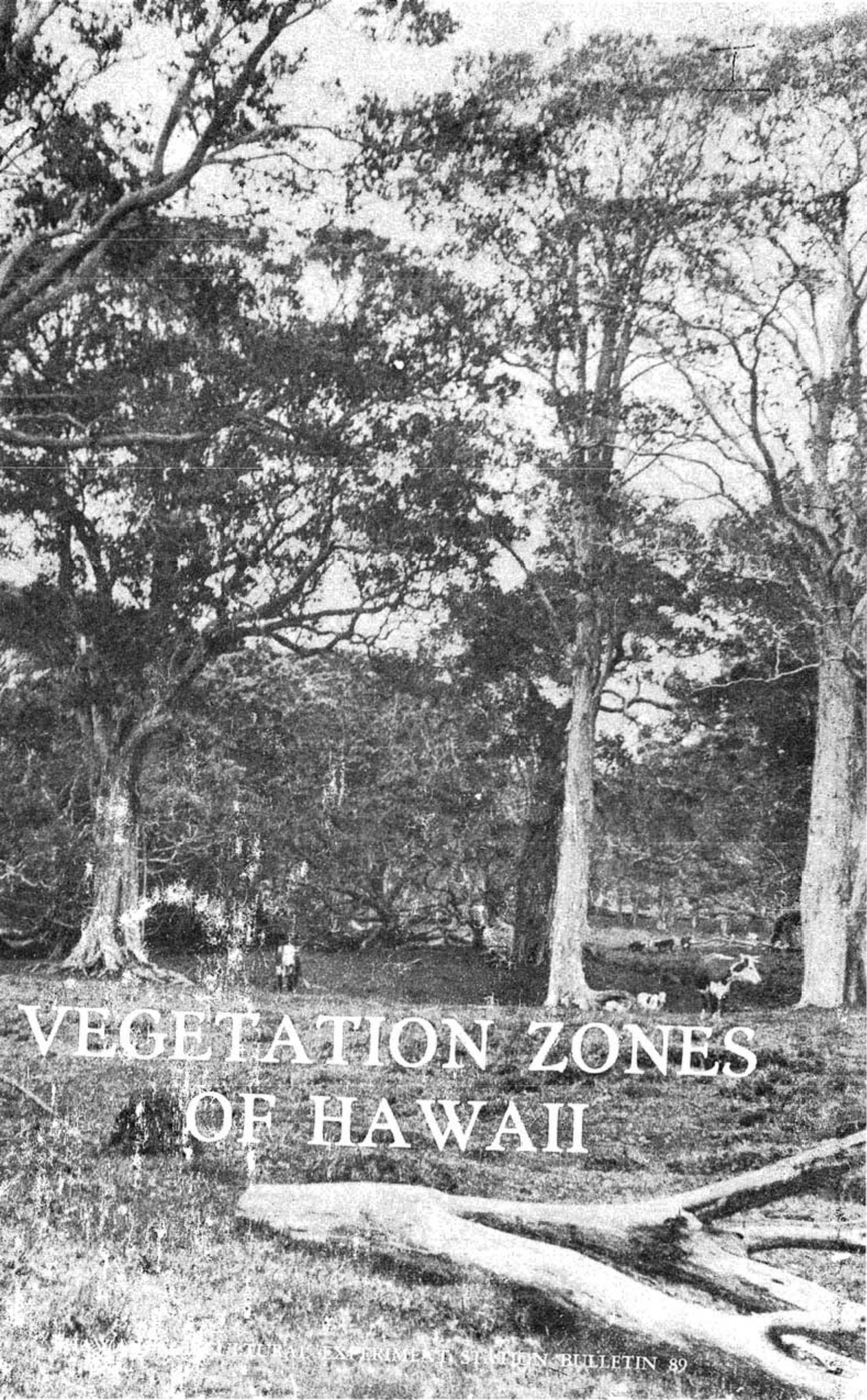
VEGETATION ZONES
OF HAWAII
LTURAL EXPERIMENT STATION BULLETIN 89

HAWAII AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF HAWAII

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ENTOMOLOGY: F. G. HOLDAWAY, Ph.D., Entomologist—W. LOOK, B.S., Associate in Entomology—T. NISHIDA, B.S., Junior Assistant in Entomology.

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PARASITOLOGY: J. E. ALICATA, Ph.D., Parasitologist.

PLANT PHYSIOLOGY: H. F. CLEMENTS, Ph.D., Plant Physiologist—E. K. AKAMINE, M.S., Associate in Plant Physiology—T. KUBOTA, B.S., Junior Assistant in Plant Physiology.

POULTRY HUSBANDRY: C. M. BICE, B.S., Poultry Husbandman.

TRUCK CROPS AND PLANT DISEASES: W. A. FRAZIER, Ph.D., Associate Horticulturist—*G. K. PARRIS, Ph.D., Associate Plant Pathologist—K. KIKUTA, B.S., Associate in Plant Pathology—M. MATSUURA, B.S., Assistant in Plant Pathology—D. SUMIDA, B.S., Assistant in Truck Crops—S. T. TACHIBANA, Junior Assistant in Truck Crops.

BRANCH STATIONS AND FARMS: R. K. PAHAU, B.S., Agricultural Scientist, Kona Branch Station—FRANK MERCADO, Foreman, Poamoho Experimental Farm—K. MURAKAMI, Foreman, Haleakala Branch Station—FRANK T. MURPHY, B.S., Collaborator.

* On leave of absence.

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VEGETATION ZONES OF HAWAII

by

J. C. Ripperton, *Agronomist*

E. Y. Hosaka, *Junior Agronomist*

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TABLE OF CONTENTS

INTRODUCTION

The areas devoted to the various forms of agriculture in Hawaii comprise great extremes of environment. The topography varies from flat coastal plains to steep pali slopes, the altitude from sea level to 9,000 feet, the soil type from new lava and young soils to well weathered lateritic types, and the rainfall from as little as 10 inches to more than 250 inches a year. Moreover, such differences often occur within distances of a few miles. Obviously, such extremes have a profound effect on the natural vegetation, cultivated crops, and agricultural practices. It should be possible, therefore, to classify these varied environments into zones, each of which would have similar characteristics as to plant adaptability and agricultural use.

The study of agriculture in relation to environment has come to play an important part in land use planning in many parts of the world. On such a basis, lands are classified as to those which should be used for cultivated crops, for grazing, and for forests (4, 18, 22). As the study becomes more detailed, recommendations are made as to the kinds of crops, types of animals, rotations, and many other phases relating to the agricultural pattern. The study of range land from an ecological standpoint is comparatively modern and has added greatly to the development of scientific methods of pasture use and management (2, 3, 28, 29). Range ecology should be particularly useful in Hawaii because of the extremes of climate.

The present bulletin presents the results of a vegetation survey of the range lands of the Territory. On the basis of this survey, together with available climatological data, a series of vegetation zones is here outlined which, it is believed, provides a means of correlating the essential features of environment with agricultural use. Ten zones and phases are described as to climate, soils, and characteristic vegetation, both wild and planted species.

The proposed division into zones is intended primarily for use in the study and classification of pastures. However, because the pastured lands represent the remaining land of the Territory after the areas used for cultivated crops are taken out and include roughly one-fourth of the total area of the islands, the zones may be of general use to other phases of agriculture. No attempt has been made to develop this phase, although general references are made to present agricultural use in the description of each zone. Considerable additional work will be necessary to refine zonal boundaries and to add intrazonal detail in order to take into account localized climatic, topographic, and soil characteristics. In their present form the zones serve primarily as a general classification of environments.

GENERAL ASPECTS OF CLIMATE, SOILS, AND VEGETATION

Some knowledge of the general aspects of environment is necessary for a clear understanding of the essential interrelation existing between the factors of environment and the vegetation which develops in harmony with them. There follows a popular discussion of climate and vegetation characteristic of Hawaii.

CLIMATE

by

STEPHEN B. JONES[1]

Climate sets the broad limits of plant distribution and land use. Within a given climatic region, variations in landforms and soils may produce differences in plant cover, but even these variations may be thought of as stages in the trend towards final equilibrium of climate and mature soil.

Back of Hawaiian climates stand the broad features of the Pacific Ocean. If we trace any aspect of Hawaiian climate to its origins, we shall be led to the ocean, and perhaps beyond that, to Siberia or even to Antarctica. For the moment, let us consider the quadrangle of ocean bounded by Latitudes 20 and 25 North and Longitudes 155 and 160 West (31). The Hawaiian chain crosses the southwest corner of this quadrangle. The northeast trade winds blow over it about three-fifths of the time in winter and almost continuously in summer. The trades blow out of the great high pressure cell which normally lies northeast of Hawaii and west of California. This cell is neither stationary nor always present. It moves north and south with the seasons. In winter the trade winds frequently are interrupted by storms which sweep across the North Pacific. These storms often arise from the contact of cold Siberian air and warm Pacific air near Japan. When such a storm passes north of Hawaii, the high pressure cell is weakened or disrupted, the trade winds cease, and calms or south or west winds ensue. These "kona" winds blow towards the storm, which has low atmospheric pressure at its center.

In this quadrangle the mean temperature of the water is 75 degrees (ignoring decimals). The mean temperature of the air is 74 degrees. The slightly lower temperature of the air comes from its general motion from the colder northeast. That the air is cooler than the water has an important consequence. The air is being warmed from the sea surface and so becomes light and rises, creating convection currents and carrying up water vapor evaporated from the sea. This convection is usually not very strong, but it is enough to

[1] Asst. Prof. of Geography, Univ. of Hawaii.

give trade-wind climates moderate humidity and a sky dotted with woolly cumulus clouds. Only when the vertical convection currents are intensified, as by the invasion of cold air aloft, is the cloud formation apt to lead to rain. During kona winds the air temperature may be slightly higher than the sea temperature, for southerly winds bring air from regions warmer than ours. Kona air, therefore, may be slightly cooled at its lower surface. Less tendency towards convection exists than in trade-wind weather, which retards the upward movement of water vapor. Thus the surface layer may become very humid. If light wind or calm prevails also, the effect on man is enervating.

During both trade-wind and kona weather, but more conspicuously during the latter, changes of weather known as atmospheric fronts occur. Atmospheric fronts are the contacts between masses of air of different temperature and humidity. The best-known change in Hawaii is between trade-wind air and kona air, and vice versa. Such changes may occur quietly, with only a shift of wind or of cloud forms, but atmospheric fronts often are marked by severe weather. Cool air may push under warm air which, rising, is cooled to the point of condensation. On continents frontal changes may produce heat waves and cold waves and may be accompanied by blizzards, tornadoes, or violent thunderstorms. In our tropical oceanic area, fronts are not marked by strong contrasts of temperature.

Little is known of the rainfall over the oceans because of obvious difficulties of measurement. A good guess is that our quadrangle receives about 20 inches a year. Rain is reported only once in ten observations, mostly as "passing showers," although winter brings more steady rain. Clouds cover four- or five-tenths of the sky on the average; the woolly cumulus type are the most common. Winter brings more completely cloudy days, but also more clear ones, for summer trade-wind skies are characteristically cloud-dotted. Fog is almost unknown.

One of the most important features of an oceanic climate is the small annual range of temperature. This characteristic comes from the great storage of heat by the water in summer and its gradual release in winter. (On land this "heat turnover" is confined to a few feet of soil and is relatively small in amount.) Seasonal change of temperature is thus slight in the oceans. For the quadrangle here considered, the annual range is five degrees. In similar latitudes in the Sahara, annual ranges of more than thirty degrees are experienced. A second consequence of this storage and release of heat in the oceans is a long delay between the times of high and low sun and the crest or trough of the year's temperatures. In the seas we are describing, March is the coolest month and September the warmest. On the islands, the delay of the seasons usually is less.

Upon the background of this oceanic quadrangle there is now pictured the climates of the Hawaiian islands. Our aim is to portray what happens to the oceanic air as it streams over and around these mountainous islands. Trade winds prevail over all others—in an average year, in the proportion of four to one. When trade winds strike low coasts, they give a shore climate which is little different from that of the ocean. One need go but a short distance inland, however, to find a slight increase in mean temperature and daily and annual ranges greater than over the oceans. Waimanalo, Oahu, for example, has a mean temperature of 75 degrees, a daily temperature range of 13 degrees, and an annual temperature range of 8 degrees. But these regions of dry windward climate are, at most, strips a mile or two wide. They exist only where there are coastal plains or where air can escape lifting by lateral flow. Elsewhere on windward coasts the lifting effect of landforms produces heavier rainfall. Lifted air expands at the lower pressures aloft and is cooled by expansion. The level at which this cooling will produce clouds varies from day to day, as does the amount of rainfall that is precipitated. However, trade-wind air usually gives clouds with 2,000 feet of lifting and produces rain two days out of three. Cloudy and rainy windward slopes are relatively cool and have low daily and annual ranges. Mean temperatures slightly lower than those of the oceanic air are to be expected at sea level. The change of temperature with altitude may be less than the usual value of one degree for each 300 feet (fig. 1, p. 9). Daily ranges of 10 or 15 degrees and annual ranges of 5 or 6 degrees prevail.

Where the mountains are long and low, as on Oahu, rains carry over the summits and give an overlapping belt of heavy precipitation. On the higher islands there is an upper limit to mountain clouds and rainfall, not because the air is "squeezed dry" but because it flows around the summit with little lifting rather than over them. The level of maximum rain and of the upper limit varies from day to day, but the configuration of the land has an important bearing. A smooth dome like Kilauea spreads the air with moderate uplift. The valleys that converge on Waialeale (Kauai) or scoop-shaped Iao Valley (Maui) force the air to greater heights. Rainfall induced by lifting on mountains is the greatest, most reliable, and seasonally best distributed that the islands receive. Mountain rainfall (some of which is frontal, not solely due to mountain lifting) is the mainstay of island water supply. Each of the four largest islands has areas receiving two hundred inches or more annually. Above the cloud belts, the amount of rainfall diminishes markedly. It has been estimated that the summit of Mauna Kea may receive but fifteen inches (11).

As trade-wind air descends the leeward slopes, it becomes warmed by compression. As the air temperature rises, mountain clouds evaporate and the scattered trade-wind cumulus reappears. Altitude for altitude, lee slopes generally are warmer than windward slopes, though there is little difference between leeward and dry windward stations in mean temperature. The change of temperature

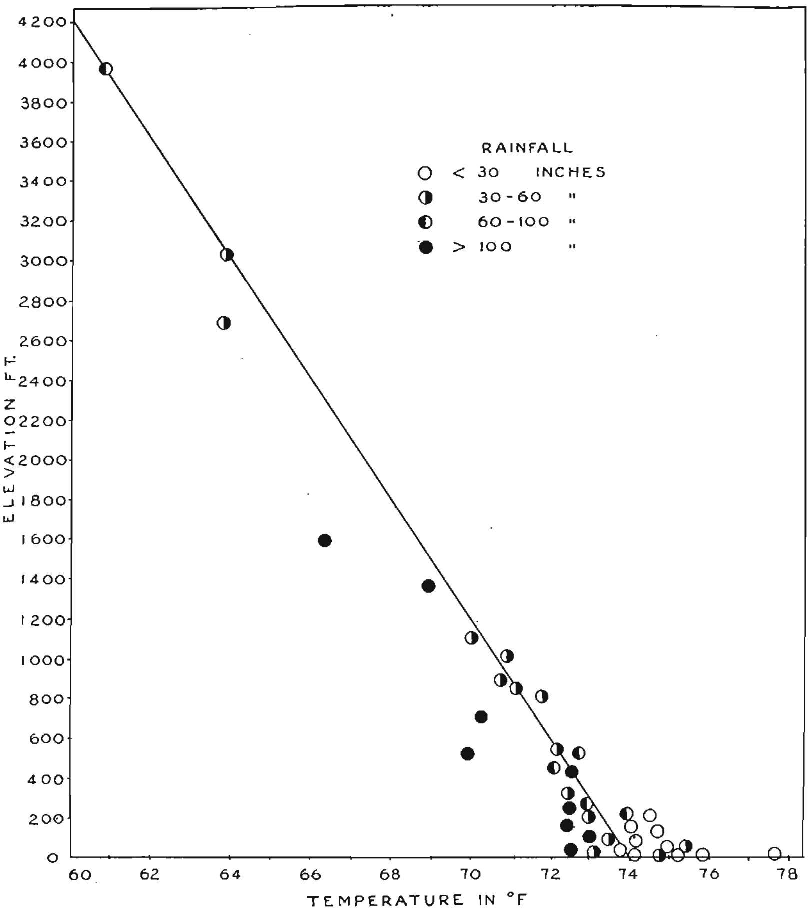

Fig. 1—Relation of mean annual temperature to altitude and rainfall.

with altitude may be greater than the usual one degree per 300 feet (fig. 1, above). Lee slopes usually have greater daily and annual ranges than windward slopes and shorter delays of seasonal extremes. Daily ranges of 18 or 20 degrees are not unusual, the days being warmer but the nights cooler than on windward sides. Clear skies favor strong heating by day and rapid radiation at night. High daily range probably stimulates plant growth if moisture is adequate (7). Dew is more common in leeward than windward localities. Annual ranges may exceed 8 degrees. August and January are usually the warmest and coolest months, respectively, whereas at some windward stations most exposed to sea influences, September and February are the extremes.

