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volume 3

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THE HAWAIIAN ECOSYSTEM AND ITS ENVIRONMENTAL DETERMINANTS WITH PARTICULAR EMPHASIS ON PROMISING AREAS FOR GEOTHERMAL DEVELOPMENT

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1. Volcanic Origins

The geologic history of the Hawaiian Islands can be best understood in terms of a series of volcanic episodes spanning tens of millions of years and extending along a stupendous fracture zone across the mid-Pacific ocean floor for at least 1500 miles. The earlier parts of this story are probably obscured in deeply submerged and buried layers of lava which may even, long since, have been recycled through the surfaces of lava domes built up along the rift. Many such domes exist along this line; at least 26 of them appear above the present surface of the sea forming the islands, the Hawaiian Archipelago (Stearns 1946).

The most worn-down, submerged or almost submerged, and oldest of these are toward the northwest end of the rift and the highest, presently active, and youngest are at the southeast end. Volcanic activity presumably started at the northwest end and gradually, over a period of many millions of years, advanced southeastward, creating new islands of fresh lava and leaving weathered and eroded ones behind, these to subside gradually and finally to be capped by coral reefs, lying at sea level, growing upward as fast as subsidence proceeded. On these the only dry land is the coral rock left behind by a recent slight lowering of sea-level and coral debris piled up by storms. The Hawaiian atolls are Kure, Midway, Pearl and Hermes, Lisianski and Laysan. Southeastward the volcanic islands now appear as masses of laminated basalt, built up layer by layer of lava flows and ash falls, these deeply weathered and eroded, but becoming less so the nearer the southeast end of the chain is approached.

On Gardner and French Frigate (surrounded by a coral ring) only tiny pinnacles of volcanic rock remain. Necker, Nihoa, and Kaula are reduced to rocks. Niihau is a low partial dome. Only Niihau, of the aforementioned islands, is regularly populated by native peoples.

Kauai (Population - 34,700 est.) is a large symmetrical dome with a smaller one on its southeast flank. The main mass is deeply dissected into valleys and canyons. Waialeale, its tallest mountain, is 1600 m high. On the windward side are massive cliffs cut into valleys. This pattern reappears on the windward coast of all the larger islands. The erosional characteristics that result in vertical cliffs in Hawaiian basalts have been discussed by Palmer (1927) and Stearns (1946).

Oahu (Population - 719,600 est.) is composed of two domes, each with one side eroded off, the remaining parts forming the parallel Waianae and Koolau ranges, separated by a depression formed by the meeting of flow slopes. The Waianae Mountains are older and have been cut by erosion into very rugged skeletonized terrain. The Koolaus still preserve some of the original flow slopes on the west side, but have fluted cliffs on the windward (east) side (Palmer 1927).

Molokai (Population - 6,400 est., eastward, is also composed of two domes, with cliffs on the windward side. Here the mountain ranges are set end to end rather than parallel.

Maui (Population - 52,900 est.) again is built out of two domes, in this case rather symmetrical, connected by a low isthmus. West Maui is older, deeply weathered and dissected into steep radiating valleys. Haleakala, East Maui, is a young dome 3085 m high, active as recently as 1750, and still showing an enormous crater or caldera. In the shadow of Maui lie the deeply weathered and eroded domes of Lanai, Kahoolawe and Molokini.

The Island Hawaii (Population - 80,900 est.) consists of five separtate domes with their bases merged. The northwest one, Kohala, is old and weathered with cliffs and valleys on its windward coast. Mauna Kea, the highest mountain in the oceanic part of the Pacific Basin, 4240 m, is a recently extinct volcano. It shows signs of Pleistocene glaciation (Gregory and Wentworth 1937; Wentworth and Powers 1941). Hualalai has been dormant since 1801, but is covered by relatively fresh lava. Mauna Loa, currently active, is a broad smooth dome, with a caldera in the summit. Its surface is covered by relatively new, scarcely weathered lava flows. Kilauea, a lower, but very active dome, is a natural volcanological laboratory with frequent periods of activity.

Thus, the substrata for the vegetation of the Hawaiian Islands are the basaltic lava and ash poured forth by the volcanoes, and soil derived from the weathering and disintegration of this basalt. Locally there is also the limestone of the elevated coral reefs and coral sand flats that surround the older islands, or even make up their entire surface. Every degree of weathering may be seen and some deep old soils exist, where they have not been removed by recent accelerated erosion. In some of the soils the process of laterization has gone fairly far. There are bauxite beds, although the ironstone crusts seen in many tropical countries are lacking (softer lateritic layers have been described for Hawaii by Sherman, 1950). The weathering of the basalt to clay and clay-like soils, greatly decreases its porosity and increases its water-holding capacity.

The Islands lie entirely within the trade wind belt. The northeast trades, moisture laden after a thousand mile sweep across the Pacific, hit the mountainous islands, rise forming rain clouds and continually drench the windward slopes and crests with heavy "orographic" rainfall. This precipitation may be carried on down the leeward slopes to a considerable distance, but it falls off rapidly and the leeward slopes become markedly drier at lower levels. This falling off of rainfall between the wet crests of the Koolau Range at the head of Manoa Valley to Diamond Head is a striking phenomenon; in a gradient of four miles, from Pauoa Flats to the Honolulu Substation, the rainfall decreases from 4300 to 600 mm (U. S. Weather Bureau, 1960). The rainfall on Mt. Waialeale (elevation 1600 m) on the Island of Kauai, is famous, and in some years is well over 15,000 mm indicated by finding that the 600 inch rain gauge has overflowed at the time of the annual reading.

