this first-generation effort will soon be far outdated.

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Chapter X- Generic Index to Organisms Known from the Park

The following alphabetical list of genera is an index to the organisms known to occur in the Park as recorded in the text of this Atlas or in the publications listed with the particular name. An asterisk (*) before a generic name means that the organism is recorded from near, but not within, the Park. The citations which follow a generic name lead to the bibliography, the previous chapter of this Atlas, or to the chapters within the Atlas where the record may be found. One citation, the year date of which is followed by an asterisk, is given as a useful general reference for the genus and does not necessarily refer to the Park. In parentheses following each generic entry are one or more words providing clues as to the kind of organism to which the generic name applies and, in some cases, to a reference where it is mentioned in the text above or to other supplementary information.

Acridotheres (bird): Munro, 1960.* (Chapt. VI, H.)

Acroporium (moss): Bartram, June 1933.* (Chapts. VI, C; VII, E; VIII.)

Adiantum (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Agapanthus (plant): Fagerlund, 1947; W. F. Hillebrand, 1888.* (Chapt. VI, D.)

Agave (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Ageratum (plant): Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Agrostis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Ahnfeltia (alga): Smith, 1964.* (Chapts. VI, A; VII, G.)

Aira (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; A. S. Hitchcock, 1935.* (Chapt. VI, D.)

Aluda (bird): Munro, 1960.* (Chapt. VI, H.)

Alcea (plant): Willis, 1960.* (Chapt. VI, D.)

Alectoris (bird): Munro, 1960.* (Chapt. VI, H.)

Aleurites (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965;* Degener, 1930.* (Chapts. VI, D; VII, H, F; VIII.)

Allium (plant): Neal, 1965.* (Chapt. VI, D.)

Alphitonia (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Alpinia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Alsidium (alga): Dawson; H. Kylin, 1956.* (Chapt. VII, G.)

Althaea (plant): Neal, 1965.* (Chapt. VI, D.)

Alyxia (plant): Fagerlund & Mitchell, 1944; Rock, undated; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C.)

Amansia (alga): McCaughney, 1918.* (Chapts. VI, A; VII, G.)

Amaranthus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Amphidium (moss): Bartram, June 1933.* (Chapt. VI, C.)

Amsinckia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anabaena (alga): Prescott, 1951.* (Chapt. VI, A.)

Anacystis (alga): Prescott, 1951.* (Chapt. VI, A.)

Anagallis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Ananas (plant): Degener, 1930; Neal, 1965.*

Anas (bird): Munro, 1960.* (Chapt. VI, H.)

Anastrophyllum (moss): Miller, 1963; (Chapt. VII, E.)

Andropogon (plant): Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, C; VIII.)

Anemone (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anoectochilus (plant): Fagerlund & Mitchell, 1944; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Anous (birds): Munro, 1960.* (Chapt. VI, H.)

Anser (bird): Munro, 1960*. (Chapt. VI, H.)

Anthemis (plant): Fagerlund & Mitchell, 1944, Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Anthoxanthum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapts. VI, D; VII, B; VIII.)

Antidesma (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Antirrhinum (plant): Neal, 1965.* (Chapt. VI, D.)

Apium (plant): Neal, 1965.* (Chapt. VI, D.)

Araucaria (plant): Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Arcella (shelled amoeba): Kudo, 1960.* (Chapt. VII, G.)

Arctotis (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Ardisia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Buddleja (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, D.)

Bufo (toad): (Chapt. VI, G.)

Bulbostylis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Willis, 1960.* (Chapts. VI, D; VIII.)

Buteo (bird): Munro, 1960.* (Chapt. VI, H.)

Buxus (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Caesalpinia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Cajanus (plant): Fagerlund & Mitchell, 1944, Fagerlund, 1947; Degener, 1930; Neal, 1965.*; Hillebrand, 1880.* (Chapt. VI, D.)

Caladium (plant): Degener, 1930; Neal, 1965.*; Hillebrand, 1888.*

Calipidia (plant): Rock, undated, Unpub. ms; Degener, 1930.* (Ref. to only).

Callistemon (plant): Neal, 1965. (Chapt. VI, D.)