As the trade winds stream about the islands, their velocity is greatly influenced by landforms. Most windward shores have steady winds, brisk but seldom violent. In mountain gaps, such as the Maui Isthmus or Waimea, Hawaii, funnelling of air gives higher velocities. The same effect is produced by mountain shoulders and island tips projecting across the wind, like South Point, Hawaii. Where mountains are low or where valleys concentrate the air flow, lee slopes may be windy. Other lee slopes, sheltered by high mountains, are places of abundant calm. These calm sectors may receive light southwest breezes while strong northeast trades blow over the general region. The southwest winds may be eddies or they may be convectional sea breezes induced by the strong heating of calm lee slopes. The two localities best known for convectional southwest breezes are Kona, Hawaii, and Ulupalakua, Maui. In these localities, in the summer season of strongest heating and convection, clouds blanket the slopes almost every afternoon because of expansional cooling of the ascending sea breeze. In Kona, a summer maximum of rainfall is thus produced, giving forests in what otherwise would be a semiarid region.

Lee slopes obtain much of their rain from frontal storms accompanying kona weather. Therefore, most lee stations have a winter maximum of rain, in the season when North Pacific storms are numerous and the trade winds irregular. Lee-slope summers (except in Kona) are often nearly rainless. Dependence upon kona-wind fronts makes lee-slope rainfall unreliable. In the rainy Koolau Mountains of Oahu, a year's rainfall seldom varies more than 20 per cent from the normal. On the dry Waianae coast, deviations nearly 50 percent from normal are to be expected (23). Downtown Honolulu, with a normal rainfall of 25 inches, has had as few as 11 and as many as 45 inches.

Reliability of rainfall is of great importance to the agriculturist not provided with irrigation water. While periods of excessive rain and cloud may be injurious, on lee slopes it is periods of drought that are most feared. To give a rough measure of the frequency and length of droughts in Hawaii, rainfall records of 24 stations for the period 1907-38 were examined. A calendar month with less than one inch of rain was called a dry month. It was found that at stations with normal rainfall of 60 inches or more, dry months were almost nil. The one exception was in Kona (Kealakekua), where winter droughts are not uncommon. As normal rainfall decreases from 60 inches, the frequency of dry months increases. Stations with 40 inches of rain can expect 20 percent of all months to have less than one inch. Stations with 20 inches a year can expect 60 percent of dry months. Not only do drier stations have more dry months, as is to be expected, but also their dry periods are much longer. Stations with more than 40 inches of rain a year had within the period studied no dry spells longer than three calendar months. At 20-inch stations, dry periods more than three months in length accounted for 80 percent of all dry months. Dry stations with windward exposure fare better than leeward stations of similar rainfall, especially in regard to long droughts.

Despite the fact that more than 200 weather bureau stations and many experimental, plantation, private, and army and navy weather stations exist in the islands, some with records beginning well back in the nineteenth century, there is much still to be learned about Hawaiian climates. Rainfall is the factor best known, for many stations record that alone. However, most of the rain gages have been placed in plantation or water-supply areas. For large portions of the Territory there are little data. This lack is particularly great for the higher parts of Maui and Hawaii and for dry areas not used for sugar cane or pineapples. We are not sure of the limits of heavy rainfall in many mountain areas, such as windward Haleakala. Measurements of rainfall intensity—of the rate at which rain falls—are very few in the islands, although of great importance for flood control, water supply, soil conservation, and unirrigated agriculture. Many rain gages, because of their inaccessibility, are read only at intervals of a week or more and so do not tell us daily rainfalls. In some cases, evaporation during the interval between readings may introduce errors.

We can make fair estimates of mean temperatures from altitudes, but details of temperature range and variability are little known except for plantation areas. Sun temperature measurements with black-bulb thermometers or thermographs seem to have a closer relationship to plant growth than the shade temperatures ordinarily recorded. Many such instruments are now installed, but mainly in plantation areas. Ordinary data for "rainy days" (days with 0.01 inch or more of precipitation) or even instrumental records of hours of sunshine are not sufficient to determine sun temperatures.

Evaporation measurements have been made at a few weather bureau stations and in experimental and plantation work, but few are directly applicable to ranch lands. Run-off and infiltration are of great importance in determining relationships of plant growth to rainfall, but few such measurements have been made in the islands. On steep, porous lava slopes facing the sun, evaporation, run-off, and infiltration may reach high figures. Wind velocities and the detailed pattern of air circulation about mountains and in valleys are known largely by indirect evidence. More exact data of many kinds are necessary before detailed knowledge of the climates of specific localities is possible.

The climatic phases of the present work are necessarily based on judicious use of available information. Application to Hawaii of standard climatic classifications by Jones and Bellaire gave regional patterns useful as a general picture but unsatisfactory in detail (17). Field studies of vegetation by Ripperton and Hosaka suggested modifications, especially in regions of scanty rainfall data. Annual rainfall and altitude (roughly proportional to temperature) set the main outlines.

SOILS

The processes of soil formation are largely controlled by climate, and the broadest classification of the soils of the world forms a pattern quite similar to that of climates. In Hawaii, rainfall plays the dominant role in determining the rate of soil formation as well as the characteristics of the soil produced. The great variations in annual rainfall occurring in short distances produce correspondingly great differences in soils. In contrast, temperature effects at any given altitude are relatively constant, and below about 6,000 feet they are manifested primarily in the rate of soil formation. Above about 6,000 feet, low temperatures retard the rate of rock decomposition, and frequent freezing weather causes considerable physical disintegration of the rock. The principal soil groups or associations adopted by the U.S.D.A. soil survey recently completed in Hawaii (30) conform generally with the proposed vegetation zones. While climate determines the major soil characteristics of soil formation in each zone, variations in soil type within the zone are very marked because of age and physical texture of the parent rock, relief, and drainage; thus, mapping of the individual soil types produces a very complex pattern.

In other parts of the world where the natural vegetation remains and detailed ecological investigations have been completed, it is generally possible to relate definite plant associations to certain soil types, so that agricultural possibilities of the various soil types may be determined by a survey of the vegetation of virgin lands. At the present stage of ecological investigation in Hawaii, with few exceptions, it is not possible to establish definite relationships between the different soil types and plant species as differentiated from the concurrent direct effect of climate on the plant. Obvious relationships are obscured by the destruction of the natural vegetation in most places and by the rapidly changing aspect resulting from the introduction of exotic species. It remains for future studies to establish these more exact relationships of soil types and plant species that inhabit them. In the discussion of vegetation zones is given a description of the soil characteristics of each zone.

VEGETATION

Little or nothing is known of the plant cover of the Hawaiian islands prior to their discovery in 1778 by Captain Cook. The forest was probably much more extensive than at present, particularly at lower elevations. At least, we know from the landshell distribution records, remnant clumps of forest trees, and observational accounts of the early visitors to the islands that the forest extended far below the present boundaries and in many places to sea level. The natural factors which determined the limits of the forested area were primarily rainfall in the lower elevations and temperature in the upper levels, above about 10,000 feet.

The native flora of Hawaii is meager as to the number of species but is interesting because of the high endemicity. The separation of the Territory from any large body of land by over 2,000 miles of open ocean prevented the successful migration of many species. Of the 1,200 native species known, 85 percent are endemic, that is, they are found nowhere else in the world. With the rapid influx of peoples from many parts of the world, exotic or foreign species rapidly increased. A total of over 2,000 exotic species have now been recorded. This large influx has produced profound changes in the vegetation, especially in the lowlands. Aided by clearing for agricultural use, fire, and grazing animals, exotics have supplanted native species over a large part of the Territory.

The study of the natural or wild vegetation of any given place may be made in either of two general ways. The floristic method consists of the listing of species and the discussion of their origins and relationships. The ecological method is concerned not only with the species which are present but also with the grouping of plants into different communities, the trends or changes which take place, and the environmental factors which effect these changes. The natural grouping of plants into definite associations takes place as a result of competition for light, moisture, soil nutrients, and the like. Two species which have similar growth habits enter into direct competition, and generally one or the other becomes dominant under a given set of environmental conditions. Plants which have distinctly different growth habits may exist together indefinitely. Thus a tall tree may occur with a shade-tolerant shrub, and below this canopy there may be small ferns, grasses, or sedges. Although subject to minute variation as to amount and kind of secondary species, such natural groupings into associations have a few species which are dominant and occur over large areas.

Using the general classification of vegetation, one can point out five formations in the islands: shrub, forest, parkland, bog, and moss-lichen. Not all of these formations exist, nor are the altitude limits of each the same on the several islands. The shrub formation is found in varying width along coastal lowlands. On the lee or dry sides of the islands it extends farther up the slope than on the windward or wet sides. The forest formation is found above the shrub formation and extends from about 1,000 to 7,000 feet altitude, but within this formation there is considerable variation, resulting from the varying aspect of the topography in relation to the prevailing winds, rainfall, differing temperatures produced by altitude, lava flows, cultivation, and grazing. The parkland formation is situated on the upper slopes of the high mountains of Maui and Hawaii at about 7,000 feet altitude, where the climate is high, dry, and cool. The bog formation is located in areas of extremely high rainfall at 4,000 to 6,000 feet altitude, where the topography is usually level and the drainage is poor, with open water channels between the hummocks of generally low and stunted plants. The moss-lichen formation is found on the summits of the high mountains above the timber line. This formation is alpine in character with low rainfall and frequent frost. Snow covers the ground occasionally during the winter months, but it very seldom persists except in depressions near the summit.

SHRUB FORMATION

This type is chiefly characterized by guava, lantana, koa haole, klu, cactus, and pili grass. In wet locations along stream beds and shaded slopes, guava forms a dominant cover, but in dry areas and in rocky places other species are common. In certain localities, cactus and koa haole form homogeneous thickets. Other vast areas are spotted by clumps of lantana with Bermuda grass and Natal redtop covering the interspaces. Pili grass occurs in solid to scattering patches in the open rocky places.

FOREST FORMATION

Here tall trees with undergrowth of shrubs and ferns intermixed with tangling vines are found. At the higher altitudes, where fogs are common, the trees are covered with epiphytes. In the lower section kukui trees, 25 to 50 feet tall, form a conspicuous light-colored canopy along the gully bottoms. On the lower islands koa forms a good stand between 1,000 and 1,500 feet altitude with staghorn fern as an undergrowth. However, on the higher islands koa is dominant from 3,500 to 6,000 feet altitude. Mamani is found from 5,000 feet to the timber line at 10,000 feet. Ohia lehua is the characteristic tree in the wet forests at 1,500 to 4,000 feet elevations and on new lava flows at lower altitudes. Along the dry coastal alluvial flats and gullies, algaroba trees 20 to 40 feet tall form a good growth. On the flats they form a solid stand and a rather open growth on the slopes. Under the trees swollen fingergrass makes good growth during the rainy season.

PARKLAND FORMATION

This type is characteristic of open vegetation with scattering clumps of trees and occasional shrubs. Common plants are *Raillardia,* mamani, naio, ohelo, puakeawe, aalii, bracken fern, heu pueo, and mountain pili.

BOG FORMATION

This type is characterized by specialized plant development. Some of the common plants are violets, sundew, ohia lehua, *Plantago, Lobelia, Cyperus, Panicum,* and moss. The bigger plants, such as *Lobelia* and ohia lehua, form small clumps on top of isolated hummocks and are completely or partly covered with moss. *Cyperus* and *Panicum* form tufts in colonies.

MOSS-LICHEN FORMATION

This formation is found above the zones of seed-bearing plants and where the ground is barren of higher plants. Occasional chance clumps of silver sword and Hawaiian bent grass have been recorded.

To understand and interpret the status of a vegetation occurring in any given place, it is desirable to know its development. The basic concept of plant ecology is that vegetation is dynamic and subject to continuous change until an equilibrium is established between the plants and their environment as well as between the different species growing together. This is the highest development a vegetative sward can attain under a given environment and is known as the climax type, which is relatively permanent under the existing conditions. A striking example of the successive changes of vegetation that are taking place in Hawaii is manifested in adjacent lava flows of different ages. A lava flow that cuts through an ohia lehua forest is first populated by lower forms of plant life such as algae, lichens, and mosses. Later on, ferns appear and after a period of time the original forest redevelops (9).

Seldom is a pure stand of one species found under natural conditions; plants tend to form communities. In a newly plowed field, the community is unstable. Quickly developing plants take possession first; these are followed by larger, deeper-rooted, perennial types. Where sufficient ecological data are available, the successive steps or changes in vegetation can be predicted to the final climax association, which is relatively permanent and subject to change only when some factor such as a lava flow, cutting of the forest, fire or grazing animals upsets the equilibrium. Very little work on the study of plant associations and plant succession has been done in the Territory. Forbes (9) and Skottsberg (27) conducted an investigation on plant succession on new lava flows; Hosaka (16) made detailed studies of the plant associations and probable succcession in the Kipapa Gulch on Oahu; Robyns and Lamb (24) have mapped the plant formations on the island of Hawaii and suggested possible successions and climax associations. None of these investigations was conducted over a long enough period of time to permit any final conclusions.

DERIVATION OF VEGETATION ZONES

In the division of an area into zones that are of general significance to agriculture, either climate or vegetation may serve as the essential basis. The strictly climatic approach is illustrated by the classification of Jones and Bellaire (17). As Jones states (see page 11), such climatic classifications "gave regional patterns useful as a general picture but unsatisfactory in detail." Zonation on the basis of vegetation alone presupposes that the native vegetation is relatively undisturbed or that the major introduced species have reached their ultimate distribution. Under existing conditions it appeared that a combination of the two methods offered the most reliable basis of division into zones.

The characteristic types of vegetation and the distribution of species upon which the vegetation aspects of the vegetation zones are based are the result of a pasture survey made in 1936 and 1937. A total of six months was spent by the junior author in the initial survey, in which all the islands of the Territory except Niihau and Kahoolawe were visited and all the important pasture areas surveyed. Subsequently, numerous localities were resurveyed to verify zonal boundaries and to determine the seasonal aspect of the vegetation. In making the survey, the major areas were traversed up and down the slope and on the contour to establish the points of transition from one vegetation type to another. Each area of similar vegetation was then surveyed as to the species present and the relative abundance of each. The intensity of the survey varied with the homogeneity of the vegetation and the importance of the pasture land. No attempt was made to cover the entire area of the Territory. Forest reserve, national parks, and waste lands were generally not surveyed except to determine the general aspects of vegetation.

After satisfactory relationships between vegetation, rainfall, and altitude at a series of points were established, certain isohyets (i.e. lines connecting points of equal rainfall) and altitude limits at which transition in vegetation types occurs were selected as tentative zonal boundaries. These tentative boundaries, based primarily on climatic data, were then revised up or down the slope wherever the vegetation indicated such a change to represent growth conditions more accurately. Such a procedure does not contest the relationship of vegetation and climate since factors other than total rainfall and temperature are often important in determining plant distribution, particularly at a higher elevation. The aggregate of vegetation types of the cleared and uncleared portions, the density of cover, and persistence of planted species, together with certain characteristic dominants, were taken as the basis of final revision of zonal boundaries. These zones thus represent the general aspects of the vegetation as it now exists. As a convenient basis for setting up tentative divisions between zones, climatic data were used.