This orgraphic rise of the trade winds is effective only between sea level and 2000 m altitude; above this level, since the islands are of limited lateral dimensions, the wind tends to go around or at least not to go over the top, and the upper parts of the mountains tend to be dry. Since the drainage may be extreme, moderately to severely arid conditions may result. Little is known of the rainfall on the high volcanoes, but at the U. S. Weather Bureau station at about 3400 m on Mauna Loa, the figures for five years average 595 mm annually. Snow covers the top of Mauna Kea and Mauna Loa some years for as much as three months and patches may remain throughout the year in shaded spots. Another phenomenon influencing the rainfall pattern on the very high islands is convection. Certain areas on the lee sides, where normally extreme aridity would be expected, receive afternoon rains as a result of the rise of air warmed by the sun.

The regional climate of the Hawaiian Islands has exhibited great fluctuations in the late geologic past (Selling, 1948; Gregory and Wentworth, 1937). Recent climatic influences on the evolution of the flora and fauna and on the patterns of the vegetation cannot yet be exactly determined, but were undoubtedly far-reaching.

2. Bio-Colonization

The first problem in reconstructing the history of Hawaiian life is to explain the presence and nature of plants on such remote and isolated islands. Thousands of miles of ocean constitute a formidable barrier to almost all groups of land plants.

Various hypotheses have been advanced proposing land bridges connecting the island with continental land masses. These are wholly unsubstantiated by geological evidence. Even the supposed biological evidence for them on close examination appears thoroughly unconvincing (Skottsberg 1931a; 1931b; Zimmerman 1948). Skottsberg (1956) has summarized the theories on this question for the whole Pacific. For our purposes we will assume that the Hawaiian volcanic domes were built up from deep water.

The first land available for plant and animal colonization must have been an unstable mound of volcanic material, tuff or perhaps firm lava, somewhere in the western end of the Hawaiian chain in the neighborhood of the present Kure and Midway Islands. This may have been 20 or more millions of years ago. It seems a reasonable assumption that islands have existed here since the mid- or possibly even the early Tertiary.

We may assume that, then as now, fruits, seeds, and other propagules of plants were being carried about by winds, ocean currents and birds, and occasionally dropped or washed ashore. Paleobotanical evidence indicates that the species assemblages on the continents surrounding the Pacific were different in detail from those now there. Thus, the plants that may have become established on the young island would have represented a selection from the species then extant. Little paleobotanical work has been done on the oceanic islands and it is not likely that a very complete fossil record has been preserved in thier volcanic deposits. Hence, we have no way of knowing the actual story of the early colonization of the new lava and ash domes. By study of the remote (i.e. present day) descendants of these pioneers in similar habitats now existing, such as new lava flows and ash beds (Forbes 1911; Skottsberg 1931a; Fosberg 1959), we can to some degree reconstruct the ecological conditions then prevailing. An approximate average frequency of successful colonizations can be inferred again by studying what is here now and allowing for the amount of evolutionary differentiation that has taken place. We cannot, however, have much of an idea of what became established, flourished, and has since disappeared. The only attempt to make an estimate of frequency (Fosberg 1948) is based on an estimate of 5 to 10 million years above-water history for the islands. It was judged that one successful establishment of a new organism every 20,000 to 30,000 years would be sufficient to account for the present array of species.

As plants became established on the new substrata there was nothing to impede their multiplication in vast numbers until all the suitable ground was covered. In these early stages, and later, as long as new lava flows and ash beds were being formed, open habitats were available where competition was reduced and prospects for survival high, allowing for the coexistence of non-deleterious mutations and gene recombinants. Thus both the persistence of relics and the development of polymorphism were favored. As more and more colonists became established, soil formed and a more complex and more close vegetation developed, lessening the opportunity for new colonists to establish themselves with certain exceptions such as shade tolerant species or varieties. This process would, naturally, be repeated with each subsequent emergent volcanic island.

As long as active building up was taking place, surfaces of the domes could remain fairly even. New lava flows, however, tended to isolate parts of the plant populations, at least those plants favored by some soil development and shade. Evolution was encouraged both by isolation and by periodic catastrophic reduction in population and size. During periods of volcanic quiescence erosional processes set in. In time the deep valley development now seen on older high islands appeared. Both the high ridges and the valleys between them serve as barriers to the migration of plants and serve to isolate populations of plants which can then differentiate into distinct taxa. The further progress of the erosion cycle may well have broken down physical barriers in some cases before reproductive isolation was achieved. Or by one means or another the barriers may have been crossed by seeds and isolation thus broken down, allowing separate taxa to hybridize and introgression and gene flow to take place between the populations. Marked climatic fluctuations which occurred during the Pleistocene almost certainly gave a great impetus to evolution also.

Evolution under conditions of reduced competition as described above and from a very limited assortment of original types would also be expected to result in the production of curious growth forms with characteristics not commonly found in certain plant groups. The progeny of the few stocks present would occupy niches ordinarily held by members of other families.

The lack of grazing animals was also a factor in the survival of many unusual forms: it removes the common selective advantage of spininess. There is almost a complete lack of spines and thorns in the indigenous flora, and it may have its origin here.

One other factor that may have contributed to the diversification of the Hawaiian flora was the presence of such a large number of islands separated by relatively narrow channels. These, while acting as barriers, would have been crossed by the plants far more frequently than would the surrounding sea between this and other archipelagoes. Thus many plant groups would have found their way to all or most of the islands but would have had sufficient isolation to develop endemic species.

By the dawn of the human period, a flora had been built up from few original stocks, which showed enormous diversity and which occupied practically every available niche. This flora, under the influence of extreme local physical diversity, had formed a great assortment of vegetation types. These were forest types in most cases, where the conditions were not extreme. Being evolved in the absence of man and of large hoofed animals, the plants had no special adaptations for resistance to the effects of these animals. In older areas the vegetation was a fully closed one, and invasion by newcomers was not readily accomplished.

Early man came, brought with him the pig, an assortment of useful plants and probably weeds. The effect on the vegetation must have been drastic, locally at least. Vegetation in favorable sites was destroyed to make way for agriculture and for trails and villages. Some native plants were doubtlessly utilized though man must have found very little that he could eat in this flora. Pigs caused great disturbance. At least two plant species, candlenut and rose apple, either by their own competitive ability or aided by disturbance, came to dominate certain habitats. Agricultural vegetation types such as taro marshes and coconut groves were created. In the dry areas fire may have played a significant role. Some grassland associations were probably brought into existence by burning in marginally dry areas.