Calophyllum (plant): Neal, 1965. Hillebrand, 1888.*

Calothrix (alga): Smith, 1950.*; Prescott, 1951.* (Chapts. VI, A; VII, G.)

Calymperes (moss): Botany group, 1963; Bartram, June, 1933.*

Camellia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Campylodiscus (alga): Smith, 1950.* (Chapt. VII, G.)

Campylopus (moss): Bartram, June, 1933.* (Chapt. VI, C.)

Canavalia (plant): Neal, 1965.*; Hillebrand, 1888.* (Chapt. VII, E.)

Canna (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* Hillebrand, 1888.* (Chapt. VI, D.)

Canthium (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Capparis (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*; Hillebrand, 1888.* (Chapt. VI, D.)

Capsicum (plant): Stone, 1959; Hillebrand, 1888.*

Cardamine (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965; Hillebrand, 1888.* (Chapt. VI, D.)

Cardiospermum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947 Stone, 1959; Neal, 1965.* Hillebrand, 1888.* (Chapt. VI, D.)

Carex (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpubl. ms; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VII, B; VIII.)

Carica (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* Hillebrand, 1888.* (Chapt. VI, D.)

Carpodacus (bird): Munro, 1960.* (Chapt. VI, H.)

Cassia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.*; Hillebrand, 1888.* (Chapts. VI, D; VII, E; VIII.)

Cassytha (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII,E.)

Catharanthus (plant): Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Catillaria (lichen): Magnusson & Zahlbruckner, II:10, 1944; (Chapt. VI,B.)

Caulacanthus (alga): Boergesen,1940-57.* (Chapt. VII, G.)

Cenchrus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Centaurea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Centaurium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, B.)

Centella (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Centroceras (alga): Dawson, Oct. 1954.* (Chapt. VII, G.)

Cephalozia (moss): Miller, 1963.* (Chapt. VII, E.)

Cerastium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888*; Neal, 1965.* (Chapt. VI, D.)

Ceratodon (moss): Bartram, June 1933.* (Chapt. VI, C.)

Cestrum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Chaetomorpha (alga): Smith, 1950.* (Chapt. VII, G.)

Charpentiera (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Chasiempis (bird): Smathers, 1963a, Unpubl. report; Munro, 1960.* (Chapt. VI, H.)

Cheirodendron (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VII, B, C; VIII.)

Chelonia (turtle): Carr & Ingle, 1959.* (Chapt. VI, G.)

Chen (bird): Munro, 1960.* (Chapt. VI, H.)

Chenopodium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965*; Hillebrand, 1888.* (Chapt. VI, D.)

Chlamydomonas (alga): Smith, 1950.* (Chapt. VI, A.)

Chlorella (alga): Smith, 1950.* (Chapt. VI, A.)

Chloris (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Chlorococcum (alga): Smith, 1950.* (Chapts. VI, A; VII, F.)

Chlorosarcina (alga): Smith, 1950.* (Chapt. VI, A.)

Chlorosarcinopsis (alga): Smith, 1950.* (Chapt. VI, A.)

Chnoospora (alga): Taylor, 1960.* (Chapt. VII, G.)

Chroococcus (alga): Smith, 1950.* (Chapt. VI, A.)

Chrysanthemum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Chrysopogon (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VIII.)

Cibotium (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Lamoureux (App.B), 1963; Botany group, 1963; Degener, 1930; Stone, 1959; Neal, 1965*; Hillebrand, 1888.* (Chapts. V, E; VI, D; VII, B, C, D, E; VIII.)

Cuphea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B., C.)

Cuscuta (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Cyanea (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Cyanisticta (lichen): Magnusson & Zahlbrucker, I: 86, 1943.* (Chapt. VI, B.)

Cyathodes (plant): Degener, 1930; Hillebrand, 1888.* (Chapt. VI, D.)

Cyclosorus (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D, VII, B.)

Cydonia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cylindrocapsa (alga): Prescott, 1951.* (Chapt. VI, A.)

Cynodon (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Cynoglossum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Cyperus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VII, B, C, D; VIII.)

Cyrtandra (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VIII.)