Since in much of the pastured and cultivated lands the trees and shrubs have been more or less completely removed, it seems inappropriate to use the terms "forest zone" or "parkland," or to characterize the zones by the names of plant species or associations which are often non-existent. Letters have therefore been used to designate the different zones. Where the zone has been subdivided into phases on the basis of altitude, these are designated by a subnumeral—(1) for low, and (2) and (3) for the higher phases. Five zones have been defined. Three of them have been further subdivided, so that there is a total of ten subdivisions. The divisions below about 6,000 feet conform in a general way to total rainfall; above this altitude no rainfall data exist. However, temperature becomes an important factor of growth above this elevation, and the region can be satisfactorily subdivided on the basis of altitude alone.

Table I lists the ten zones and phases and their general limits as to rainfall and altitude as well as the vegetative aspects of the natural coverage and cleared pastures. The limits of rainfall and altitude given are only approximate. This variation results from differences in physiographic features of the different islands, arrangement of zones in different localities, and changes in boundaries due to vegetative aspects.

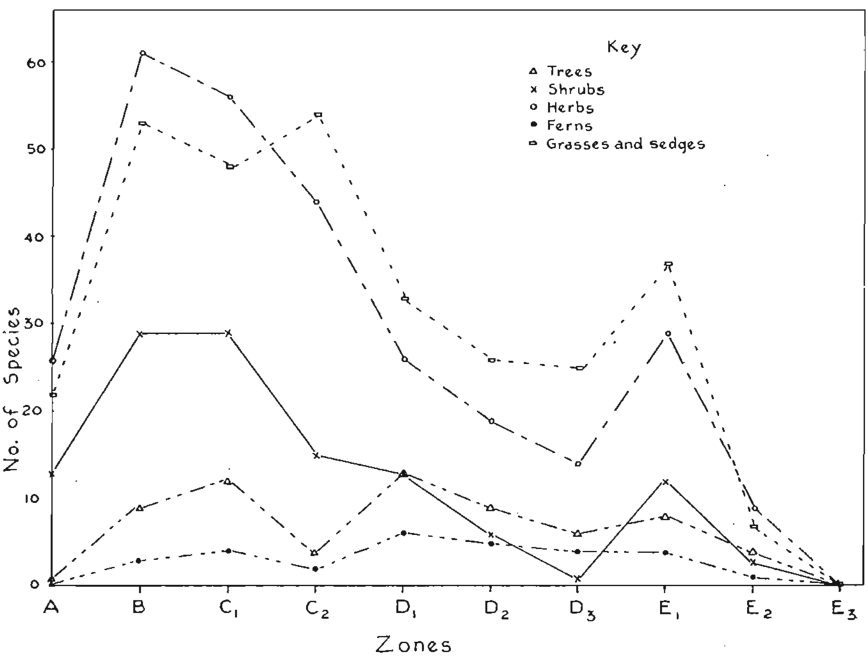

Fig. 2—Zonal distribution of pasture plants.

Figure 2 (p. 17) shows the number of species subdivided into the five commonly used growth forms—trees, shrubs, herbs, grasses and sedges, and ferns—which are found in the different zones. These numbers do not include the species found only in cultivated fields and forest reserves; nor do they include ornamentals. It is generally recognized that under extremes of environment the number of species is lower than in more moderate habitats. Locations with adequate moisture distributed throughout the year, normally resulting in forests, are not as rich in number of species as are regions of seasonal rainfall. Destruction of a sub-climax or climax plant association and the formation of a regressional stage or unstable community generally results in larger numbers of more varied types of plants. As the species here listed do not comprise all of those found in the zone and since many of the areas represent unstable plant communities that are being markedly changed by grazing and pasture management, exact conclusions are not justified. In many respects, however, the relative differences in total numbers and plant types bear out what would be expected in the various zones. Zones A and E_2 represent extreme environments where seed-bearing species grow, the former being very dry and the latter both dry and cold. Zones B and C have seasonal climates with the greatest numbers of annual herbs and grasses. Zone D with its ample rainfall has much smaller numbers of these annuals, the principal species being perennials.

It should be stressed that the proposed division into zones is of a general and preliminary nature. The data on many phases of climate are fragmentary or entirely lacking, particularly with respect to local characteristics. Were these factors known, it would no doubt be possible to show an even closer correlation between climate and vegetation. No attempt has been made to construct the zonal boundaries in sufficient detail to account for the finer variations in topography. Differences in soil type within the zones have also been largely disregarded, so that a fresh lava flow, a pali slope, and an alluvial bottom area are classed alike. The vegetative type is taken as that found on a normally developed soil profile. These important local characteristics should constitute the basis for subsequent subdivision of the zones into phases.

The classification has been developed specifically for pastures made up of both wild and planted species. Pasture plants, particularly grasses, have a generally wider range of adaptability than most cultivated crops. Moreover, the pasture sward comprises a variety of species, and considerable fluctuation in the mixture is possible without changing the essential value or use of the pasture. Thus, environmental differences which would be of major importance with a specific crop under intensive cultivation can be disregarded in connection with pasture use.

As further data become available as to climate and vegetation relationships, the zonal boundaries may be changed. There is great need for more exact information as to the differences in climatic and soil requirements of native and introduced species. Indicator species, thus defined, would be of great value in refining the zonal boundaries as well as establishing finer subdivisions within the zone. A strictly ecological approach based on long continued field studies of plant succession is obviously impossible at the present time.

TABLE 1

VEGETATION ZONES, THEIR ALTITUDE AND ANNUAL RAINFALL LIMITS, AND CHARACTERISTICS OF NATURAL VEGETATION.

Zone	Phase	Map color	Approximate altitude limits (feet)	Approximate total rainfall limits (in. per year)	Vegetation Characteristics	
					Natural cover	Species
A		Yellow	Less than 1000	20 or less	Xerophytic shrub with coastal fringe of trees	algaroba, koa haole, swollen finger grass, feather finger-grass, pili grass, bristly foxtail.
B		Orange	Less than 3000	20-40	Xerophytic shrub with some trees in upper part	lantana, koa haole, klu, cactus, uhaloa, ilima, false mallow, Natal redtop, pili grass, native panicums, hakonakona.
C	1-low	Green-dark	Less than 2500	40-60[1]	Mixed open forest and shrubs	koa haole, guava, lantana, Spanish clover, Bermuda grass, kukaipuaa, pilipiliula.
	2-high	Green-light	2500-4000		Mixed open forest	Bermuda grass, Spanish clover, wild geranium, bristly-fruited mallow, plantain, rattail.
D	1-low	Pink-medium	Less than 1500[2]	60 or more[1]	Shrub and closed forest	guava, sensitive plant, Boston fern, Hilo grass, rice grass, basket grass, honohono, staghorn fern.
	2-med.	Pink-dark	Variable		Closed forest	ohia lehua, tree fern, staghorn fern.
	3-high	Pink-light	4000 to less than 7000		Open forest	koa, pukamole, sheep grass, mountain pili, rattail, alapaio fern, tree fern.
E	1-low	Blue-medium	4000-7000	50 or less	Open forest and shrub	koa, mamani, heu pueo, mountain pili, large Hawaiian lovegrass, kalamaloa, sweet vernal, bracken fern, alapaio fern, Kentucky bluegrass.
	2-med.	Blue-dark	7000-10,000		Mainly upland open shrub	mamani, naio, Raillardia, heu pueo, kalamaloa, bracken fern.
	3-high	Blue-light	Over 10,000		No seed-bearing plants	barren except for mosses and lichens. (Occasional clumps of silver sword and Hawaiian bent grass.)

[1] Minimum rainfall is less than 60 inches at higher levels.
[2] The boundary between D_1 and D_2 varies with location and present utilization. In general it represents the highest point of satisfactory utilization for most crops, as adjudged by climate, soil type, and present crops growing.

DESCRIPTION OF ZONES

The following description of each of the vegetation zones gives the principal aspects of climate, topography, soils, and vegetation.

ZONE A

This zone is located on the lee side of the islands or on the low windward lands with no mountain background high or close enough to cause cloud formation and precipitation. Most of the zone is between sea level and 500 feet altitude, but in places it extends to 2,000 feet. Where water is available, the arable parts are devoted to sugar production. Grazing constitutes the only other use of importance.

CLIMATE

The normal wind velocity varies from relatively high across the ends of the islands or through gaps to very light on the lee side of mountains high enough to deflect the trade winds. The rainfall is usually below 20 inches annually, though some areas with higher rainfall are included where winds produce high evaporation or the steep slope causes excessive run-off. The lowest official long-period record is at Lahaina, Maui, with a mean annual rainfall of 11.80 inches. Winter rains of Kona origin are more abundant and frequent than summer rains. These kona rains are often torrential, and because of a combination of high evaporation and high run-off on the slopes the proportion utilized by the plants must be very low. Long dry periods are common. For example, at Kaanapali, Maui, there have been ten 8-month periods during the past 31 years in which less than 1 inch of rain fell per month. Mean annual air temperatures are about 75 degrees Fahrenheit at sea level, a few degrees higher than on the windward side. Maximum temperatures are much higher and minimum temperatures lower than on windward slopes, the former often exceeding 90 degrees Fahrenheit. Although no records are available, soil temperatures must be excessive on the partially denuded, sun-baked slopes of much of the area.

TOPOGRAPHY AND SOILS[1]

Zone A consists of coastal flats and the sloping lands, which in places extend to 2,000 feet altitude. On the moderate to abrupt gradients there are numerous small gullies, and on Hawaii and Haleakala, Maui, rock outcrops and undecomposed lava flows are common. Wind and water erosion on the slopes are severe, owing

[1] These zonal descriptions of soils are from field notes and observations in making a soil classification of the Territory of Hawaii by Z. C. Foster, Assoc. Soil Scientist, Soil Conservation Service, formerly Asst. Soil Surveyor, Bureau of Plant Industry, U.S.D.A.

to lack of adequate plant coverage and the generally dusty nature of the soil.

Soils derived from pyroclastics or volcanic ash occur principally on Hawaii and the south slope of Haleakala, Maui. They consist of a thin brownish organic layer and an underlying yellowish ash. The surface layer is fluffy and dusty and easily eroded by both wind and water. Rock outcrops are common, and very little of this type is arable. Where conditions of growth are not too rigorous and erosion has not been too severe, plants grow well in these rocky areas.

Soils derived from alluvium are found more commonly in the valley bottoms and deltas and some of the low-lying adjoining areas. They vary in texture from heavy black clays to sandy loams and from consolidated alluvium to recent deposits. They are well adapted to many types of agriculture where irrigation water is available.

Soils derived from lava are the friable red-brown loams, which occur on the slopes and have a uniform color and structure to considerable depths. On the steeper slopes, erosion has been generally severe; in places the original soil has been completely carried away, and the present surface layer is a heavy-textured clay. The noneroded parts are among the most productive soils of the islands under irrigation. Such soils have a neutral to slightly alkaline reaction.

Soils derived from marine material consist of unconsolidated sands as well as strata or crusts of consolidated material. Often a thin mantle of reddish loam, which is generally too shallow to plow, has developed on the consolidated material.

VEGETATION

The vegetation of this zone is of the lowland shrub type with the exception of the coastal fringe of the algaroba tree. All of the dominants are exotics, although most of them have been long established. The ground coverage is generally sparse, and conditions are semi-desert in character. The algaroba is particularly conspicuous; where ground water is close to the surface, it grows to a height of 35 feet or more and forms dense stands. On the slopes it decreases sharply in size and density and is not found to any extent above 1,000 feet. The principal shrubs are klu, koa haole, and ilima. Klu is an undesirable thorny bush, although it seldom forms thickets. Koa haole is found in this zone only in the gully bottoms and rich alluvial flats. The small shrub, ilima, is widely distributed throughout the zone, but it is never dense enough to become obnoxious. Australian saltbush is often conspicuous on the flats. Only occasionally is lantana prominent.

Perennial grasses are conspicuously absent, but a number of annual species spring up in abundance after rains. Bristly foxtail is found mostly under the algaroba trees and is acceptable forage even when dry. Swollen fingergrass and feather fingergrass maintain themselves by natural seeding. Pili grass is chiefly an annual in this zone; several small native panicums are common.

Because all the dominant species are exotics and their growth considerably affected by grazing, it is difficult to determine trends toward definite associations. Robyns and Lamb (24) believe that algaroba will form a climax along the coast. The vegetation remains fairly stable with comparatively little invasion by species adapted to the adjacent moister zones.

ZONE B

Zone B lies above Zone A where the latter is present. Its occurrence is similar to that of Zone A except that narrow coastal strips are found on the windward side in places. Its upper altitude limits extend as high as 3,000 feet in places, but the average is about 2,000 feet. Where water is available, sugar cane is planted in a large part of the arable land below about 1,200 feet and generally produces high yields. Above the sugar cane, pineapples take up the best lands. Grazing constitutes the only other land use of importance.

CLIMATE

The features of air circulation and rainfall distributions are similar to those of Zone A. The total rainfall limits average approximately 20 to 40 inches. These limits vary with the proportion of the rainfall which is absorbed by the vegetation. Where utilization of moisture is low, because of strong winds or high runoff, the upper limit may be greater than 40 inches. Conversely, where the rainfall is more effectively used because of higher altitudes or favorable topography, the lower limit may be less than 20 inches.

TOPOGRAPHY AND SOILS

Where Zone B comprises the coastal area, its topography and soils are similar to those of Zone A. Where it occurs above the latter, the alluvial and marine soils are absent.

Soils of this zone have a more definite and well developed surface layer than Zone A and under similar topography are less eroded, owing to more adequate vegetative cover. Soils derived from pyroclastics have a surface layer definitely darker and higher in organic matter than those of Zone A, and the ash mantle is generally deeper. Soils from lava have a characteristically bright red subsoil with a somewhat darker surface soil. Included in this zone are soils which have developed under a higher effective rainfall than the present one before destruction of the forest. These soils are distinctly different from the friable red loams; they have an acid reaction and a granular surface soil and are distinctly less fertile than the red loams formed under drier conditions. A notable example of this is a large area above Kekaha on Kauai.

VEGETATION

The vegetation is of the lowland shrub type, and plant coverage is generally good except on the steeper slopes and ridges. The shrubs are more numerous and vigorous, and the annuals are longer-lived than in Zone A. Where this zone borders the ocean on the leeward side, algaroba is generally prominent. Lantana and cactus are widely distributed and often form dense thickets, choking out all undergrowth. Koa haole is well adapted and often forms a dense stand 10 to 15 feet high on the flats, gullies, and rocky soil areas. In open places the smaller shrubs, ilima, uhaloa, and Japanese tea are prominent. Annual or short-lived herbs are prominent during the rainy seasons. These include Spanish needle, false mallow, pualele, cocklebur, picridium, and zinnia. Pili grass is particularly prominent in the lower drier parts of this zone; during the wet months many places take on the appearance of a sown field of grain. Kakonakona and other native panicums are common during the winter and spring. In the upper part Bermuda and Natal redtop often make excellent growth and constitute a perennial grass coverage lacking in the drier lands below. Sour grass is a particularly prominent grass pest on Oahu in this zone, and sporadic growth is appearing on the other islands in similar locations.

The plant community is unstable and subject to an evolutionary change. Lantana and cactus have spread over vast areas. It is believed that koa haole might after a long period supplant lantana if allowed to compete without grazing; under grazing the trend is greatly retarded.

ZONE C

This zone lies above the B zone except where it reaches the sea. On the lower mountain it often forms a band more or less completely encircling them, dipping down to or near the coastline on the windward side. On the plateaus of moderate altitudes it widens into comparatively extensive areas. The zone varies in altitude limits from sea level to a maximum of 4,000 feet. Because of the marked effect of such a difference in altitude on vegetation, the zone has been subdivided at about 2,500 feet, the lower phase being adapted to the more tropical and the upper to more temperate species.

This is the most desirable zone for non-irrigated agriculture and includes a large part of the diversified farming of the Territory. It contains the largest proportion of arable land with good-quality soil. The climate is suited to a greater variety of crops than either the wetter or drier zones. During the average season the moist spring and drier summer permit the natural maturing of corn, cereals, potatoes, and legumes—a common difficulty in the wetter zones. Sugar and pineapples are the principal crops in the low phase, and good yields are secured. The upper phase is too high for either crop, although pineapple extends to nearly 3,000 feet in one locality on Maui.

In the lower phase, ranching is restricted mostly to the gullies and poor lands. In the upper phase, the non-adaptability of the two major crops results in the use of some very good land for grazing, and here are located some of the finest pastures in the Territory.