After hundreds of years of occupation by the Polynesians certain equilibria between man's activities and the vegetation may have come about. Fairly stable patterns, different in some areas from earlier ones, may have evolved.

Then came European man, and with him came cattle, goats, sheep, other domestic mammals, new agricultural plants, and new methods for their culture. Most important he brought commerce and agriculture for profit. A rising rate of disturbance was accompanied by a never-ending stream of new exotic plants -- both economic plants and weeds. Whole vegetation types were destroyed. New ones were substituted for them, especially sugar cane and pineapple fields. Erosion was accelerated and whole new habitats were created, mostly to be occupied by the exotic plants that were being introduced.

Almost none of the original vegetation types remained unaffected, though some were far more vulnerable than others. Few of the newcomers would have been able to invade the original closed, undisturbed vegetation, but disturbance was general, and with the pressure of increasing population and the availability of new tools and chemicals the disturbance and change proceed ever more rapidly.

Now almost all the vegetation types that are commonly seen excepting certain of those on new lava and ash around Kilauea Volcano, are composed largely or entirely of non-Hawaiian plants. And most of the people who live here do not even know this. The cane, the pineapple, the guava, the papaya, the showy trees taht line the streets, the weeds that invade gardens and waste places, and the coconut palm were all brought by man from elsewhere, and almost no Hawaiian plants have been brought into cultivation.

B. Climatology and Physiography

1. Highlights and Biological Consequences

Hawaii is the only state which lies within the tropics, and the only state composed of relatively small islands completely surrounded by ocean. These facts contribute to its unique climate.

Descriptions of the macroclimates of Hawaii have been provided by Blumenstock (1961), Britten (1962), Price (1966), and Blumenstock and Price (1967).

The main Hawaiian Islands are the summits of volcanic mountains, as indicated by the fact that 50 percent of the state land area lies above an elevation of 600 meters (2,000 feet), and 10 percent lies above 2100 meters (7,000 feet). The maximum elevations (in meters) of the six major islands are: Hawaii - 4,206; Maui - 3,055; Kauai - 1,597; Molokai- 1,515; Oahu - 1,231; Lanai - 1,027.

Almost half the land in the state lies within 8 km (5 mi.) of the coast. Only about 5 percent, all on the island of Hawaii, is more than 33 km inland. Thus the marine influence on the climate is pronounced.

During most the year the northeast tradewinds account for the dominant air movements over the state, and rainfall distribution is influenced primarily by the trades and the terrain. From May through September the trades are prevalent 80 to 95 percent of the time. From October through April the trades are prevalent only 50 to 80 percent of the time.

Major storms, associated with cold fronts, lows, and upper air lows and troughs, occur, on the average, from two to seven times per year, usually between October and March. It is during such winter storms that dry leeward lowlands receive most of their annual rainfall. In fact, most areas of the state, except for the Kona coast of Hawaii, have higher rainfalls in the winter than in the summer, although most areas with high rainfall remain relatively wet all year. Hurricanes may occasionally pass close to Hawaii, but between 1904 and 1967 only four came sufficiently close to affect the islands, and only one actually passed through the islands.

Day length in Hawaii is relatively uniform throughout the year. In Honolulu the longest day (including twilight) is 14 hours, 10 minutes; the shortest is 11 hours, 40 minutes. The uniform day-length and the small annual variation in the altitude of the sun above the horizon, result in relatively small variations in the amount of incoming solar energy. This, and the nearly constant flow of fresh ocean air of relatively uniform temperature over the islands, are the major factors which contribute to the very slight seasonal changes in air temperature in the islands.

The overall pattern in Hawaii is one of equable temperature conditions. Below 1,523 meters the difference in mean monthly temperatures between warmest and coolest months does not exceed 5°C., while the average daily range in temperature is between 4°C and 9°C. The highest temperature of record is 38°C (100°F), but temperatures above 35°C (95°F) are extraordinarily rare even in the dry leeward lowlands, and outside such areas temperatures of 32°C (90°F) and above are quite uncommon. The lowest temperature of record is -10°C (14°F), recorded at 3,055 meters on Haleakala, Maui. When long term records from the summits of Mauna Kea and Mauna Loa, above 4,115 meters, are available, it is possible that temperatures as low as -15°C (5°F) or less may be recorded.

Under trade-wind conditions a temperature inversion is typically present between about 1,523 and 2,130 meters. This inversion layer is correlated with a moisture discontinuity and has an effect on both relative humidity and rainfall. Below the inversion the RH commonly averages 70 to 80 percent in windward areas and 60 to 70 percent in leeward areas. Avoce the inversion the RH is generally below 40 percent and often as low as 5 to 10 percent.

While the average annual rainfall of the state as a whole is about 180 cm (70 inches), variation from place to place is so great as to make this figure meaningless. At Kawaihae on the leeward coast of Hawaii the average annual rainfall is less than 18 cm; at Mt. Waialeale on Kauai it is 1215 cm. Rainfall gradients are extremely steep, exceeding 190 cm per km in many places. Along the 4 km line from Hanalei Tunnel to Mt. Waialeale on Kauai the gradient is 100 cm per km. In general leeward lowlands and mountain peaks above 2,500 meters elevation are the driest areas, while maximum rainfalls are recorded at or near the crests of mountains less than 1,800 meters high, and at 610 to 1,220 meters on the windward slopes of the higher mountains.

While the average annual rainfall varies tremendously from place to place, in any one place the rainfall varies as much as 200 to 300 percent from one year to another. Occasional droughts may occur in even the wettest places. The steep rainfall gradients indicate that more data are needed, especially from the more remote areas where the native biota is least disturbed; the yearly variation indicate that such data must be collected over a period of several years to be meaningful.