Cyrtomium (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VII, B.)

Cytisus (plant): Fagerlund, & Mitchell, 1944; Neal, 1965.* (Chapt. VI,D.)

Dactylis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Lawrence, 1951*, (merely mentioned); Hitchcock, 1935.* (Chapts. VI, D; VII, B.)

Dactyloctenium (plant): Hitchcock, 1935.* (Chapt. VIII.)

Dahlia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Daucus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Enteromorpha (alga): Taylor, 1950.* (Chapt. VII, G.)

Entophysalis (alga): Drovet & Daily, 1956.* (Chapts. VI, A; VII, G.)

Epilobium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*(Chapt. VI, D; VIII.)

Eragrostis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Erechtites (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C, D, E, F.)

Erigeron (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Eriobotrya (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Erioderma (lichen): Magnusson & Zahlbruckner, I:78, 1943.* (Chapt. VI, B.)

Erodium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Erythraea (plant): Rock, undated. Unpub. ms; Neal, 1965.*

Erythrina (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Erythrotrichia (alga): Taylor, 1950.* (Chapt. VI, A.)

Escallonia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Eschscholtzia (plant): Neal, 1965.* (Chapt. VI, D.)

Eucalyptus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VIII.)

Eucapsis (alga): Smith, 1950.* (Chapt. VI, A.)

Eugenia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Eupatorium (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Lamoureux (App.B), 1963; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, D.)

Euphorbia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gelidium (alga): Loomis, 1960.* (Chapt. VII, G.)

Geopelia (bird): Munro, 1960.* (Chapt. VI, H.)

Geranium (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Gerbera (plant): Neal, 1965.* (Chapt. VI, D.)

Gladiolus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Gleichenia (plant): Fagerlund & Mitchell, 1944, Botany group, 1963; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gloeocystis (alga): Smith, 1950.* (Chapt. VI, A.)

Cnaphalium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C; VIII.)

Gomphosphaeria (alga): Smith, 1950.* Drouet & Daily, 1956.* (Chapt. VI, A; VII, G.)

Goniolithon (alga): Taylor, 1950.* (Chapt. VII, G.)

Gossypium (plant): Degener, 1930; Neal, 1965.*

Gouldia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms. Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C; VIII.)

Grammitis (plant): Botany group, 1963; Hillebrand, 1888.* (Chapts. VI, D; VII, C.)

Grevillea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Griffithsia (alga): Taylor, 1950.* (Chapt. VII, G.)

Gymnogramme (plant): Rock, undated Unpub. ms; Hillebrand, 1888.*

Gynopogon (plant): Degener, 1930.*

Haplostachys (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hebe (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Hedera (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Lastrea</u> (plant): (Chapt. VI, D.)

<u>Lathyrus</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Laurencia</u> (alga): Yamada,1931.* (Chapt. VI, A.)

<u>Lecanidium</u> (lichen): (Chapt. VI, B.)

<u>Lecanora</u> (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

<u>Leiothrix</u> (bird): Munro, 1960.* (Chapt. VI, H.)

<u>Leonurus</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Lepidium</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Leptospermum</u> (plant): Fagerlund & Mitchell, 1944; Neal,1965.* (Chapt. VI, D.)

<u>Leucaena</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, A, F.)

<u>Leucobryum</u> (moss): Bartram, 1933.* (Chapts. VI, C; VII, E.)

<u>Liagora</u> (alga): Abbott, 1945.* (Chapt. VII, G.)

<u>Ligustrum</u> (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

<u>Lilium</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Linaria</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)

<u>Lindernia</u> (plant): Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

<u>Linociera</u> (plant): Neal, 1965.* (Chapt. VI, D.)

<u>Linum</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal,1965.*

<u>Liparis</u> (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

<u>Lipochaeta</u> (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965.* (Chapt. VI, D.)

<u>Littorina</u> (animal): Tinker, 1958;*(Chapt. VII, G.

<u>Lobelia</u> (plant): Degener, 1930; Neal, 1965.*

<u>Lobularia</u> (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Mangifera (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E; VIII.)