CLIMATE

The total rainfall limits are between 40 and 60 inches at sea level. At the upper altitude limit of 4,000 feet, 50 inches are theoretically as effective as 60 inches at sea level because of less evaporation at the lower temperatures. Most of the rainfall is of tradewind origin. On the lee of the lower mountains and on the plateaus the rains come from the clouds carried over the mountain crests. The rainfall in those parts of the C zone on Hawaii and Maui lying to the leeward of higher mountains is produced by land-sea breezes. Kona rains and local showers are not of as great relative importance in Zone C as in the drier zones. Dry periods lasting more than a month are not common. The greatest precipitation occurs during the fall, winter, and spring months; the summer is distinctly drier. The amount of cloudy weather is, of course, greater than in the dry zones, but sunshine is generally adequate for plant growth.

TOPOGRAPHY AND SOILS

The topography of Zone C varies from gentle slopes in the coastal areas to steeper gradients on the mountain slopes, thence to the gently rolling surface of the higher plateaus. Large gullies are common, but in most places the original slope as well as the steeper sides of the gullies are well protected by vegetation. For this reason, erosion is not as active in the noncultivated areas as in the drier zones.

In the low phase, soils derived from volcanic ash are of little importance, but in the high phase they are predominant. They have a well-developed organic surface layer underlain by a soft, fluffy sandy loam subsoil high in organic matter. The subsoil varies in texture from silt or clay loams to only partially decomposed cinders and scoraceous material. Where the soil is of sufficient depth, these ash soils are unusually desirable; their loose open texture makes them easy to till, retentive of moisture, and permits deep root penetration.

Soils derived from lava are predominant in the low phase. They are characterized by a granular dark grayish-brown surface layer, 8 to 10 inches deep, and a dark reddish to chocolate-colored friable subsoil. Organic matter is higher than in Zones A or B. In general these soils are friable and easily worked but tend to become compacted. This is probably the most important class of soils in the Territory. Developed under conditions of moderate moisture and subject to less erosion than either the drier or wetter zones, they usually have good depth, respond well to fertilizer, and are adapted to a variety of crops. Typical of such soils is the central plateau on Oahu.

A greater part of the alluvial soils is derived from material washed down from areas of heavy rainfall; they are consequently more acid and of lower fertility than residual soils formed under rainfall occurring in Zone C. A good example of this type is on the windward coast of Oahu. Soils derived from marine material are of negligible importance.

VEGETATION

Low Phase. The natural vegetation consists of open shrubs and grasses, and with few exceptions the ground coverage is excellent. Guava is the predominant shrub; in the gullies where there is more moisture the plants are large, but on the slopes they are distinctly smaller than in the wetter zones. Guava ceases to be of any importance as a plant pest above about 1,500 feet on the slopes, although in the gullies it extends to 2,000 feet or more. Lantana is also widely distributed, but it has neither the vigor nor the density of growth that characterize it in the B zone. Koa haole forms dense thickets in localized areas below about 700 feet. Of the smaller shrubs, false vervain (joee) makes dense growth in places and is a troublesome pest. Indigo, Japanese tea, ilima, and uhaloa are scattered throughout but are not generally prominent.

Grasses are particularly vigorous. The lesser vigor of the shrub growth may be attributed in no small degree to competition of the grasses. Bermuda is the dominant species on all areas of good soil. On the eroded slopes and poorer soils, pilipiliula, rice grass, and yellow foxtail generally become established. Natal redtop is particularly prominent along the roadsides and in plowed fields and is also a component in pastures. On Oahu, sour grass is gradually encroaching into this phase from Zone B. In that part adjacent to Zone D, Hilo grass becomes important.

In lands which have been plowed a varied and vigorous stand of herbs develops, such as Spanish needle, garden spurge, galinsoga, pigweed, pualele, dandelion, and Boston fern. These are suppressed to a large degree after Bermuda grass becomes established. In the B zone such herbs continue to form an important part of the vegetation, as there is no perennial grass sufficiently aggressive to hold them in check.

High Phase. There is considerable evidence that much of this phase was originally forested, but at present much of the forest has disappeared. The uncleared sections are open to thick stands of a mixture of ohia lehua and koa. In the more open places the shrubs aalii and puakeawe predominate with some undergrowth of grasses. The cleared areas are essentially grassland, and little difficulty is encountered in preventing the encroachment of trees and shrubs, except on Maui where pamakani is prevalent. Guava and lantana, the most common shrubs of the lower phase, cease to be of importance.

Bermuda is the dominant grass over much of the better grassland areas. In the wetter parts where the soils become compacted because of trampling, or where the fertility is lower, rattail tends to dominate. In certain regions the best planted pasture-species composition is found. Natal redtop is very conspicuous in the drier parts where the climate is more seasonal. Smooth kukaipuaa is important, especially where Bermuda grass is less vigorous. A variety of herbs is found; they include bull thistle, wild geranium, gosmore, bristly-fruited mallow, plantain, and dandelion. Spanish clover is particularly prominent in the central localities of the zone.

ZONE D

Most of this zone occurs on the windward side of the high mountains. On the lower mountains it includes the mountain crest and the higher levels to the leeward.

In the low phase, sugar cane is grown in the arable parts without irrigation. Excessive rainfall and limited sunlight reduce the yields and quality of juices below that of the drier zones. Pineapples were formerly grown in the drier parts on some islands but have been almost entirely abandoned because of disease, low yield, and poor fruit-quality. Truck crops are grown to a certain extent, although insects and diseases are often troublesome. Dairying is well suited to this phase, and the animals may be pastured on fresh, succulent grasses throughout the year. In the high phase, leafy truck crops are particularly well adapted. Nearly all of the middle phase is included in forest reserve and constitutes the principal sources of artesian, tunnel, and surface water for irrigation of the drier zones.

Ranching in the low phase is generally restricted to the poorer soil areas and unarable parts. Only a few parts of the middle phase represent cleared pastures. The high phase, although occurring only on Maui and Hawaii, includes some important ranching land.

CLIMATE

Except for the Kona district of Hawaii, rainfall is largely ot trade-wind origin and is thus less variable than is true of the other zones. Winds are generally brisk in the lower parts but seldom strong. The air temperature in this zone has an annual mean of 73 degrees at sea level, which is 2 to 3 degrees lower than that on the leeward side. Increased cloudiness, and nearly continuously moist soil magnify the effect of this temperature difference.

The minimum rainfall limit of this zone is 60 inches at sea level. At high altitudes it may be as low as 50 inches, owing to greater effectiveness. Judging from soil characteristics, this minimum rainfall represents the approximate point at which evaporation is equal to rainfall. The maximum rainfall in the zone varies among the different islands; usually it is in excess of 200 inches. On the lower mountains the maximum is at the crest or somewhat to the leeward. On the high mountains the rainfall decreases above 3,500 feet and a high drier section is found. Except for abnormal years the rainfall is adequate for plant growth during all seasons of the year.

Generally excessive rainfall, inadequate sunlight, and leached, acid soils are the limiting factors in growth of many cultivated crops.

This zone is divided into three phases: the low, middle, and high. No satisfactory division between the low and middle phases could be made on the basis of total rainfall, altitude, or vegetation. The method finally adopted was one of present utility, the upper limit of the low phase being the highest level of present or probable future utilization for agricultural crops. The high phase lies above the belt of maximum rainfall, its lower altitude boundary being usually above 4,000 feet. The climate is one of cool temperatures and frequent fogs, producing conditions similar to the humid parts of the temperate zones.

TOPOGRAPHY AND SOILS

The high rainfall of this zone has resulted in extensive erosion in the past, so that many parts consist mainly of deeply cut gorges and steep-sided ridges. Above the zone of maximum rainfall, erosion has been less severe.

Because of the excessively moist conditions under which soil formation has taken place in the low and middle phases, the distinction between soil types derived from pyroclastic material and lava largely disappears. In general, as the rainfall increases, the soils become more acid with less available plant nutrients, a decreasing silica content, and a higher amount of organic matter. Relief and underlying substrata are important. Pronounced slopes are severely eroded; gentle slopes and impervious substrata often result in swamps.

Although the soils of the high phase are derived mostly from ash, they have not weathered to the degree of being highly colloidal, being mostly loam or sandy loam in texture. There are some tracts of deep soil in this phase, and these are generally of excellent fertility. Over much of this phase, however, the ash mantle is thin and the underlying lava is only partly decomposed.

VEGETATION

Low Phase. The most characteristic shrub is guava, which has covered many thousands of acres with a growth so dense that little grows underneath except ferns. Ohia lehua occurs in the upper part to a certain extent and is dominant to sea level on the more recent lava flows on Hawaii. Hala and kukui are abundant in localized areas. Associated with the guava and in cleared parts, staghorn, amaumau fern and Boston fern are common. False vervain is a troublesome shrub in certain localities. A variety of grasses, sedges, and herbs is found. Hilo grass is dominant in the better soil areas. Rice grass and yellow foxtail are more likely to populate poorly drained or thin soil areas. Carpet grass has become quite widespread and forms almost solid stands in places, often displacing the other grasses and checking to some extent the reestablishment of guava and other shrubs. The sedges, kaluha, and cyperus are prominent throughout. The herbs include the small creeping Chinese violet, the trailing honohono, and tarweed. Sensitive plant and Spanish clover are the only forage legumes of prominence.

Middle Phase. This phase is almost entirely in forest reserve. Ohia lehua is the dominant tree on the island of Hawaii, while on the other islands this tree is associated with koa. Guava extends well up into this phase in places, about 2,500 feet being the maximum altitude. The ferns such as alapaio, staghorn, amaumau, Boston fern, and tree fern are prominent in the open parts and beneath the tall trees as undergrowth. Where the trees have been cleared, Hilo grass is generally the dominant plant with lesser amounts of rice grass and other common wetland species.

High Phase. This phase is principally of the open forest type of vegetation. Koa is the dominant tree with ohia lehua as the associated species in the lower part. The tree growth has been mostly destroyed in the areas pastured, leaving generally open grasslands. The alapaio, amaumau, staghorn, and bracken ferns are common undergrowth.

Rattail is the dominant grass over much of this phase; brome fescue, sheep grass, and heu pueo occur in lesser amounts. Sweet vernal grass has become a prominent component on the windward part of Hawaii and is present on Maui. Its fibrous roots and profuse seeding aid it in overrunning the other grasses. In some localities excellent stands of temperate pasture plants are found.

ZONE E

This zone occurs on Maui and Hawaii only. The low phase extends from about 4,000 to 7,000 feet and the high phase from 7,000 feet to about 10,000 feet. It thus represents the comparatively dry upper slopes of the high mountains, Haleakala, Mauna Loa, Mauna Kea, and Hualalai. It lies above the high phase of Zone D in the wetter localities and the high phase of Zone C in the drier parts.

Only a small part of the total area is used for agriculture, the temperature being too low and the soils generally too shallow for cropping. Accessibility would be a serious problem were an attempt made to open these high areas for general agriculture. The forest reserve and national parks take up a considerable part of the total. Ranching comprises the only form of agriculture except for a small area in truck crops on Maui.

CLIMATE

Comparatively little climatological data are available for this zone. The mean annual temperature at 4,000 feet is about 60 degrees Fahrenheit, 50 degrees Fahrenheit at 7,000 feet, and 40 degrees Fahrenheit at 10,000 feet. Temperature fluctuations are somewhat greater at the higher altitudes. The difference in maximum and minimum temperatures recorded at Hilo (40 feet) is about 40 degrees Fahrenheit, and at Humuula (6,685 feet) it is 60 degrees

Fahrenheit. Frosts are not infrequent as low as 4,000 feet, and ice formation is appreciable at 7,000 feet. Above about 7,000 feet even the summer temperatures are too low to permit good growth, and above about 10,000 feet practically no plant growth occurs.

It is generally believed that the rainfall is between 20 and 40 inches per annum, the greater amounts being at the lower levels. Frequent snows cap the tops of Mauna Kea and Mauna Loa, and occasional snow falls on Hualalai and Haleakala. Lying above the belt of maximum rainfall, this zone has much less cloudy weather than below, but fogs are frequent in the lower part. Wind velocity varies from low to fairly strong, depending on the altitude and location.

TOPOGRAPHY AND SOILS

The upper slopes of most of the older high mountains are characterized by many ash cones. These have largely covered the surface with a loose mantle of gravelly ash. In the upper and drier parts this gravelly ash has been little weathered. Such soils have low water retentivity, and shallow-rooted plants suffer from the lack of water. In the moister parts of the low phase, some accumulation of organic matter is evident. In places where the ash is deep and fine-textured very good plant growth results.

VEGETATION

Low Phase. The vegetation consists of plateau parkland and, in the drier parts, of mountain parkland types. The typical form is that of scattered clumps of trees with open grassland between. On the Mauna Loa slopes, lava flows have greatly affected the natural coverage. Ground coverage is generally somewhat sparse, increasing in density and proportion of trees in the moist deep soil sections. The dominant trees are koa in the lower, and mamani and naio in the upper parts. Alapai and bracken ferns are common associates of koa. The shrubs puakeawe and aalii are common even where the trees have disappeared. Pamakani is a particularly prominent and troublesome shrub on Maui. A considerable number of herbs is present; they include hawksbeard, pukamole, gosmore, plantain, sheep sorrel, and mauulaili. The grasses are principally of the bunch type. Where this phase is above the D zone, rattail is prominent in places. Over most of the zone are the native grasses, heu pueo, mountain pili, mountain lovegrass, kalamaloa, and brome fescue.

Middle Phase. The trees in this phase are generally no larger than tall shrubs. Mamani and naio are the dominant plants. Grass coverage is sparse; the species listed in the low phase are the principal ones present. Practically none of this phase is used for pasturage or for any other type of agriculture.

High Phase. This phase is found on the nearly barren summits of Mauna Kea and Mauna Loa; plant growth is principally moss and lichen with occasional clumps of silver sword and Hawaiian bent grass.

ZONAL CHARACTERISTICS OF PASTURES

The range lands of the Territory are nearly all permanent pastures; temporary or seasonal pastures as the terms are commonly used elsewhere are seldom found in Hawaii. On many ranches, a portion of the land is arable and is converted into "fattening paddocks" by plowing and seeding at intervals of from 5 to 10 years. The remainder of the range is natural or wild vegetation together with such other species as can be established by broadcast seeding. Such permanent pastures reflect to a marked degree the effect of the environmental factors of climate and soil. As a result of many years of observation on the part of the writers, current ranch practices, and the present vegetation survey, it is possible to give in considerable detail the characteristics of the pastures in each zone. The following discussion lists the principal forage species which occur in the open range and those which are best adapted to the planted pastures, pasture management, and use; listed also are the possibilities of further pasture development in each zone.

ZONE A

The pastures of this zone consist of two contrasting types, the coastal flats with their generally thick stands of algaroba trees and the sloping lands above, often severely eroded and with only sparse shrubby vegetation. The ripe pods of the algaroba drop during the summer, from about June to November, and are much relished by cattle. This, together with the shade the trees afford, makes valuable pasturage during the period when the remainder of Zone A and Zone B is of little value. The most rigorous conditions are those on the shoulders at the ends of a mountain range, where strong air currents cause wind erosion as well as rapid evaporation of the scant moisture that falls. In a few places like South Point, Hawaii, relatively deep deposits of wind-blown soil produce excellent pasturage, although it is of short duration in the average season. Large sections of nearly barren lava flows on Maui and Hawaii are worthless as pasture.

Algaroba is by far the most valuable forage plant in this zone. Koa haole is not widespread, occurring primarily in valley bottoms. Repeated attempts to establish the plant by broadcasting on the slopes have had little success. Pili grass is without doubt the best grass in this zone; although it is an annual here, it is longer-lived than the other grass species. Bristly foxtail is excellent forage and is eaten even when dry; swollen finger- and feather fingergrasses are not first class forage but are probably to be recommended in this zone where better grasses will not grow. The native *Panicum* species are good feed but are too small and short-lived to be worth spreading. Of the herbaceous plants, saltbush is particularly desir-

Fig. 3—Zone A: characterized by a fine growth of algaroba trees on the coastal flats and small valleys. The sloping lands have only a sparse covering of small shrubs.

able as are the seasonal Spanish needle, false mallow, and nettle goosefoot.

The more promising of the newer introductions are Buffel grass *(Panicum coloratum)*, Klein's Buffel *(Panicum prolutum)*, pitted beardgrass *(Andropogon pertusus)*, fuzzy top *(Andropogon barbinodis)*, and *Cenchrus biflorus*.