In considering rainfall-vegetation interactions, the phenomenon of "fog drip" must be taken into account. On mountain slopes and crests where clouds are frequent at ground level, condensation of moisture on the vegetation may contribute significantly to the water available to both plants and soil. Thus, wherever possible, methods of measuring rainfall should involve measuring "fog drip" or condensation.

Blumenstock and Price (1967) have recognized seven climatic subregions in Hawaii:

"These are defined chiefly by the major physiographic features of the State and by location with reference to windward or leeward exposure. Since one region grades into another, it would be misleading to attempt to draw sharp boundaries between adjacent regions. In general, however, the regions and their characteristics are as follows:

"(1) WINDWARD LOWLANDS, generally below 2,000 feet on the north to northeast sides of the islands. This region lies more or less perpendicular to the prevailing flow of the trade winds, and is moderately rainy, with frequent trade wind showers. Partly cloudy to cloudy days are common. Temperatures are more nearly uniform and mild than in other regions.

"(2) LEEWARD LOWLANDS, except for the Kona Coast of Hawaii which has a distinctive climate. In these areas daytime temperatures are slightly higher and nighttime temperatures are slightly lower than in windward locations. Dry weather prevails except for occasional light trade wind showers which drift over from the mountains to windward and for periods of major storms. In some leeward areas an afternoon sea breeze is common, especially in summer.

"(3) INTERIOR LOWLANDS, on Oahu and Maui. In the northeast these lowlands have the character of windward lowlands; in the southwest of leeward lowlands. The central areas are intermediate in character, and -- especially on Oahu -- are sometimes the scene of intense local afternoon showers from deep clouds which form as a result of local heating of the land during the day.

"(4) THE KONA COAST OF HAWAII. This is the only region in which summer rainfall exceeds winter rainfall. There is a marked diurnal wind regime, with well-developed and reliable land and sea breezes, especially in summer. Summer is also the season with a high frequency of late afternoon or early evening showers. Conditions are somewhat warmer and decidedly drier than in windward locations.

"(5) RAINY MOUNTAIN SLOPES ON THE WINDWARD SIDE. Rainfall and cloudiness are very high, with considerable rain both winter and summer. Temperatures are equable. Humidities are higher than in any other region.

"(6) LOWER MOUNTAIN SLOPES ON LEEWARD SIDE. Rainfall is greater than on the adjacent leeward lowlands, but distinctly less than at the same level on the windward side except that the zone of maximum rainfall usually occurs just to the leeward of the crests of the lower mountains. Temperature extremes are greater than on the rainy slopes of the windward sides of the mountains, and cloudiness is almost as great.

"(7) HIGH MOUNTAINS. Above 2,000 or 3,000 feet on the high mountains of Mauna Kea, Mauna Loa, and Haleakala rainfall decreases rapidly with elevation. Near the summits of Mauna Loa and Mauna Kea, rainfall is scant and skies are clear a high percentage of the time. Humidities may reach very low values, of 5 percent or less. The lowest temperatures in the State are experienced in this region with values below freezing being common."

As a rule, islands are thought of as small land masses surrounded by water. Different opinions exist with regard to defining Australia as an island or continent; but, for the purpose of studying differences between island ecology and continental ecology, islands should be defined as small land masses surrounded by water. For island research the UNESCO Expert Panel on MAB Project 7 (1973) suggested an approximate upper size limit of 10,000 km^2 -- a limit which includes the Island of Hawaii.

The biological implication of "small land size" is that population sizes of perennial organisms also tend to be small. Even in the mountainous or high islands, which usually have much greater land masses than low coral islands or atolls, the recurrence of similar habitats is rather limited in comparison to most continental mountain ecosystems. Small areas restrict the size as well as the gene flow and composition of populations developing there. Greater genetic homogeneity may imply increased specialization. Whether or not this leads to a greater fragility of island populations cannot be answered as generally as is usually done, because population stability depends on both the ecological properties of the population and the nature of the regional perturbations.

One biological consequence of recent geological age is that tropical island rain forests on high volcanic islands are much younger than most tropical continental forests. In certain areas the latter may have undergone more or less uninterrupted succession from giant equisetum-lycopod and seed fern forests to primitive gymnosperm and angiosperm forests. In contrast, the origin of most existing forests on high volcanic islands is within the modern angiosperm era. For examples, the oldest parts of the high Hawaiian Islands are estimated to be merely six million years old (MacDonald and Abbott 1970). Fosberg (1948) estimated that only one arrival form was required to become successfully established every 20,000 to 30,000 years to account for today's native angiosperm flora of a little over 1,700 taxa. The shorter geological time available for community development may in part account for a lower diversity in tropical island as compared to tropical mainland communities. In that respect tropical island communities are similar to temperate mainland communities, which can be considered species-depauperate compared to tropical continental communities (Doty et al. 1969).

It may be argued that the three ecological conditions mentioned above are not unique to islands. However, the biological consequences of these three conditions are most clearly developed on islands. The main point is that these conditions have resulted in a different evolution in island ecosystems. Thus, on islands, more so perhaps than in biogeographically different continental ecosystems, the effect of a unique evolution becomes evident in many ecological relationships. The ecological relationships involve primarily the interactions among native species, and among native and exotic species. Many of the exotic species were introduced by man within the last 200 years. Man thus effectively broke the natural isolation barrier of the Hawaiian Islands.

Because of unique evolution and species assemblages, the structure of island communities is expected to be unique also. However, this is true only at the level of species composition and quantitative distribution. At the level of dominant plant life form, islands are not at all unusual. Nearly all world plant formation types can be found on high islands. There are grasslands, bogs, alpine tundras, savannas, closed evergreen rain forests, open seasonal forests, scrub formations, and deserts, to name a few of the more common biomes. These are conditioned by the peculiarities of climates and soils just as they are on continents. This gross structural similarity combined with the unique evolution of island biota and communities establishes the scientific and practical relevance of deriving general principles from the study of island ecosystems.