Marattia (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Mastigocoleus (alga): Tilden, 1910.* (Chapts. VI, A; VII, G.)

Matthiola (plant): Neal, 1965.* (Chapt. VI, D.)

Maurandya (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Medicago (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Megalospora (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Melaleuca (plant): Neal, 1965.* (Chapt. VI, D.)

Meleagris (bird): Munro, 1960.* (Chapt. VI, H.)

Melia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Melilotus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Melinis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hitchcock, 1935.* (Chapts. VI, D; VIII.)

Melosira (alga): Prescott, 1951.* (Chapt. VII, G.)

Mentha (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Merremia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Mesembryanthemum (plant): Neal, 1965.* (Chapt. VI, D.)

Messerschmidia (plant): Fagerlund & Mitchll, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, G.)

Metrosideros (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. V, E; VI, C, D, F, H; VII, A, B, C, D, E, F; VIII.)

Microcoleus (alga): Prescott, 1951.* (Chapts. VI, A; VII, G.)

Nannochloris (alga): Smith, 1950.* (Chapt. VI, A.)

Narcissus (plant): Neal, 1965.* (Chapt. VI, D.)

Nasturtium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.*

Neochloris (alga): (Chapt. VI, A.)

Neottopteris (plant): Stone, 1959; Hillebrand, 1888.*

Nephrolepis (plant): Neal, 1965*; Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Degener, 1930; Stone, 1959. (Chapts. VI, D; VII, B, C, D, E, F; VIII.)

Nephroma (lichen): Magnusson & Zahlbruckner, I:93, 1943.* (Chapt. VI, B.)

Neraudia (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VI, D.)

?Nertera (plant): Fagerlund & Mitchell, 1944; Hillebrand, 1888.* (Chapt. VI, D.)

Nestegis (plant): (Chapt. VI, D.)

Netrium (alga): Smith, 1950.* (Chapt. VI, A.)

Nicandra (plant): Fagerlund & Mitchell, 1944; Neal, 1965.*

Nicotiana (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959, Neal, 1965.* (Chapts. VI, D; VII, F.)

Nostoc (alga): Smith, 1950.* (Chapt. VI, A.)

Nothocestrum (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Neal, 1965.* (Chapt. VI, D.)

Nototrichium (plant): Neal, 1965.* (Chapt. VI, D.)

Nycticorax (bird): Munro, 1960.* (Chapt. VI, H.)

Ocellularia (lichen): Magnusson & Zahlbruckner, 1943.* (Chapt. VI, B.)

Ochrosia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms;

Odontoschisma (bryophte): (Chapt. VII, E.); Miller, 1963.*

Parmelia (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Paspalum (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Botany group, 1963; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C, D, E; VIII.)

Passer (bird): Munro, 1960.* (Chapt. VI, H.)

Passiflora (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, E.)

Pastinaca (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Pelargonium (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Peiea (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. IV, D; VII, B, C; VIII.)

Pellaea (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, B; VIII.)

Pelvetia (alga): Smith, 1964.* (Chapt. VII, G.)

Pennisetum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.*

Pennula (bird): Smathers,1963a; Unpub. report; Munro, 1960.*

Penstemon (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Pentas (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Peperomia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Mueller-Dombois & Lamoureux, 1964, unpub. ms; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B, C, E; VIII.)

Perrottetia (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B.)

Persea (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, B.)

Pertusaria (lichen): Magnusson & Zahlbruckner, 1944.* (Chapt. VI, B.)

Pterodroma (bird): Munro, 1965.* (Chapt. VI, H.)

Pueraria (plant): Neal, 1965.* (Chapt. VII, F.

Pyracantha (plant): Fagerlund & Mitchell, 1944; Neal, 1965* (Chapt. VI, D.)

Pyrenula (lichen): Magnusson & Zahlbruckner, I:13, 1943.* (Chapt. VI, B.)

Radula (bryophte): Miller, 1957.* (Chapt. VII, E.)

Raillardia (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Degener, 1930; Stone, 1959; Hillebrand, 1888.* (Chapts. VI, D; VII, D.)

Raimannia (plant): Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Ralfsia (alga): Smith, 1964.* (Chapt. VII, G.)