Pasture development in this zone is limited by the lack of adapted perennial grass species. In spite of literally hundreds of introductions from the arid parts of the world, none has thus far proven satisfactory. Further search for adapted species constitutes one of the major projects of the Hawaii Agricultural Experiment Station. Cutting out a part of the trees in the dense algaroba thickets is a desirable practice since it permits better podding and some annual grass growth underneath. Here and there in small valleys where the scant rainfall concentrates, koa haole, Guinea grass, and pili grass can be established.

Resting or controlled grazing results in some improvement in ground coverage, but recovery is very slow. The usual grazing practice is to move the breeding herd and calves to the algaroba when the beans begin to drop, removing them at the end of the bean season. A certain amount of grazing is also possible in the winter, the cattle grazing up the slopes from the algaroba as soon as the rains start growth of the annuals. During favorable years, when the rainfall is greater and more prolonged than normally, animals grow rapidly and fatten well on such annuals. Where a ranch is situated entirely in Zones A and B, without access to pastures in the wetter zones, cattle raising is hazardous. Losses of cattle, deterioration of the breeding herd, and depletion of the pastures resulting from overstocking are common during exceptionally dry years. Possible procedures for ranches thus situated are reduction of the herd to that which can be supported in the driest year, preservation of reserve feed by haying during periods of good growth in the pastures, and the sale of stocker cattle to ranches with more favorably situated pastures.

In places where irrigation water is available, Napier, Guinea, and koa haole may be grown, and the carrying capacity as grazing paddocks or as a source of forage for pen feeding is very high. Production of forage under irrigation is common practice for dairy cattle but has yet to be proven economical for beef cattle.

ZONE B

Although the pastures of Zone B resemble those of Zone A in the type of herbage and the seasonality of growth, the forage is more varied and abundant. Grazing is more prolonged, and in the more favorably situated areas considerable pasture improvement is possible. Where the zone borders the ocean, the desirable algaroba is present, but since much of it lies on the slopes above Zone A, the pod crop is usually small. On the steep slopes and mountain shoulders, the vegetation is sparse, and erosion is in evidence. The numerous small valleys and gullies in which moisture tends to accumulate can be made into excellent fattening paddocks with algaroba, koa haole, pili grass, and Guinea grass. In some parts of this zone on Hawaii and Maui where the soils consist of numerous rocks interspersed with some soil, an unusually fine growth of forage is produced. In the arable parts of the zone, clearing and plowing make possible high grade, though seasonal, fattening pastures.

On the open range throughout the zone, the forage is probably more varied than in any other zone, as it is made up of a variety of shrubs, grasses, and numerous herbs. Of the shrubs, koa haole is particularly valuable and can often be established by sowing seed on the open ground or in lantana thickets. In many valleys and flats

Fig. 4—Zone B: showing scattered and relatively stunted growth of algaroba with more vigorous stands in the small depressions. The native Pili grass is shown in the foreground.

are nearly pure stands of koa haole which produce fine pasturage.

Pili grass makes its best growth and is perennial in this zone; when rested periodically to permit reseeding, it can be maintained without difficulty. The free-seeding Natal redtop has spread over nearly all of this zone and has been of great value in places which previously had little grass cover. Guinea grass has been widely planted and spreads by natural seeding in places. Annual grasses constitute an important part of the forage. In addition to the bristly foxtail, swollen finger-, and feather fingergrasses of Zone A, are smooth kukaipuaa, hairy sandbur, hakonakona, kakonakona, and several native panicums.

Good forage herbs are especially numerous, including saltbush, Spanish needle, red pualele, and horse weed. The annual legumes—Indian sweet clover, and bur clover—are prominent in places during the winter and spring months and add greatly to the grazing value of the pasture. Little beggarweed is widespread but is too small to have much value as forage. Cactus is regarded as a pest on the better ranches, and attempts are being made to eradicate it, but in certain areas it is regarded as a lifesaver to cattle during very dry years, when it serves as the only source of water in addition to having some feed value.

In planted pastures, the most commonly used species are koa haole, Guinea grass, and giant Bermuda. Napier grass will persist but is probably less desirable than Guinea grass. Rhodes grass produces fine yields and persists well. Molasses grass makes limited growth, but because of the cheapness of the seed and quick germination, it is used considerably.

Less widely distributed species of value are fuzzy top, pitted beardgrass, Australian bluegrass, Wilder grass, Desmanthus, and Florida beggarweed. Recent introductions of promise are Klein's Buffel grass, Buffel grass, *Brachiaria brizantha, Pennisetum ciliare,* and *Cenchrus biflorus.*

Pasture development in this zone has been probably more extensive in recent years than in any of the other zones. This has been due partly to the increased recognition of the exceptionally high quality of the forage in these drier sections and partly to the use of modern heavy equipment, such as tractors, bulldozers, and special cut-away disc plows. With these implements dense thickets of lantana and cactus can be cleared and the land plowed and planted at a figure that is low compared with that when hand methods are used. The growth rate is rapid in these relatively warm conditions, and such improved pastures are of exceptional value to ranches which have depended on upland fattening paddocks, as the low-lying pastures are at their best in the winter months when growth in the upland pastures is slow because of cold weather. Some ranches are following approved soil conservation methods of pasture improvement in contour furrowing and planting the pasture, thus preventing erosion and at the same time concentrating the rainfall in the furrows. Considerable areas in practically worthless stands of lantana still remain and are capable of improvement.

ZONE C

A large percentage of Zone C constitutes good grazing land or can be converted into good pastures. Of least value are those areas in which the zone consists of a narrow strip on the steep mountain slopes, where excessive gullying and denudation have occurred.

This is the intermediate zone, between the extremes of moisture at lower levels and of temperature at higher levels, and generally constitutes the most favorable growth conditions for pasture species. The usually adequate rainfall permits the growth of a variety of permanent sod grasses. Seasonal changes are pronounced because of both temperature and rainfall. Spring and early summer conditions are conducive to abundant growth of both perennial and annual species with the drier summer months optimum for the flowering and normal seed development. Temperature, because of differences in altitude, has a striking effect on the distribution of many species, particularly the annuals.

Perennial grasses are particularly abundant in this zone. Bermuda grass, which is the basic grass over most of the area, is valu-

Fig. 5—Zone C_2: This zone of moderate rainfall supports fine tree growth, and excellent year-round pasturage can be developed. This is the zone best adapted to non-irrigated agriculture.

able from a pasture standpoint. It provides forage of good quality; it will stand heavy and continuous grazing; and is an important factor in preventing erosion. On the steeper slopes and poorer soils, pilipiliula, yellow foxtail and rice grass, although of poor forage value, provide good coverage. Rattail occupies somewhat similar environment and is apparently an indicator of poorer and compacted soils. Generally regarded as a rather poor forage, it is well eaten when young. Natal redtop is a short-lived perennial in this zone and is an important source of forage. It is distributed throughout almost the entire zone and volunteers in any plowed or rested field. Smooth kukaipuaa is conspicuous in the upper phase and while rather small in size, is generally well eaten. It is the only one of the kukaipuaas which persists well in permanent pastures. Carpet grass was formerly planted extensively in the cool moister parts of the upper phase and is very aggressive and persistent. It is now generally regarded as inferior. Spanish clover is widespread throughout both phases. It occurs in densest stands in the upper phase, where it is well eaten. Koa haole volunteers in parts of the low phase and makes a vigorous growth but is not as widespread as in Zone B.

Of the planted species, paspalum is without doubt the most important. It was extensively planted in the early part of the century and still persists. In many pastures where it has apparently been smothered out, an excellent stand reappears after plowing the sod. It is one of the most palatable of grasses, will grow well in mixed swards, will stand heavy and continuous grazing, and has a high carrying capacity. It is not sensitive to temperature, growing from sea level to 5,000 feet. Kikuyu is a more recent introduction but is widely planted in this zone from sea level to 5,000 feet. It is easy to establish and is effective in holding various plant pests in check, but it is not generally regarded to be as palatable or nutritious a grass as paspalum. Its aggressiveness is also objectionable in that it tends to choke out other species and form a "one grass" pasture.

The large tropical forage grasses like Napier, Guinea, and panicum are ideally adapted to the low phase; they are temperature-sensitive, however, and the growth rate decreases rapidly in progressing up the slope so that it seldom pays to plant them above about 2,500 feet. Other grasses, well adapted but of lesser importance, are Rhodes grass and molasses grass. The former is persistent, but many ranchers feel that it has a low palatability for beef cattle; the latter does not usually persist under grazing except in relatively dry rocky places.

This zone contained most of the former extensive plantings of pigeon pea. This species is moderately sensitive to temperature. It grows slowly as high as 4,000 feet, but podding is light above about 3,000 feet. The decrease in interest in this fine legume for pastures is apparently due to its short life under grazing conditions, 4 or 5 years being an average. Breeding for types with shorter, stockier growth and tougher stems less susceptible to breaking by the animals appears to offer possibilities.

A number of pasture legumes, common to the temperate zones, have become established. White clover is found in the upper phase adjoining Zone D, and vetch, black medic, bur, and Indian sweet clovers occur throughout the zone, more especially in the drier more seasonal parts of the upper phase. In the upper phase, growth begins in early spring and the plants come to seed during the drier summer period. They occur in limited amount as winter annuals in the low phase.

Annual herbs and weeds are considerably repressed by the sod grasses, but when the pasture is plowed, a great variety of good forage species develops. These include Spanish needle, large kukaipuaa, pualele, hairy sandbur, horse weed, purslane, and plantain.

This zone has the climatic and soil features that make it ideal for pastures of many types. A great variety of the best forage species is adapted, so that one may select according to the use he wishes to make of the pasture. The rougher range lands may often be improved by broadcast seeding alone and are excellent for year-round grazing of the breeding herd and young stock. Planted pastures may be seeded to the sod grasses like paspalum or kikuyu, or to the larger forage like Napier grass, Guinea grass, panicum grass, and pigeon pea. In the upper phase, the temperate legumes add greatly to the forage value. Planted pastures usually have a high carrying capacity and fatten cattle quickly. Temporary pastures as a part of a farm rotation also have possibilities, since the seeded grasses establish themselves quickly.

Management plays an important part in the development and maintenance of desirable pastures in this zone. In contrast to the drier zones, the vigorous growth of the sod grasses, especially Bermuda and kikuyu, tends to choke out all other species. These sod grasses will stand heavy and continuous grazing but tend to become one-grass pastures with a consequent lowered value, especially for fattening. Periodic plowing is an excellent method of breaking up the sod and permitting renewed vigor of the secondary species. The Parker Ranch follows the practice of plowing the Bermuda grass sod about once every five years. With careful management to permit the annual grasses and clovers to mature, reseeding of these species is generally not necessary. In places a crop of corn is planted after plowing. The value of the corn generally pays for the costs of plowing, and the tillage further breaks up the sod and stimulates the secondary species. The extensive rattail areas on Maui and Hawaii have been greatly improved by periodic plowing and seeding to various grasses and legumes.

Considerable use is made of Napier grass for fattening paddocks in the low phase. Although generally considered a soilage crop, it will persist for a number of years with careful rotational grazing and has an exceptionally high carrying capacity.

Control of several shrubs presents difficulties, the principal ones being guava and lantana in the lower, and joee and pamakani in the upper phase. Periodic plowing provides only temporary control. Recently power mowers have been used, especially on the Ulupalakua Ranch on Maui and Grove Farm on Kauai, with outstanding success against pamakani, Sacramento bur, and melastoma. Periodic burning is also done, not only to control such pests, but also to remove the dense mat of dry foliage in Bermuda grass sods. The former is certainly to be recommended, and the latter may have occasional merit if used judiciously.

ZONE D

This zone, with its adequate and often excessive rainfall throughout the year, is subject to less seasonal fluctuation in forage type than the other zones. Perennial trees, shrubs, and grasses predominate, and annuals are of little importance. Because of the marked differences in adapted species and pasture value, the three phases are discussed separately.

Low Phase. The natural grass growth is of generally low palatability and nutritive value, particularly when it is mature. In pastures where continuous grazing keeps the grasses short, the young growth is fairly palatable. Hilo grass, which grows in the better soil areas, is preferable to rice grass, and yellow foxtail is definitely inferior. Glenwood grass is palatable but is too small to be of much importance. Carpet grass was extensively planted at one time to replace Hilo grass but is now generally regarded as inferior to it. Sensitive plant is the most widely distributed forage legume.

Fig. 6—Zone D_3: Semi-open pastures which result from grazing the native ohia and koa forests. Destruction of the trees permits the growth of the Alapaio fern. Kentucky blue grass and white clover are well adapted to this phase.

Because of its thorny character it is sometimes regarded as a pest. If the pasture is mowed or cropped short, it is well eaten and undoubtedly has value in this phase, which is so lacking in good legumes. Spanish clover occurs to some extent but is much less palatable than when growing in the drier zones. Recently Kaimi Spanish clover has become established in a number of localities and appears to have excellent possibilities as a pasture legume in this phase. It develops creeping stems when cut or grazed and spreads rapidly. It is well liked by cattle. Pigeon pea grows vigorously in the drier parts of this phase but, like Spanish clover, has low palatability. Paspalum, kikuyu, Napier, Guinea, and panicum grasses grow well in the more fertile parts but not on the poorer slopes.

Pasture development and use must be approached with careful consideration of the limitations of this phase. Clearing and subsequent control of the obnoxious guava is very costly unless such operations can be performed by machinery. The slopes are generally too poor to support growth of the better grasses. The depressions and especially the better drained parts of abandoned rice and taro lands, together with the drier and more fertile sloping lands, can be converted into good pastures. Two types of swards are possible in these improved areas, one made up of the large forage grasses like Napier and panicum, the other of the smaller sod or creeping grasses like paspalum and kikuyu. Although the first produces a large amount of forage, there is no feasible way of preventing reinfestation with guava and other plant pests. The present trend is toward the smaller grasses, with periodic mowing to control the pests. Of the two, kikuyu is being more extensively planted at present because of its aggressiveness and rapidity of establishment.

Pasture fertilization has been tried experimentally, and there is some evidence that heavy applications of lime and phosphate stimulate growth of the grasses and certain of the legumes and also increase the mineral content of the forage. The economic returns of such fertilization for pasture have yet to be proven. Napier and panicum grasses when used as soilage crops give tremendous response to nitrogen fertilization.

With few exceptions this phase is regarded as unsuited for fattening cattle. This is due apparently to low palatability and low dry-matter content of grasses and in some instances probably to mineral deficiencies. It is also possible that the nearly continuous wet cool weather in places has an adverse effect on the animal itself. Molasses and mineral and protein supplements have been fed in some localities, but the growth and finish of the animals have not been satisfactory. There are, of course, some exceptions in the drier and more fertile locations. The most common use made of this phase by the larger ranches is for the breeding herd and as a feed reserve in the dry years when forage on the other parts of the ranches has become depleted. The most satisfactory procedure for ranches located entirely in this phase would be to raise stocker cattle to be sold to the ranches with good fattening land. Should pen feeding with byproducts of the sugar and pineapple industries become important, such cattle would be much in demand. Another common use for pastures in this phase on Oahu is for dairies. Any deficiencies in the quality of the forage are made up in the concentrates which are fed.

Middle Phase. Most of what has been said of the limitations of pasturage in the low phase applies to an even greater degree to this phase. Costs of clearing the forest are high, and guava and false vervain are a constant menace. Kikuyu is about the only species being planted in the areas now being cleared.

High Phase. Located in this phase are some of the oldest pasture developments in the Territory. The relatively open koa forests permitted grass growth without appreciable clearing, and the cool moist climate was ideal for many of the best of the temperate zone pasture species. In the unimproved pastures, rattail is especially prominent, and because of relatively low palatability it tends to replace the better planted species under heavy and continuous grazing. Certain of the upland native or naturalized grasses which are still prominent in places, namely brome fescue and sheep grass, add relatively little to the forage value of the better pastures. Puu lehua grass is prominent in the thinner soil areas under open forest conditions. Sweet vernal grass is causing some concern in the improved ranches because of its tendency to choke out the other species. It is fairly well eaten in the early stages of growth but matures quickly and is then left untouched. Of the planted species, paspalum is well adapted and is important in the good soil areas. Carpet grass was extensively planted in former years and is the dominant grass in some pastures. Kentucky bluegrass is well adapted and is an important part of the sward on several ranches. Kikuyu grass is being planted as high as 6,000 feet to a considerable degree at present. Yorkshire fog is especially prominent in the upper part in the open forests. The presence of rye grass in the moist cool zone is one of the best illustrations of the effects of climate on the zonal distribution of grasses. It occurs only in the areas of best soil and best management practices. The type of clovers adapted also illustrates the same relationship. White clover is rather widespread and is especially prominent with the well-grazed sod grasses, Kentucky blue, and kikuyu grasses. Vetch is adapted but hard to maintain under grazing. Hop clover is also widespread. The annual clovers—black medic, bur, and Indian sweet—are seldom found, owing, no doubt, to the continuously moist conditions. Desirable species of lesser importance are cocksfoot, large canary grass, and tall oat grass. The herbs, including dandelion, wild geranium, and plantain, add considerably to the pasture forage in places.