The soils which have developed in the Hawaiian Islands have been produced under the whole range of climatic conditions occuring from the arid to very humid tropical regions. The high year-round temperatures have provided conditions for rapid mineral decomposition (weathering) which is controlled only by the rate of removal of the soluble constituents released during the process of weathering (leaching). The high base content and the lack of quartz in the parent materials have favored the formation of tropical soils at extreme tropical latitudes. Thus the representatives of most of the important soil groups of the tropical regions occur in the Hawaiian Islands. The studies of the typical soils have established the great similarity of Hawaiian soils to soils of the equatorial regions.

The principal Hawaiian Great Soil Groups are as follows:

1. Dark Magnesium Clays
2. Gray Hydromorphic Soils
3. Clays
4. Paddy Soils
5. Red Desert
6. Reddish Prarie
7. Low Humic Latosol
8. Ferruginous Latosols
9. Aluminous Ferruginous Latosol
10. Humic Latosol
11. Laterite
12. Tropical Reddish Prarie
13. Latosolic Brown Forest
14. Hydrol Humic Latosol

2. Isolation of Hawaii*

Of all the high volcanic islands in the world, those of the Hawaiian chain are the most remote from any continent -- or from other islands of appreciable size. They lie virtually alone in the North Pacific, separated from North America by about twenty-five hundred miles of ocean without any land except the small atolls Wake and Marcus. Looking south from the Hawaiian Islands, only atolls dot the equatorial latitudes, and the high volcanic islands such as the Marquesas Islands, the closest high islands to Hawaii, lie two thousand miles away; Tahiti and other Society Islands are even farther away. Even these islands are relatively small, and large islands, such as the Philippines, lie about five thousand miles away.

Geological evidence indicates that the Hawaiian chain has never

*This section is based largely upon Carlquist (1965, 1966a, 1966b, 1970, 1974) and Fosberg (1948, 1963, 1966, 1972).

been connected to a land mass. No now-vanished islands can reasonably be placed between the Hawaiian chain and North America. The Leeward Hawaiian Islands and the reefs in the Leeward group once may have been high islands and probably were. They never were a continuous land mass -- only islands, and rather small ones. The Leeward chain was probably never close to other island groups to the west. The most optimistic statement one can make about former land areas in the Pacific is that many of the atolls of the Pacific were once high islands, and that these may have served as stepping-stones in the dispersal of animals and plants toward the Hawaiian Islands. Such former high islands, however, were not all in existence at the same time, and probably there were not many more, if any, high islands in the Pacific at any one time than there are now. At best, former high islands extended modestly the dispersal possibilities of some groups, but they still had to cross oceanic distances to arrive on the Hawaiian Islands.

The rainfall, soil, and temperature conditions of the Hawaiian Islands make them exceptional for colonization by many groups of animals and plants. The traversing of vast oceanic distances to reach the Islands are considerable, however, and only a small number of species have succeeded over the five to ten million years during which these Islands have been available. Many large and conspicuous groups are entirely absent, or were never able to reach the Islands in prehuman times. Among plants, conifers are notably absent in the Hawaiian flora, as well as many large-seeded forest trees of Indo-Malaysia. The native Hawaiian fauna contains no mammals (except for a single bat), no reptiles, no amphibians.

The difficulties of natural dispersal across twenty-five hundred miles of ocean or more may seem enormous. This process does not need to take place frequently -- in fact, if it did, Hawaiian plants and animals would be identical with those of mainland areas (whereas more than 95 per cent of them are, in fact, found nowhere else on earth). Long-distance dispersal may be "unlikely," but it is not impossible. And many "unlikely" events can take place when ten million years are available.

In fact, if we examine those animals and plants comprising the native Hawaiian flora and fauna, we can see that each of them possessed some feature or features which gave them exceptional ability at long-distance dispersal. Some of these features have changed somewhat since the various groups arrived, but the mechanisms of transport can still be detected.

Transportation through the air is a means of travel possible for both plants and animals, but in the case of transport to the Hawaiian chain, they must be able to float exceptionally long distances. There are two ways in which this can be accomplished: the organism must be so small, or have a reproductive structure so small, that it is dust-like, as are spores, for example; or the organism must be able to fly, as do insects and birds. Over such long distances, even flying animals might be passively aided by air currents, however.

Plants which reproduce by means of spores include ferns, mosses, fungi, algae, and lichens. Any item this small can be carried almost indefinitely in air currents, especially if it reaches upper air levels. Plants with small spores can probably travel almost unlimited distances. This explains why particular kinds of fungi, fresh water algae, and mosses are rarely limited to any given area.

Ferns generally have larger spores, ranging between twenty and fifty microns. These still can travel in air, but not so readily. The ferns native to the Hawaiian Islands number about 168 species plus varieties, and these probably stemmed from about 135 original immigrants. Many (119) of the native ferns do not occur outside the Islands, which suggests that spores of their ancestors arrived only on a single occasion, and the populations then changed, rendering Hawaiian forms different from those of the mainland. The number of kinds of ferns estimated to have originally arrived on the Islands (135) is remarkably large compared to the number of flowering-plant immigrants (about 255). Fern spores have obviously been more successful at reaching Hawaiian sites than have seeds of flowering plants. In most cases, these spores have arrived by air.

Flotation in air can account for the arrival of very small seeds only, preferably those which are winged or irregular in shape and would thus have more buoyancy. It has been estimated that only 1.4 per cent of the 255 hypothetical flowering-plant immigrants to the Islands arrived in this way. Few seeds are small enough to travel in this fashion, and even the parachute-like seeds of a dandelion probably cannot travel the thousands of miles which separate the Hawaiian Islands from the source areas from which plant colonists come. Orchids are among the few flowering plants which have seeds suitable for air flotation: orchid seeds are very small, exceptionally light. However, only three orchids are native to the Hawaiian Islands, a very small number for a wet tropical country. Perhaps orchid seeds do not travel exceptionally long distances by air or have such specialized pollination requirements that they cannot become established unless the right insect is present.