Ramalina (lichen): Magnusson&Zahlbruckner, III: 2, 1945.* (Chapt. VI, B.)

Ranunculus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Hillebrand, 1888.* (Chapts. VI, D; VII, B.)

Raphanus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Rauvolfia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Reseda (plant): Neal, 1965.* (Chapt. VI, D.)

Reynoldsia (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Rhacomitrium (moss): Botany group, 1963; Bartram, June 1933; Chapt. VI, C; VII , C, F; VIII).

Rhacopilum (moss): Bartram, June 1933.* (Chapt. VII, E, F.)

Rheum (plant): Neal, 1965.* (Chapt. VI, D.)

Rhizoclonium (alga): Taylor, 1960.*(Chapt. VI, A; VII, G.)

Rhizogonium (moss): Bartram, June 1933.* (Chapt. VII, E.)

Rhododendron (plant): Fagerlund & Mitchell, 1944; Neal, 1965.* (Chapt. VI, D.)

Rhus (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, E.)

Rhynchospora (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Hillebrand, 1888.* (Chapt. VI, D; VIII.)

Richarida (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Richmondena (bird): Munro, 1960.* (Chapt. VI, H.)

Ricinus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Rockia (plant): Neal, 1965.

Rollandia (plant): Degener, 1930; Neal, 1965.*

Rosa (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Rosenvingea (alga): Dawson, 1954.* (Chapt. VI, A.)

Rubus(plant): Neal, 1965*; Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Smathers, 1963b; Lamoureux (App.B), 1963; Fagerlund, 1947; Mueller-Dombois & Lamoureux, 1964; unpub. ms; Degener, 1930; (Chapts. VI, D; VII, B, C, D; VIII.)

Rumex (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms.; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII B.)

Saccharum (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Neal, 1965.* (Chapt. VI, D.)

Sacciolepis (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Hitchcock, 1935*. (Chapt. VI, D; VII, C.)

Sadleria (plant): Fagerlund & Mitchell, 1944; Lamoureux (App. B), 1963; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VII, A, B, C, E; VIII.)

Salvia (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Samanea (plant): Stone, 1959; Neal, 1965.* (Chapt. VIII.)

Sambucus (plant): Fagerlund & Mitchell, 1944; Neal, 1955.* (Chapt. VI, D.)

Santalum (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D; VIII.)

Sapindus (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Botany group, 1963; Mueller-Dombois & Lamoureux, 1964, ms; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B; VIII.)

Sargassum (alga): Lemmerman, 1905.* (Chapts. VI, A, G; VII, G.)

Scabiosa (plant): Neal, 1965.* (Chapt. VI, D.)

Scaevola (plant): Fagerlund & Mitchell, 1944; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Scenedesmus (alga): Smith, 1950.* (Chapt. VI, A.)

Schinus (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VIII.)

Schizophyllum (fungus): Smathers, 1936b; Taylor, 1950.* (Chapt. VII, D.)

Schizothrix (alga): Tilden, 1910.* (Chapts. VI, A; VII, G.)

Scytonema (alga): Tilden, 1910.* (Chapts. VI, A; VII, A, F, G.)

Secale (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Lawrence, 1951.* (mentioned only); Hitchcock, 1935.*

Selaginella (plant): Fagerlund & Mitchell, 1944; Botany group, 1963; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, C.)

?Sempervivum (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapt. VI, D.)

Senecio (plant): Fagerlund & Mitchell, 1944; Rock, undated. Unpub. ms; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VII, B, C.)

Sesbania (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Sesuvium (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapts. VI, D; VII, G; VIII.)

Setaria (plant): Fagerlund & Mitchell, 1944; Smathers, 1963b; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B, D.)

Sicyos (plant): Fagerlund & Mitchell, 1944; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Sida (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Stone, 1959; Neal, 1965.* (Chapt. VI, D.)

Silene (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Degener, 1930; Neal, 1965.* (Chapts. VI, D; VIII.)

Sisymbrium (plant): Fagerlund & Mitchell, 1944; Fagerlund, 1947; Neal, 1965.* (Chapts. VI, D; VII, B.)