Management is very important in the high phase. The fine mixture of adapted grasses and legumes can be readily destroyed by overgrazing. There are instances of adjoining paddocks of originally the same planted sward: one, the breeding paddock consisting mainly of rattail, and the other a fattening paddock, more lightly and periodically grazed, consisting of an unexcelled mixture of grasses and legumes. Occasional plowing or simply periodic resting will often restore the original mixture.

Pasture development is greatly influenced by terrain, soil conditions, and natural tree cover. Many steep, rough, and thin soil sections are of problematical value. In the wetter parts the dense stands of ohia lehua and tree fern are costly to open up, although once developed, a fine pasture can be maintained. The open stands of koa are particularly easy to develop into good pastures. Considerable improvement is possible in many places already in pasture by broadcasting white clover. Control of shrubby pests is not difficult

Fig. 7—Zone E_1: showing the parkland type of vegetation in this high zone of relatively low rainfall. Individual trees and clumps of koa and mamani with various native bunch grasses characteristic of the open spaces.

in this phase, because the major kinds so difficult to control at lower levels are not adapted.

ZONE E

Most of Zone E is wasteland, too poor to be developed even for pastures. Many sections on Hawaii are covered with bare lava. In others the ash mantle is too thin to support good forage under the existing climate. The coarse textured soils do not retain moisture well, so that pasturage is generally seasonal. Sheep are grazed to some extent in the middle phase on Parker Ranch, but only in the lower parts is grazing of any importance. The following discussion is entirely of this low phase.

Where this phase lies above Zone D_3, the rainfall is more adequate and better distributed throughout the year than where it lies above Zone C_2. Hence, the moisture-loving Kentucky bluegrass and white clover are more common above Zone D_3, while the annuals —bromegrass, black medic, bur, and Indian sweet clovers—are better adapted above Zone C_2. Rattail is common in the moister parts only, while the upland bunch grasses provide some coverage but little grazing in the drier and upper parts. Sweet vernal is especially abundant in the windward parts and has displaced the well established, more desirable Yorkshire fog in certain localities. In the more arid parts where the Yorkshire fog is not well adapted, sweet vernal is said to have increased the carrying capacity of the pastures. Most of the forage on thin soils occurs in the small draws which concentrate the rainfall. There are on the leeward side a few deep-soil sections that can be plowed. Corn, as well as oats for hay, is grown in this phase on the Parker Ranch. Excellent pastures may then be established of ryegrass, bromegrass, Kentucky bluegrass, black medic, and bur clovers. Few of the grasses adapted to cold arid climates elsewhere have persisted in this zone. Wallaby grass is well established at the Humuula sheep station on Parker Ranch. Crested wheat has recently been tried and has grown well.

The pastures in this phase are, with few exceptions, of rather low value, and the good pockets are separated by considerable distances. Thus there is a low average carrying capacity. Grazing is generally restricted to the spring months although in Kona, due to the prevalence of summer rainfall, most of the grazing is done during the summer. Added to the adverse factors of climate and soil is the remoteness of much of this zone and the lack of water for cattle. Except on Maui, where pamakani is troublesome, the naturally occurring shrubs are easy to eradicate.

ZONAL DISTRIBUTION OF SPECIES IN HAWAIIAN RANGES

Table 2 (pp. 47-58) comprises a relatively complete inventory of the vegetation in the permanent pastures of Hawaii. Of the total of 316 species listed, only a comparatively small number are important as forage and a still smaller number would actually be recommended for planting on the range. These species vary in size from the tallest perennial tree to the smallest short-lived herb; in forage value, from the most nutritious grass or legume to those plants which are not eaten at all; in aggressiveness, from those which tend to be eliminated unless carefully pastured to those which supplant all others unless properly controlled. They thus represent the total assets as well as liabilities of the pasture. Knowledge of both is essential to successful pasture management. It is often as important for the rancher to recognize the identity and nature of the plants which are liabilities as of those of the species which are assets. The skilled rancher has it within his power to control plant competition and succession to a certain extent by cutting out undesirable trees and shrubs, by periodically plowing the pasture, and by controlled grazing; nevertheless, desirable forage species must have the ability to persist for a period of years in competition with the undesirable ones to be of any value in the permanent pasture.

Classification of the entire list of species occurring in the natural pastures on the basis of their desirability or undesirability is impractical. A plant may be desirable in one zone and a pest in another. For example, sweet vernal grass is generally regarded as an asset in the sparsely covered lands of Zone E but as a pest in the improved paddocks of Zone D_3 because it tends to choke out the better species. Kikuyu grass is generally not advocated for planting in the improved pastures of Zone C_2 because of its tendency to become a one species sward, but is generally recommended in Zones C_1 and D_1 because of its ability to compete with guava, Hilo grass, and yellow foxtail. Cactus is a dangerous pest in the better pastures of Zone B, while in certain poorer pastures of this zone where the forage is sparse and drinking water for the cattle is limited it is considered an asset. Many species are little eaten but are not sufficiently aggressive to assume the proportions of a pest; these are undesirable only in that they reduce the total area of grazing sward. Some species like pamakani, lantana, and joee are pests under all conditions but are especially dangerous in the zone where they are best adapted.

The table shows the zonal distribution of both naturally occurring and planted species in permanent pastures of the Territory, both the open range or unplowed areas as well as those plowed and planted at infrequent intervals. It does not include forage crops which could be used in temporary pastures in rotation with other crops, since such temporary pastures are of little importance in Hawaii, nor does it include chance plants or recent introductions occurring only in experimental plots.

The relative abundance of each species in the several zones is given. The long established species may be presumed to have spread to all zones to which they are adapted, and their present relative abundance indicates a fairly accurate picture of their importance in each. With respect to the more recent introductions, or those more easily destroyed by overgrazing, present distribution does not necessarily show their ultimate distribution or potential importance as valuable forage plants or as pests. For example, Melastoma, an undesirable shrubby pest, occurs only on Kauai in Zone D_1. It is probably adapted to this zone on all the islands. The present abundance of the undesirable firebush is given as "rare" in Zones D_1 and D_2, yet it is spreading at an alarming rate in certain localities, so that its ultimate abundance will be much greater unless it is eradicated. It will be noted that some species have a wide range of adaptability. For example, paspalum is found in seven zones and is of importance in three. Others are of restricted distribution; for example, bromegrass is found in only three zones and is of importance in only one.

The composite picture of the vegetation of any given zone may be ascertained by reading down the column under that zone. Those listed include the naturally occurring species as well as those which are planted. The established species that have forage value seldom warrant planting since they will develop if the pasture is plowed or rested, although this process can, of course, be speeded up by planting.

Final selection of species to be planted depends on many other factors besides zonal adaptability. The use for which the pasture is intended and the type of management which will be used, the method of land preparation and seeding, the availability and cost of seed and planting material are all important. The adaptability of a species and its ability to persist in a given zone are the first essential, however, and the table furnishes a basis for selection according to the environmental conditions best suited to each different species. For convenience the species in the table are subdivided into grasses and sedges, herbs, ferns, shrubs, and trees.

KEY TO SYMBOLS USED IN TABLE 2

1. The following symbols indicate both distribution and density:

   a (abundant)—High distribution and of sufficient size that it is a dominant part of the vegetation. (Example: Glenwood grass might have high distribution, but it is too small to be dominant. Conversely, a lower distribution of guava would be called "abundant" (a) because of its larger size.) To be classified as "abundant," the plant *must* be both widely distributed and of sufficient size to be dominant.

   c (common)—Good distribution throughout. Occasional solid stands of a species would not constitute "common." (Example: sizable patches of carpet grass or a strip of aalii would be "occasional" (o) and not "common" (c). A very small plant which is widely distributed would be common; e.g., Glenwood grass.) To be classified as "common," the plant *must* be appreciable in quantity either because of wide distribution or high density in one part.

   o (occasional)—Occasional distribution. May be either single plants or solid patches of limited distribution. (Example: patches of carpet grass or single plants of koa.)

   r (rare)—Has not been listed unless the species has potential importance either for forage or as a serious pest. A single plant or small colony might be reported from a botanical standpoint but has not been recorded here unless of potential importance.

2. Islands

K—Kauai	M—Maui
O—Oahu	H—Hawaii
Mo—Molokai	All—All islands
L—Lanai	

TABLE 2. DISTRIBUTION OF SPECIES IN HAWAIIAN RANGES

Scientific Name	Common Name	Islands	Distribution									
			Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
GRASSES AND SEDGES:												
Agrostis alba L.	redtop	H						o	o			
Agrostis retrofracta Willd.		All				o			r	o		
Aira caryophyllea L.	silver hair grass	H				r				r		
Andropogon annulatus Forsk.	angleton grass	H,Mo,O		r								
Andropogon barbinodis Lag.	fuzzy top	All	r	o								
Andropogon nodosus (Willem.) Nash	Wilder grass	O,K		o	r							
Andropogon pertusus (L.) Willd.	pitted beardgrass	M,O,K		r								
Andropogon sericeus R. Br.	Australian bluegrass	H,M		r								
Andropogon virginicus L.	broomsedge	H,O			o							
Anthoxanthum odoratum L.	sweet vernal grass	H,M						r	r	o	r	
Arrhenatherum elatius(L.)Mert.&Koch.	tall oatgrass	H				r		r	r			
Avena barbata Brot.	slender wild oat	H,M			r	r						
Avena fatua L.	wild oat	H,M,O		r	r	c						
Avena sativa L.	cultivated oat	H,M,O			r	o						
Axonopus affinis Chase	carpet grass	All			r	o	c	c				
Briza maxima L.	big quaking grass	H,M				r						
Briza minor L.	little quaking grass	H,M,L				o			o	o		
Bromus breviaristatus Buckl.	short-awned bromegrass	H,M								r		
Bromus catharticus Vahl.	brome grass	H,M				c			o	c		
Bromus commutatus Schrad.	hairy chess	H,M								r		
Bromus mollis L.	soft chess	H,M				o				r		
Bromus racemosus L.		H				o						
Bromus rigidus Roth	ripgut grass	H,M								r		

Scientific Name	Common Name	Islands	Distribution Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
GRASSES AND SEDGES, continued:												
Bromus rigidus var. gussonei (Parl.) Coss. & Dur.		H								r		
Bromus rubens L.	foxtail chess	H,Mo		r		r						
Carex sandwicensis Boeck.		H,M,O						r	r			
Cenchrus echinatus L.	sandbur	All	o	c	o	o						
Cenchrus echinatus var. Hillebrandianus (Hitch.) Br.	hairy sandbur	All	o	c	o	o						
Chloris divaricata R. Br.	Australian stargrass	O		r								
Chloris Gayana Kunth	Rhodes grass	All		o	o	o	r					
Chloris inflata Link	swollen fingergrass	All	a	o								
Chloris radiata (L.) Swartz	radiate fingergrass	All		o	o							
Chloris truncata R. Br.	Australian fingergrass	M,L,O		r								
Chloris virgata Swartz	feather fingergrass	M,L,Mo,O	o	o	r							
Chrysopogon aciculatus (Retz.) Trin.	pilipiliula	All		o	c	o						
Cymbopogon refractus (R.Br.)A.Camus.	barbwire grass	H,M		r								
Cynodon Dactylon (L.) Pers.	Bermuda grass	All	r	c	a	a	o			o		
Cynodon Dactylon (L.) Pers.	giant Bermuda grass	All	r	o	r		r					
Cyperus Kyllingia Endl.	kaluha	All					c	o				
Cyperus polystachyus Rottb.		All					c	o				
Cyperus rotundus L.	nut grass	All			c		o					
Dactylis glomerata L.	cocksfoot	H,M,K				o			o	o		
Dactyloctenium aegyptium(L.) Richt.	beach wiregrass	All	o	o								
Danthonia pilosa R. Br.	hairy oatgrass	H,M							r	o		
Danthonia semiannularis R. Br.	Wallaby grass	H,M							r	o		
Deschampsia nubigena Hbd.	kalamaloa	H,M								o	r	

Digitaria Henryi Rendle	Henry's crabgrass	All			o	r	o	r			
Digitaria pruriens (Trin.) Busse	kukaipuaa	All			o	o	o	r			
Digitaria pseudo-ischaemum Busse	creeping kukaipuaa	All				r	o				
Digitaria sanguinalis (L.) Scop.	kukaipuaa	All		o	o	o	o				
Digitaria violascens Link	kukaipuaa	All		o	o	c	r			o	
Echinochloa colonum (L.) Link	jungle rice grass	All		o	r		r				
Eleusine indica (L.) Gaertn.	wire grass	All		r	o		r				
Eragrostis amabilis (L.) W. & A.	hakonakona	All	o	o							
Eragrostis atropioides Hbd.	hard-stemmed lovegrass	H								o	o
Eragrostis Brownei (K.) Nees	sheep grass	H,M				o			o	o	
Eragrostis cilianensis (All.) Link	stink grass	All	r	o							
Eragrostis deflexa Hitchc.	deflex lovegrass	H,M								r	
Eragrostis grandis Hbd.	Hawaiian lovegrass	All			r	r				o	
Eragrostis leptophylla Hitchc.	mountain lovegrass	H								o	r
Eragrostis pectinacea (Michx.) Nees	Caroline lovegrass	All		r							
Eragrostis variabilis (Gaud.) Steud.	variable lovegrass	H,M								o	
Festuca dertonensis (All.) A. & G.	brome fescue	H,M,L			r	c			o	c	
Festuca elatior L.	tall fescue	H				r			r	r	
Festuca megalura Nutt.	foxtail fescue	H				r				r	
Festuca rubra L.	red fescue	H,M				r				r	
Fimbrystylis diphylla (Retz.) Vahl	fimbrystylis	All					o	o			
Gastridium ventricosum (Go.) Sch. & Thell.	nit grass	H,M				r				r	
Heteropogon contortus (L.) Beauv.	pili grass	All	c	a	o						
Holcus lanatus L.	Yorkshire fog	H,M				r		r	o	o	
Hordeum murinum L.	wild barley	H,M				r					
Hordeum vulgare L.	barley	H,M				r					
Ischaemum Byrone (Trin.) Hitchc.		H					r				
Lamarckia aurea L. (Moench)	goldentop	M			r						
Lolium multiflorum Lam.	Italian ryegrass	H,M				o			o	o	
Lolium perenne L.	perennial ryegrass	H,M				o			o	o	
Melinis minutiflora Beauv.	molasses grass	All		o	o	o	o				

Scientific Name	Common Name	Islands	Distribution									
			Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
GRASSES AND SEDGES, Continued:												
Microlaena stipoides (Labill.) R.Br.	puu lehua	H				o		r	o	r		
Oplismenus hirtellus (L.) Beauv.	basket grass	All			o		c	o				
Panicum Colliei Endl.		H,M,L	o	o								
Panicum maximum Jacq.	guinea grass	All	r	o	o		o					
Panicum nubigenum Kunth		L,Mo,O	r	o								
Panicum pellitum Trin.		M	o	o								
Panicum purpurascens Raddi	para grass	All		r	c	r	c	r				
Panicum ramosius Hitchc.		Mo		r								
Panicum repens L.	quackgrass	H					r	r				
Panicum tenuifolium H. & A.	mountain pili	H,M							o	c	o	
Panicum torridum Gaud.	kakonakona	All	o	c								
Panicum xerophilum (Hbd.) Hitchc.		H,M	o	c								
Pappophorum brachystachyum Jaub. & Spach.	pappus grass	M		r								
Paspalum conjugatum Bergius	Hilo grass	All			o	o	a	a				
Paspalum dilatatum Poir.	paspalum	All		o	o	c	c	o	c	o		
Paspalum fimbriatum H. B. K.	Panama paspalum	O		r	o							
Paspalum orbiculare Forst.	ricegrass	All			c		a	c				
Paspalum Urvillei Steud.	vasey grass	H,O			r	r	r					
Pennisetum ciliare (L.) Link		H		r								
Pennisetum clandestinum Hochst.	kikuyu grass	All		r	o	o	o	o	r			
Pennisetum complanatum (Nees) Hemsl.		H,L,O		r								
Pennisetum purpureum Sch.	Napier grass	All		r	o	r	o					
Pennisetum Ruppelii Steud.	fountain grass	H		r								
Pennisetum setosum (Sw.) L. Rich.	feathery pennisetum	L,O		r	o							