The ohia lehua tree, Metrosideros polymorpha, has seeds small enough to permit air flotation. Metrosideros trees have reached virtually all the high islands of the Pacific, and thus can be said to be easily dispersible. We can clearly see the ability of ohia lehua seeds to travel on the wind where lava flows are concerned. New lava flows acquire a growth of young Metrosideros trees soon after the lava cools. Many plants which have wind-dispersed seeds may have reached the Hawaiian Islands in some way other than air flotation; such seeds can, nevertheless, travel by air within the Islands, and thus reach new lava flows. Plants such as Dubautia and Rumex are often seen as colonists on lava flows, and probably the seeds arrived there by air, although they may have reached the Islands via birds.

If passive flotation of seeds can account for arrival of seeds of only a few flowering plants, dispersal of small flying insects should be more feasible. Zimmerman has estimated that the approximately four thousand species of native Hawaiian insects evolved from between 233 and 254 original colonizations. Thus many more wind-borne insects than wind-borne seeds arrived in the Islands.

The insects which have successfully colonized the Hawaiian Islands in prehuman times are those adapted to long-distance dispersal and subsequent colonization. Small body size is the most important key to this transport, and in fact most Hawaiian insects are notably small. Buoyancy in the air due to small body size may seem negligible where most animals are concerned, but with very small ones, small body size does, in fact, yield greater floatability on that count alone. There are some exceptions to smallness among Hawaiian insects, notably the crickets and grasshoppers. Grasshoppers have resistant eggs, notably resistant to dryness and temperature extremes. Some large insects do migrate -- dragonflies and butterflies, for example. The one large Hawaiian butterfly, Vanessa kamehamehae, may stem from migratory butterflies. Likewise, the two large Hawaiian dragonflies may be explained in this fashion.

Birds are much too large to be carried passively, and only active flight can explain their presence on the Islands. Migratory birds, such as marine birds, shore birds, and waterfowl offer no great problems in this respect -- and these groups are all rather well represented on the Hawaiian chain. The number of native Hawaiian land birds, however, is rather small. Only seven colonizations can account for all the land birds, in the strict sense, now native to the Hawaiian Islands. This seems a very modest number, but is perhaps understandable. Land birds do not stray very far from land ordinarily, so only a few exceptional instances of transport over such long distances would be expected.

The list of birds not native to the Hawaiian Islands but observed there on one or more occasions as stragglers include the following: pelagic cormorant, reef heron, white-faced glossy ibis, lesser snow goose, American white-fronted goose, emperor goose, black brant, cackling goose, mallard duck, green-winged teal, baldpate, gadwall duck, buffledhead, harlequin duck, red-breasted merganser, lesser scaup duck, canvasback, greater scaup duck, marsh hawk, American osprey, blackbellied plover, killdeer, Pacific godwit, Wilson's snipem short-tailed snadpiper, pectoral sandpiper, red phalarope, northern phalarope, ring-billed gull, herring gull, California gull, Point Barrow gull, Bonaparte's gull, Pacific kittiwake, artic tern, black-naped tern, marsh hawk, and belted kingfisher.

All guesses concerning the role of air or wind in dispersal are valid only if suitable air currents do, in fact, reach the Hawaiian chain. Trade winds from the northeast form a steady stream toward the Islands during most of the year. During the winter months, the Kona storms constitute large weather systems, some of which traverse long distances from the coast of Mexico or Central America. Storms that feed into these consistent Hawaiian weather patterns could contribute spores, insects, etc., to Hawaiian sites.

A significant source of strong wind currents which has not been generally appreciated yet with respect to dispersal is the northern hemisphere jet stream. The jet stream is a pathway of ultra-high-speed air which occurs as a continuous band at thirty thousand to forty thousand feet around the northern hemisphere. Typically, it accelerates over certain regions, decelerates over others, farther north at some seasons, farther south at others in a predictable pattern which can, in fact, be mapped. For example, the January path of the jet stream leads from southeast Asia, where it begins to accelerate, to the Hawaiian Islands, where it decelerates markedly. The top speed, 122 miles per hour, could account for rapid transport: an object in the jet stream could be carried to the Hawaiian Islands in a little over two days, according to the speeds shown. The jet stream tends to sweep warm air upward on its equatorial side, cold high air downward on its northern side. Strong updrafts from storms could funnel plant and animal material upward to a point where the jet stream could catch it and hurtle it eastward. The vortex-like nature of the jet stream would tend to keep material air-borne. Deceleration of a jet stream could account for dropping of material. Another possibility is that rain clouds, rising high, as over the Hawaiian mountains, bring material down from high altitudes in rainfall.

The path of the jet stream from southeast Asia matches well the source areas which must have contributed most heavily to the Hawaiian flora and fauna. Except for animals and plants brought by ocean currents -- and these are relatively few in number -- most have depended directly or indirectly on transport in air. The predominant west-to-east direction of air movement in the northern hemisphere, of which the jet stream is an exaggerated form, favors fulfillment of the Indo-Malaysia-to-Hawaii pattern. Of Hawaiian insects, 95 per cent are "Pacific" (as opposed to "American") in origins. "Pacific" implies Indo-Malaysia plus parts of the Pacific closer to Hawaii. Indo-Malaysian origin is stamped on a somewhat smaller, but still predominant proportion of Hawaiian land shells, ferns, and flowering plants. The Indo-Malaysian character of the native Hawaiian flora and fauna might be due to the efficiency of transport from these areas but another important factor might be that animals and plants best suited to the Hawaiian climate would mostly be those native to wet tropical areas most like those of the Islands -- namely other Pacific islands. The coasts of North and South America are mostly drier, and subject to greater temperature extremes; organisms adapted to these conditions would be expected to be poorer candidates for success in the Hawaiian Islands. It is, then, perhaps surprising that as many as 20 per cent of Hawaiian flowering plants are, in fact, American in their relationships.

Seeds can become embedded in mud on feet or other parts of birds, and travel in this way. This is likely to happen if seeds are small, if the plants grow in wet, muddy places, and if the birds frequent these places and then migrate. Plants of marsh, big, riverbank, or pond could be dispersed best in this way. In the Hawaiian flora, only a small number of plants appear to have arrived in this fashion. Seeds small enough to be caught in mud on birds' feet might also be transported in several other ways, even possibly by wind dispersal. Observations in various parts of the world suggest that this mode of transportation is genuinely effective. Perhaps 12.8 per cent of the hypothetical original immigrants to the Hawaiian Islands might have arrived in this way.

Some plant and animal parts are viscid, and can become attached to bird feathers. Adaptations of this kind are sometimes subtle, and not easily seen. For example, Plantago has small black seeds that seem to have no special adaptation for dispersal. However, when soaked in water, they quickly develop a slimy covering which, when allowed to dry, can attach the seed to various surfaces, such as feathers or other parts of a bird. A mucilagenous covering on seeds can also be seen in Hawaiian species of Euphorbia (akoko) and Lepidium.

Slimy materials are probably also basic to long-distance transport of land snails. Land shells can withstand dryness by sealing themselves onto leaves, branches, even feathers, by means of this glue-like secretion. Land snails have, in fact, been seen attached to birds. The eggs of land snails can travel in a similar way.

Long-distance travel for land molluscs would be difficult for species with large shell size, unless travel is by eggs alone. Interestingly, many of the land shells native to the Hawaiian Islands are quite small.

Some Hawaiian plants have seeds coated with sticky substances. One such plant is Boerhavia, a common beach plant of the tropical Pacific. The small fruits of this plant are sticky at the angles, and adhere very readily to bird feathers. These fruits are borne a few inches above the ground, and are thus perfectly placed for coming into contact with feathers as a bird runs along the ground.

Attachment of a fruit by a mechanical device is one of the most effective ways in which a seed or fruit can travel. Devices such as barbs, hooks, bristles, prongs, or even stiff hairs on fruits have evolved chiefly in relation to furry animals. Regardless of this mode of origin, these devices serve equally well to attach fruits and seeds to feathers -- all they require is contact with birds. It is estimated that 12.8 per cent of the Hawaiian flora's ancestors arrived in this way.

Some seeds are tipped by a circle of bristles, like the spokes of an umbrella.

Bidens, known to Hawaiians as kokoolau and to mainlanders as the weed spanish needle or beggar tick, has fruits ideally suited for animal dispersal. They are often caught on clothing because they are needle-like and penetrate between fibers; the two or three prongs on the body of the fruit can also do this, mimicking the action of a fishing spear. These prongs are barbed, moreover, so once the fruit has lodged in a hairy surface, it is unlikely to fall off.

Seeds with a miniature fishhook ought to be ideally suited to catching on feathers, and therefore reaching islands. And so they are, as is proved by the sedge Uncinia, which has reached other islands of the world in addition to the Hawaiian Islands. Although Bidens and Uncinia have special attachment mechanisms, seeds which are merely covered with bristles or hairs are nearly as good at long-distance transport. Seeds of grasses can travel in this way, for example.

Surprisingly, the means of seed dispersal which seems the most difficult appears to have brought more flowering plants to the Hawaiian Islands than any other mechanism. About 39 per cent of the 255 plants ancestral to contemporary native Hawaiian flowering plants arrived via birds that ate seeds, carried them internally, and excreted them on arrival. Fruit-eating birds might also get fruits attached to them externally by chance. Fruits and seeds attractive to birds are exceptionally obvious in the Hawaiian flora. Because these are so typical of wet forests in Indo-Malaysia, they may have established preferentially in Hawaii despite the difficulties involved in dispersal.

Plant families which mostly have dry fruits can be represented by fleshy fruits in the Hawaiian flora. This indicates that long-distance dispersal is relatively more successful for these fleshy types. Most members of the mint family have small dry seeds. The

Hawaiian mints are unusual: Phyllostegia and Stenogyne have seeds covered with a succulent layer which is green, then turns purple. Many continental members of the lily and nightshade families have dry capsules which release seeds when capsules shake in the wind. Hawaiian representatives of these families all have fleshy fruits.

Shore birds eat mostly molluscs and other small animals at the shoreline, but observations repeatedly indicated that they also eat a certain amount of fruits and seeds. Even if these are a minor item in their diet, they can be very effective in the dispersal of the seeds and fruits when millions of years and millions of individual birds are involved. Shore birds and waterfowl might have been effective in bringing the approximately one hundred fleshy-fruited immigrants which originally arrived in the Hawaiian Islands.

Black shiny seeds probably have been brought internally in birds, because they are quite attractive to birds even when their fruits are not fleshy. Pelea, Zanthoxylum and Pittosporum are conspicuous Hawaiian plants that bear shiny black seeds in dry pods. Of these, Pittosporum has seeds which are sticky, perhaps sufficiently to adhere to feathers. Many birds pick up nonsticky black seeds and other shiny objects. Even marine birds appear very fond of such objects, and have been found both to carry them to their nests and on occasion to eat them.

Dispersal by flotation in seawater might be thought to be highly effective and to have brought many plants to the Hawaiian Islands. In fact, only 14.3 per cent of the original flowering-plant immigrants to the Hawaiian Islands are clearly adapted to oceanic drift, while another 8.5 per cent may have arrived by rare or freak flotation events. The best way to see plants adapted to flotation on ocean currents is to visit a seashore location. Plants which drift on ocean currents are beach plants -- and rarely evolve into inland sites. An exception to this can be seen in the Hawaiian flora, however, where some of the coastal plants have, in fact, evolved inland into dry forest. Most of the coastal flora has seeds or fruits capable of floating -- as shown by Pandanus, Ipomoea, and Erythrina. Some plants, such as Portulaca, have stems and leaves which float. In addition to floatability, seeds or plant portions must be able to resist seawater for weeks, and must arrive alive on beach sites and be able to grow there. Plants with these capabilities arrive on shores year after year, and so evolutionary changes, which require isolation of one population from another, tend not to occur.