Phalaris tuberosa L.	large canary grass	H,M				r			r		
Poa annua L.	annual bluegrass	All			r	o			o	o	
Poa pratensis L.	Kentucky bluegrass	H,M				o		o	c	c	r
Polypogon lutosus (Poir.) Hitchc.	ditch polypogon	H,M,O				r		r			
Polypogon monspeliensis (L.) Desf.	rabbitfoot grass	H,M,O				r		r			
Sacciolepis contracta (W.&A.)Hitchc.	Glenwood grass	All			o	o	c	c	o		
Setaria geniculata (Lam.) Beauv.	yellow foxtail	All			c	o	c	o			
Setaria verticillata (L.) Beauv.	bristly foxtail	All	c	o	o						
Sorghum halepense (L.) Pers.	Johnson grass	All		o							
Sorghum vulgare (L.) Pers.	sorghum	All	r	o							
Sphenopholis obtusata (Michx.)Scribn	prairie wedge grass	O			r						
Sporobolus capensis (Willd.) Kunth	rattail grass	All		r	o	c			o	o	
Sporobolus diander (Retz.) Beauv.	Indian dropseed	All			o		o				
Sporobolus indicus (L.) R. Br.		H,K			r						
Sporobolus virginicus (L.) Kunth	beach rattail	All	c								
Stenotaphrum secundatum (Walt.)Ktze.	buffalo grass	All			c	o	o	o			
Tragus Berteronianus Schult.	bus grass	M		r							
Trichachne insularis (L.) Nees	sour grass	Mo,O	o	c	c		r				
Tricholaena repens (Willd.) Hitchc.	Natal redtop	All	o	c	c	c	o				
Trisetum glomeratum (Kunth) Trin.	heu pueo	H,M							r	o	r
HERBS:											
Ageratum conyzoides L.	ageratum	All		o	o		o	r			
Acanthospermum australe (Loe.)Ktze.	kukai hipa	All		o	o						
Achillea Millefolium L.	yarrow	H				r		o			r
Alysicarpus vaginalis DC.	alysicarpus	O		r							
Amaranthus gracilis Desf.	slender amaranth	All		o	o						
Amaranthus hybridus L.	spleen amaranth	All		o	o						
Amaranthus spinosus L.	spiny amaranth	All		o	o						
Anagallis arvensis L.	pimpernell	All		o	o	o				o	
Argemone glauca L.	prickly poppy	All		o							
Asclepias curassavica L.	milkweed	All		o	o	o					
Atriplex Muelleri Benth.		H,M	o								

Scientific Name	Common Name	Islands	Distribution									
			Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
HERBS, Continued:												
Atriplex semibaccata R. Br	Australian saltbush	All	c	r								
Bidens pilosa L.	pilipili	All	o	c	c	o	o	r				
Boerhaavia tetrandra Forst.	alena	All	o									
Bryophyllum pinnatum Kurz	air plant	H,M,O			o	r						
Centaurea melitensis L.	Maltese thistle	All	o	o								
Centaurium umbellatum Gilib.	European centaury	All		o								
Centella asiatica (L.) Urban	Chinese violet	All			c		c	o				
Chenopodium ambrosioides L.	Mexican tea	All		r						r		
Chenopodium carinatum R. Br.	keeled goosefoot	H,Mo		r								
Chenopodium murale L.	nettle goosefoot	All	o	o								
Cirsium vulgare (Savi) Airy-Shaw	bull thistle	All			o	c				o		
Commelina diffusa Bur.	honohono	All			o		c	o				
Crepis pulchra L.	hawksbeard	H,M				o			o	c		
Cucumis dipsacens Ehr.	wild spiny cucumber	All	o									
Cuphea carthagenensis(Jacq.)McBride	tarweed	All			o		c	o				
Datura Stramonium L.	Jimson weed	All		r								
Desmodium triflorum (L.) DC.	little beggarweed	All		o	c		o					
Desmodium uncinatum (Jacq.) DC.	Spanish clover	All		r	c	c	c	r		r		
Drymaria cordata (L.) Willd.	drymaria	All			o	o	o					
Elephantopus tomentosus L.	elephantopus	K		o	o		r					
Emex spinosa Campd.	emex	H,Mo,O		o		r						
Emilia coccinea (Sims) Sweet	orange pualele	M,L		o	o							
Emilia sonchifolia (L.) DC.	red pualele	All		o	c							
Epilobium oligodontum Hauss.	pukamole	H,M				o			r	c	o	
Erigeron albidus (Willd.) Gray	horseweed	All	r	o	o	r						

Erodium cicutarium L'Her.	filaree	H,M,L,Mo		r	r	o				o	r
Euphorbia geniculata Ortega	wild euphorbia	All		o	o						
Euphorbia hirta L.	garden spurge	All		o	c						
Euphorbia Hypericifolia L.	graceful spurge	All		o	o						
Foeniculum vulgare Gaert.	sweet fennel	H				r					
Gaillardia pulchella Foug.	gaillardia	O		o							
Galinsoga parviflora Cav.	galinsoga	All		o	c	o				o	
Geranium carolinianum var. australe (Benth.) Fosb.	wild geranium	H,M				c		o	o	r	
Gnaphalium japonicum Thunb.	cudweed	H,M								r	
Gnaphalium purpureum L.	purple cudweed	All			r						
Gnaphalium sandwicensium Gaud.	enaena	All			r	r					
Heliotropium anomalum H. & A.	hinahina	All	o								
Heliotropium curassavicum L.	hinahina	All	o								
Hesperocnide sandwicensis Wedd.	stinging weed	H				r					
Hippobroma Longiflora (L.) G. Don		H,K					r				
Hydrocotyle verticillata Thunb.	hydrocotyle	All			o		c	o			
Hypericum japonicum Thunb.		H,M							o	o	o
Hypochaeris glabra L.	smooth gosmore	All			r	o					
Hypochaeris radicata L.	gosmore	All				c	r	o	c	c	
Ipomoea indica (Bur.) Merr.	morning glory	All		o	c	r	r				
Ipomoea pentaphylla (L.) Jacq.	hairy morning glory	All		r	o						
Ipomoea tuberculata Roe.	koali-ai	All		r	o						
Jacquemontia sandwicensis Gray	pauohiiaka	All	o								
Lepidium virginicum L.	pepper plant	All		o							
Lespedeza striata (Thbg.) H. & A.	lespedeza	H,M				r					
Malva rotundifolia L.	cheese weed	All		r	o	o					
Malvastrum coromandelianum (L.)Gar.	false mallow	All	o	c							
Medicago hispida	bur clover	All		o	o	o				o	
Medicago littoralis var. inermis Morris.		H				r					
Medicago lupulina L.	black medic clover	H,M			o	c				o	

Scientific Name	Common Name	Islands	Distribution Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
HERBS, Continued:												
Melilotus indica All.	Indian yellow clover	H		o	o	c						
Modiola caroliniana (L.) G. Don	bristly-fruited mallow	H,M				c			o	o		
Momordica Balsamina L.	balsam apple	All		o	o							
Nama sandwicense Gray		All	o									
Nicandra Physalodes Pers.	apple of Peru	O	o									
Ocimum basilicum L.	basil	O	r	o								
Oxalis corniculata L.	sorrel	All		r	o		o					
Passiflora foetida L.	passiflora	All		o								
Phaseolus lathyroides L.	wild pea bean	All		o	c							
Physalis peruviana L.	poha	All			o	r	r					
Picridium tingitanum Desf.	picridium	All	c	c								
Plantago lanceolata L.	plantain	All			o	c			o	c		
Plantago major L.	laukahi	All			o		o					
Plantago virginica L.	dwarf plantain	H,M				o			r			
Polygonum densiflorum Meissn.	kamole	H,M,O,K				r	o					
Portulaca cyanosperma Egler	small pigweed	K	c									
Portulaca oleracea L.	pigweed	All	r	o	c		o					
Portulaca villosa Cham.	hairy pigweed	H,O	r									
Prunella vulgaris L.	self heal	H,M						o	o	o		
Raimannia odorata (Jacq.) Spra. & Riley	evening primrose	H,M				r				r		
Ranunculus hawaiiensis Gray	buttercup	H,M						r				
Rumex acetosella L.	sheep sorrel	H,M				r			c	c	r	
Salvia coccinea Juss.	crimson sage	H,M,L,Mo		o	r							
Salvia occidentalis Sw.	hopweed	All		o	o							

Senecio sylvaticus L.	European groundsel	H,M,Mo						r			r
Sesuvium Portulacastrum L.	sea purslane	All	o	r							
Sherardia arvensis L.	spur-wort	H,M				o					
Siegesbeckia orientalis L.	small yellow crown-beard	All			o		r				
Silene anglica L.	catchfly	H,M				o					
Sisyrinchium acre Mann	mauulaili	H,M							o	c	o
Solanum nodiflorum Jacq.	popolo	All		o	c		o				
Sonchus oleraceus L.	pualele	All		c	c		o				
Stachys arvensis L.	stagger weed	All			c		o				
Stachytarpheta jamaicensis (L.)Vahl	Jamaica vervain	All		o	c		o				
Stellaria media L.	chickweed	H									r
Synedrella nodiflora (L.) Gaer.	nodeweed	All		o	o		o				
Taraxacum vulgare (Lam.) Sch.	dandelion	All		o	c	c		r	o	r	
Tribulus cistoides L.	nohu	All	c	o							
Tridax procumbens L.	tridax	M	o	o							
Trifolium arvense L.	rabbit-foot clover	H								r	r
Trifolium pratense L.	red clover	H				r			r		
Trifolium procumbens L.	hop clover	H,M				o			c	o	
Trifolium repens L.	white clover	H,M				o			o	o	
Tritonia Pottsii Baker	montbretia	H					o	r			
Verbena littoralis H.B.K.	verbena	All		o	c	c				c	
Verbena venosa Gill. & Hook		H		r							
Verbesina encelioides (Cav.) B.& H.	golden crown-beard	All	c	o							
Vernonia cinerea (L.) Less.	iron weed	All	o	o	o						
Veronica arvensis L.	corn speedwell	H,M				c				o	
Veronica plebeja R. Br.	small speedwell	H,M				c				o	
Veronica serpyllifolia L.	speedwell	H								r	
Vicia sativa L.	common vetch	H,M				o				r	
Xanthium saccharatum Wall.	cocklebur	All	o	c	o						
Youngia japonica (L.) DC.	Asiatic hawksbeard	All			o		o	r			
Zinnia pauciflora L.	zinnia	All	o	c							

Scientific Name	Common Name	Islands	Distribution									
			Zones									
			A	B	C_1	C_2	D_1	D_2	D_3	E_1	E_2	E_3
FERNS:												
Asplenium densum Brack.		H,M								r	r	
Cibotium Chamissoi Kaulf.	tree fern	All					o	c	o			
Dryopteris dentata (Forst.)C.Chri.	parasitic shield-fern	All			r		o					
Dryopteris paleacea (Sw.) C.Chri.	alapaio	All						c	c	c		
Gleichenia linearis (Bur.) Clarke	staghorn	All					a	a	c			
Nephrolepis exaltata (L.) Schott.	Boston fern	All			c		c	c				
Pellaea ternifolia (Cav.) Link	kalamoho laulii	H,M		r								
Pteridium aquilinum var. decompositum (Gaud.) Tryon	bracken fern	All		r	o	o				c		
Sadleria cyatheoides Kaulf.	amaumau	All				r	c	c	c	r		
Stenoloma chinensis (L.) Bedd.	palaa	All		o	c		o					
SHRUBS:												
Abutilon molle Sweet	mao	All	r	o								
Acacia Farnesiana (L.) Willd.	klu	All	c	o								
Atriplex lentiformis (Torr.) Wats.		Mo	r									
Bidens Menziesii var. filiformis Sherff.	kokolau	H		r		r						
Cajanus Cajan (L.) Millsp.	pigeon pea	All		r	o	r	r					
Cassia Leschenaultiana DC.	Japanese tea	All		c	c		r					
Cassia occidentalis L.	miki palaoa	All		o	o		r					
Chenopodium sandwicheum Moq.	alaweo	All		r	r					o		
Clerodendron fragrans Vent.	clerodendron	O					r					
Crotalaria incana L.	fuzzy rattle pod	All		o	o		r					
Crotalaria longirostrata H. & A.	crotalaria	M			o	o						
Crotalaria mucronata Desv.	rattle pod	All		o	o		r					

Desmanthus virgatus Willd.	desmanthus	M,Mo,O	r	o	r						
Desmodium tortuosum DC.	Florida beggarweed	O,H,K		r							
Dodonaea viscosa (L.) Jacq.	aalii	All		o	o	o				o	
Dubautia scabra (DC.) Keck		H,M								o	o
Eupatorium adenophorum Spr.	pamakani	M,L,Mo,O			o	c	o	r		a	
Gossypium tomentosum Nutt.	brown cotton	M,L,Mo,O	o								
Indigofera suffruticosa Miller	indigo	All		r	c	o	r				
Lantana Camara L.	lantana	All	o	a	c		o				
Leucaena glauca Benth.	koa haole	All	c	a	c		o				
Lipochaeta subcordata Gray		H								r	
Lythrum maritimum H.B.K.		H,M,O				o				o	
Melastoma malabathricum L.	melastoma	K					c				
Mimosa pudica L.	sensitive plant	All			o		c	r			
Mirabilis Jalapa L.	four-o'clock plant	All		r							
Nicotiana glauca Grah.	tree tobacco	H,M,O		r	r						
Opuntia megacantha Salm-Dyck	panini	All	o	c	o						
Pluchea indica (L.) Less	pluchea	O,K	o	r							
Plumbago zeylanica L.	ilieo	All		r							
Psidium Guayava L.	guava	All		o	c		a	o			
Ricinus communis L.	castor bean	All		o	o	r					
Rubus hawaiiensis Gray	akala	H,M						r	c	o	
Rubus rosaefolius Smith	thimbleberry	All				o	o	c	o	o	
Rumex giganteus Ait.	rumex	H,M						r			
Santalum ellipticum Gaud.	sandalwood	All		o	o						
Schinus terebinthifolius Raddi.	Christmas berry	All		o	o						
Sida acuta Burm.	wild ilima	All			r		r				
Sida fallax Walpers	ilima	All	c	a	c						
Sida rhombifolia L.		All		o	r						
Solanum pseudo-capsicum L.	Jerusalem cherry	H,M								o	
Stachytarpheta cayannensis (Rich.) Vahl	false vervain	All		o	c	o	c				
Styphelia Douglasii (Gray) Muell.	puakeawe	H,M								c	

Scientific Name	Common Name	Islands	Distribution Zones A	B	C1	C2	D1	D2	D3	E1	E2	E3
SHRUBS, Continued												
Styphelia Tameiameiae (Cham.)Muell.	puakeawe	All			o	o				o	o	
Tephrosia purpurea (L.) Pers.	ahuhu	All	o	r								
Triumfetta Bartramia L.	Sacramento bur	H,M		o	r	o						
Triumfetta rhomboidea Jacq.	triumfetta	O			o							
Ulex europaeus L.	gorse	M				o						
Vaccinium reticulatum Sm.	ohelo	H,M				o				o	o	
Vitex trifolia L.	polinalina	All	c									
Waltheria indica var. americana (L.) R. Br.	uhaloa	All	o	c	c	o						
Wikstroemia sp.	akia	All		r	o							
TREES:												
Acacia Koa Gray	koa	All			o	o	o	c	a	a	o	
Aleurites moluccana (L.) Willd.	kukui	All			o		c	c				
Eugenia Cumini (L.) Druce	Java plum	All		o	o		o					
Metrosideros collina (Forst.)Gray	ohia lehua	All			o	c	a	a	c	o		
Myoporum sandwicense (A.DC.) Gray	naio	All		o						c	c	
Myrica Faya Ait.	fire bush	H,M,O					r	r				
Pandanus odoratissimus L.	puhala	All			o		c					
Pithecellobium dulce (Roxb.)Benth.	opiuma	All		o	o							
Prosopis chilensis (Mol.) Stuntz	algaroba	All	a	c								
Psidium Cattleianum var. lucidum Hort.	waiwi	All		o	o		o					
Samanea Saman (Jacq.) Merr.	monkey pod	All		o	o		r					
Sophora chrysophylla (Salisb.)Seem.	mamani	H,M								c	a	

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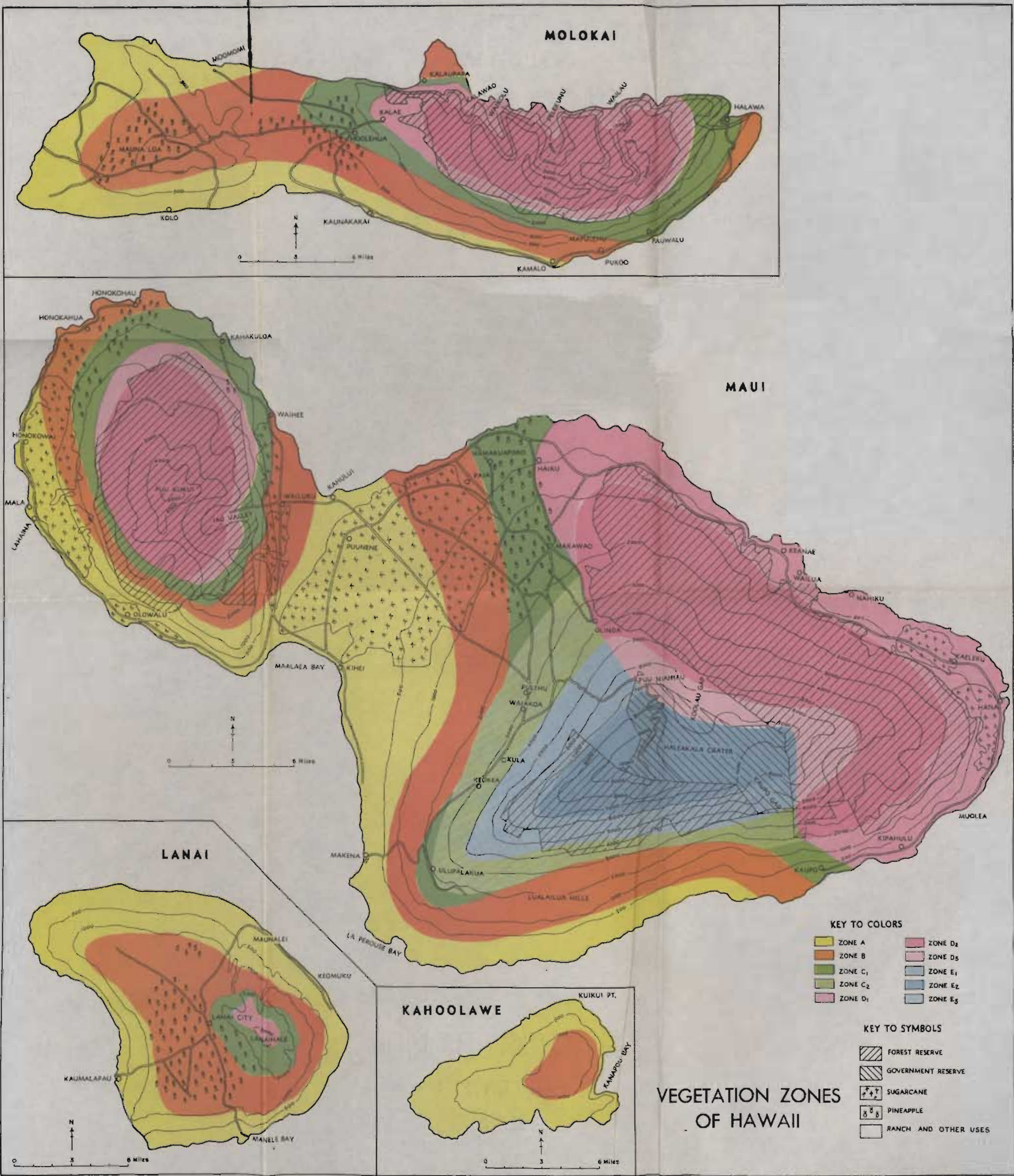
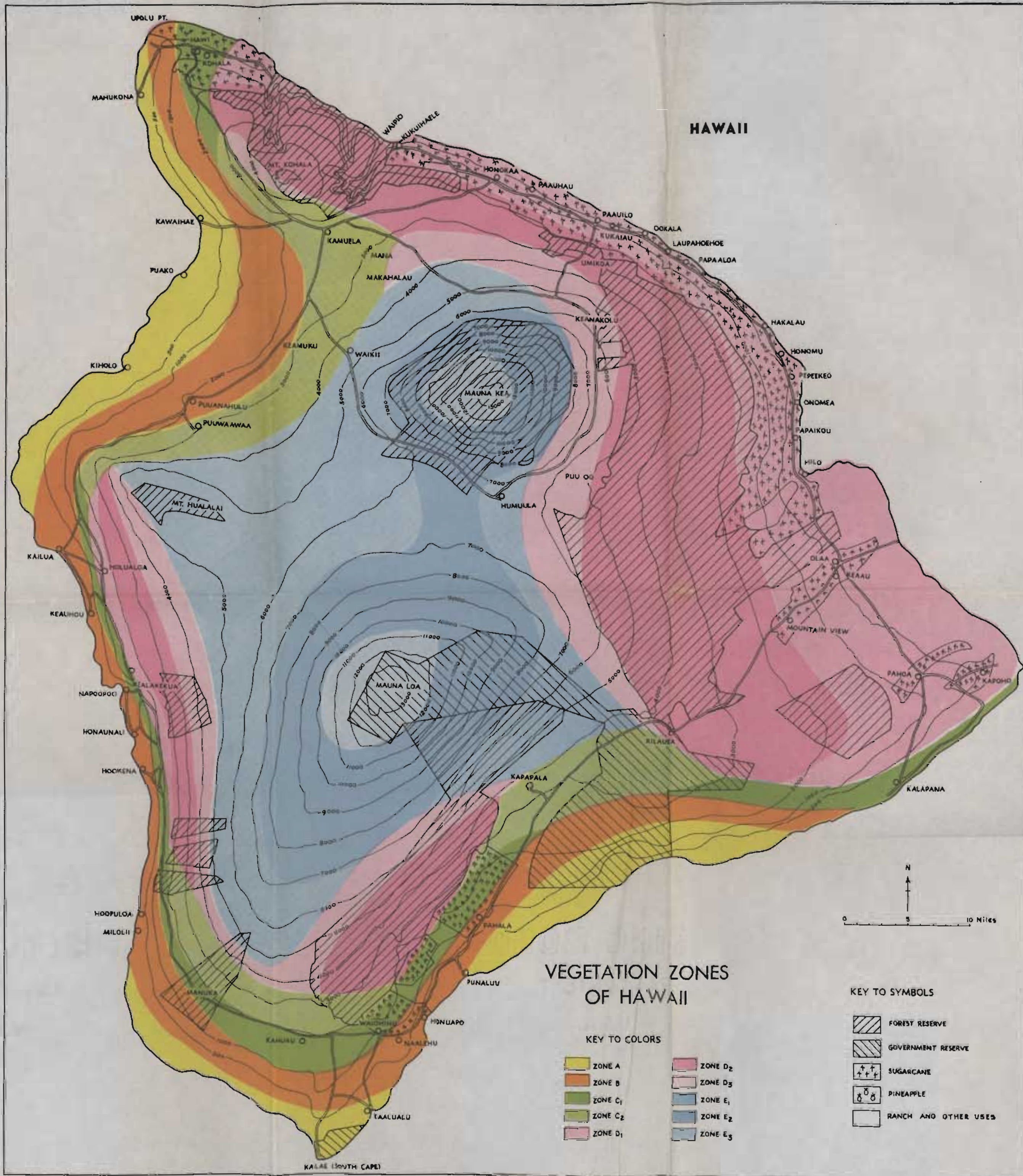
EXPLANATION OF MAPS

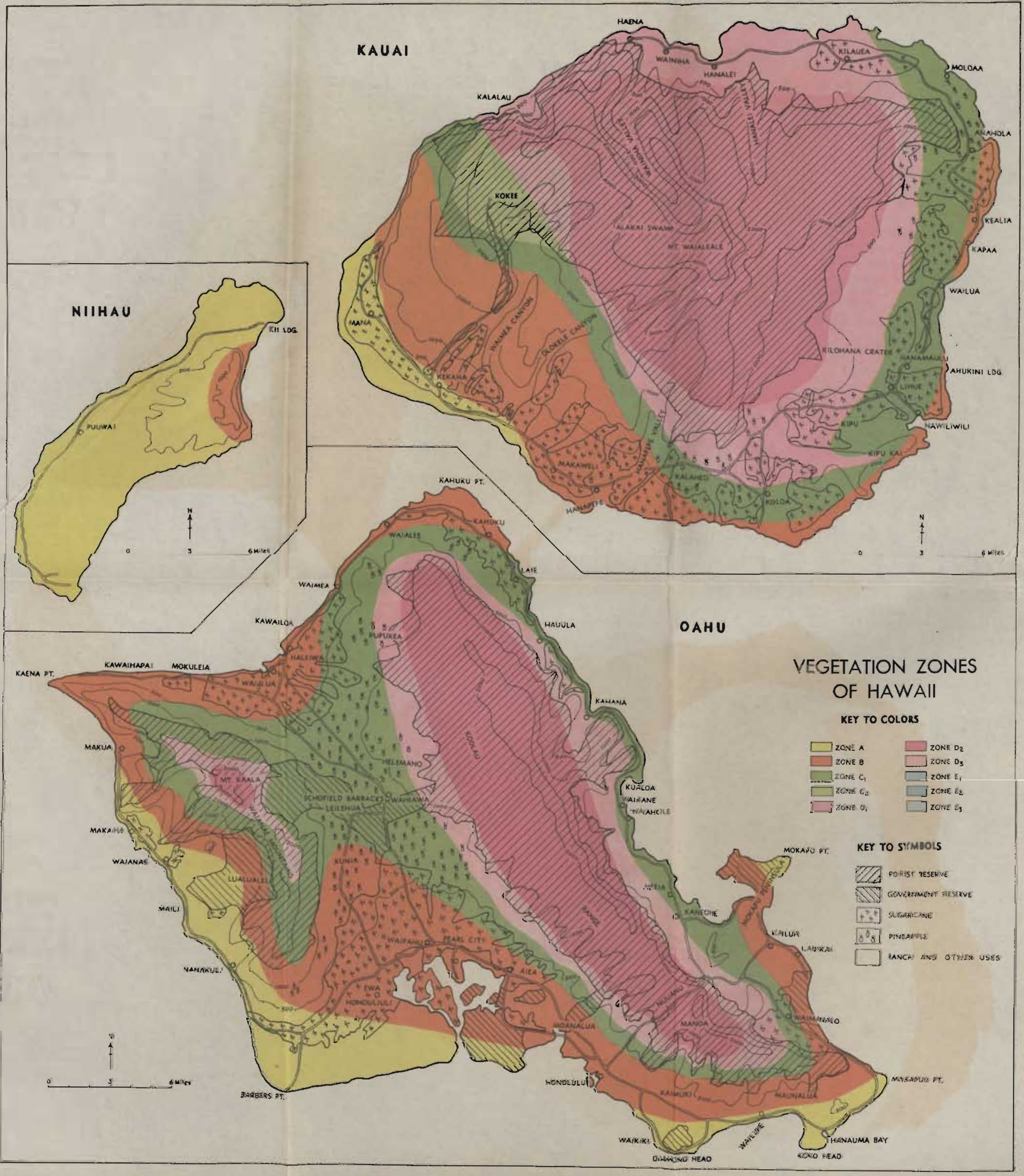
Colored maps of all the islands are attached hereto. The colors delineate the different vegetation zones and phases; a color key appears on each map. The major towns and localities are given; although no sharp distinction exists between the two, those commonly regarded as towns are designated by a circle (o).

Major land uses are shown by symbols; the key to the symbols appears on each map. "Government lands" include both federal and Territorial lands withheld from agricultural use and do not include lands owned by the Territory that are used or are available for homesteading, or leased to private individuals or corporations for agricultural use. "Forest reserve" includes both Territorial and private lands devoted exclusively to forest reserve. "Range and other uses" comprise all the lands of the Territory not included in the other classifications of land use. Truck and other miscellaneous crops occur in areas too small to be entered in maps of this size. Large tracts of waste land occur, especially on Hawaii. It is not possible to segregate these waste areas from the poorer pastured lands, because one merges into the other.



VEGETATION ZONES OF HAWAII


HAWAII
UPOLU PT.
HAWI
KOHALA
MAHUKONA
WAIPIO
KUKUIHAELE
MT. KOHALA
HONOKAA
PAAUHAU
PAAUILO
OOKALA
KUKAIAU
LAUPAHOEHOE
PAPAALOA
UMIKOA
KAWAIHAE
KAMUELA
MANA
PUAKO
MAKAHALAU
KEANAKOLU
HAKALAU
KEAMUKU
WAIKII
HONOMU
PEPEEKEO
KIHOLO
MAUNA KEA
ONOMEA
PUUANAHULU
PUUWAAWAA
PAPAIKOU
HILO
PUU OO
MT. HUALALAI
HUMUULA
KAILUA
HOLUALOA
OLAA
KEAAU
KEAUHOU
MOUNTAIN VIEW
MAUNA LOA
PAHOA
KAPOHO
KEALAKEKUA
NAPOOPOO
HONAUNAU
KILAUEA
HOOKENA
KAPAPALA
KALAPANA
HOOPULOA
MILOLII
PAHALA
PUNALUU
MANUKA
HONUAPO
WAIOHINU
KAHUKU
NAALEHU
KAALUALU
KALAE (SOUTH CAPE)
N
0
5
10 Miles
VEGETATION ZONES OF HAWAII
KEY TO COLORS
ZONE A
ZONE B
ZONE C1
ZONE C2
ZONE D1
ZONE D2
ZONE D3
ZONE E1
ZONE E2
ZONE E3
KEY TO SYMBOLS
FOREST RESERVE
GOVERNMENT RESERVE
SUGARCANE
PINEAPPLE
RANCH AND OTHER USES


VEGETATION ZONES OF HAWAII
KEY TO COLORS
ZONE A
ZONE B
ZONE C1
ZONE C2
ZONE D1
ZONE D2
ZONE D3
ZONE E1
ZONE E2
ZONE E3
KEY TO SYMBOLS
FOREST RESERVE
GOVERNMENT RESERVE
SUGARCANE
PINEAPPLE
RANCH AND OTHER USES
KAUAI
HAENA
WAINIHA
HANALEI
KILAUEA
MOLOAA
KALALAU
ANAHOLA
KOKEE
ALAKAI SWAMP
MT. WAIALEALE
KEALIA
KAPAA
WAILUA
MANA
WAIMEA CANYON
OLOKELE CANYON
KILOHANA CRATER
HANAMAULU
AHUKINI LDG.
KEKAHA
LIHUE
KIPU
NAWILIWILI
MAKAWELI
KIPU KAI
KALAHEO
KOLOA
HANAPEPE
NIIHAU
KII LDG.
PUUWAI
OAHU
KAHUKU PT.
KAHUKU
WAIALEE
LAIE
WAIMEA
KAWAILOA
HAUULA
PUPUKEA
KAENA PT.
KAWAIHAPAI
MOKULEIA
HALEIWA
WAIALUA
KAHANA
MAKUA
HELEMANO
KOOLAU
MT. KAALA
KUALOA
WAIKANE
WAIAHOLE
SCHOFIELD BARRACKS
WAHIAWA
LEILEHUA
MAKAHA
WAIANAE
MOKAPU PT.
KUNIA
LUALUALEI
MAILI
KANEOHE
WAIPAHU
PEARL CITY
KAILUA
LANIKAI
NANAKULI
AIEA
EWA
HONOULIULI
NUUANU
MANOA
MOANALUA
WAIMANALO
HONOLULU
MAKAPUU PT.
BARBERS PT.
KAIMUKI
MAUNALUA
WAIKIKI
DIAMOND HEAD
HANAUMA BAY
KOKO HEAD
0
3
6 Miles