Some plants typically grow well in beach situations and have seeds which can withstand exposure to seawater, yet they may have seeds and fruits poor at flotation or incapable of it. Such plants may take advantage of "rafting" -- flotation of an entire plant, or entire mats of vegetation. Such a lucky arrival might never be repeated, so the new population would be isolated and might well develop into a new species. The Hawaiian cotton (Gossypium sandvincense) is a plant which seems to fit these specifications. A tree of the dry forest, the koa (Acacia koa) also may have had this history. Its closest relative is not in the Pacific at all, but is Acacia heterophylla of Mauritius. Both probably floated from Australia by some rare chance. The seeds of both could probably withstand seawater, even though they had no flotation mechanism. Perhaps branches or entire trees floated. The wili-wili (Erythrina sandwicensis) might be another example --

the only relative in the Pacific is located on Tahiti, although one would expect a tree readily carried by seawater would become established on many Pacific islands.

Infrequent events of dispersal to the Hawaiian chain by oceanic drift may be explained in another way also. The seawater path to the Hawaiian chain is not as easy as it might seem. If we examine the currents of the Pacific, we see that across the equatorial zone, three currents run: the north and south equatorial currents flow westward, and between them the counter current runs eastward. If a seed from the southern hemisphere floated into the south equatorial current, it would likely be carried westward; if by luck it managed to enter the counter current, it would be swept far eastward again. Only by the rarest chance would it cross the three currents and arrive on a Hawaiian shore. There are many common South Pacific shore plants absent on Hawaiian beaches -- evidently for this very reason. Some of these have been introduced to the Islands by man, and have gone wild readily, proving that the conditions were right for their growth; only their inability to disperse prevented their presence. Such plants include mangroves (Rhizophora, Bruguiera); Calophyllum inophyllum and Terminalia catappa, both known as kamani to the Hawaiians; and Barringtonia and Hernandia. Although it is not certain, there seems a strong likelihood that coconut palms did not occur on the Hawaiian Islands before the Polynesians brought them.

The requirements for success of an immigrant which arrives intact are so numerous that we might guess that establishment, not transport, is the major constraint. Successful colonists in the Islands seem to have the following qualities. They tend to be weedy, capable of living in a pioneer habitat such as a beach, a bare lava flow, a landslide. Bogs could also be considered pioneer habitats, as could the branches of trees for epiphytes. In the case of animals, a versatile diet favors establishment. Plant-eating insects are more likely to establish on islands.

Barren lava flows, contrary to appearance, offer many opportunities for colonization. By observing the plants of new lava flows in the Hawaiian Islands, we can see re-creations, almost in the sense of a laboratory demonstration, of how original colonizations occurred.

Aa lava tends to favor plant growth because it contains many crevices which provide pockets of shade and which can retain water. The minerals of new lava certainly favor a wide variety of plants. The tall ohia lehua forest of the Kona District, Hawaii, is growing on lava which has very little soil, but rainfall conditions are good, and that overriding factor has permitted the forest.

The idea that vegetation of bare surfaces begins with a crust of lichens, that these develop pockets of soil which permit progressively larger plants to grow, and that a forest ultimately develops, is a theory clearly refuted by what happens on a Hawaiian lava flow. Lichens do appear on certain new lava flows, but most abundantly in wet, foggy regions. Even so, flowering plants appear at the same time, often before lichens. And these flowering plants include trees.

Ferns appear early on lava flows, a fact that upsets the idea of ferns as delicate plants of wet, shady regions. Ferns are actually often quite weedy -- otherwise these ancient plants would never have survived to the present. <u>Sadleria cyatheoides</u>, a fern found only in the Hawaiian Islands, grows both on sunny new lava flows and in wet, mature forests. Good dispersability of its spores aids the appearance of this fern on new lava.

Some plants, like the ohia lehua, are peculiarly suited for growth in pioneer situations. The ohia lehua forms aerial roots easily. If a grove of ohias is inundated by a thick blanket of pumice, ohias are not suffocated; the aerial roots on upper stems reroot the plant. This happened with ohias buried up to half their height or more by pumice in the 1959 Kilauea-Iki eruption.

One plant often aids another to invade new lava. Where one plant takes root, it creates a small amount of shade and this may permit other plants to germinate under it. Or seeds may blow along a cinder field, lodging at the base of a fern and taking root. In this way, small colonies of plants may appear. The 1959 Kilauea-Iki eruption killed some ohia lehua trees, but left them standing. At the bases of these trees, ferns and other plants have taken root because water seeps around the dead trunks and provides conditions just right for germination. Empty tree molds often contain seedlings. — evidently the shade in these favors growth.

If a lava flow occurs in a very dry locality, plants will be slow to appear. Lava flows known to have been formed before 1750 are still bare in some cases. Pahoehoe flows, with their smooth crusts, are less inviting for plant growth than are aa flows, however, pahoehoe crusts may collapse, and the shady recesses below the crust provide conditions ideal for germination. Cracks eventually develop in pahoehoe flows, and these provide suitable sites. On the Hilina Pali near Kilauea, a light fall of pumice, evidently from the 1959 Kilauea-Iki eruption, has filled some small crevices and depressions in pahoehoe. This has been all that was needed for plant growth, because these crevices can now retain water for days at a time, and so seedlings have appeared.

Wet forest plants can quickly invade lava -- if the flow occurs in an area of wet forest. There always seem to be seeps or crevices that offer sufficient water for these plants. Once vegetation begins on a lava flow, the process tends to accelerate. Shady places are soon available for shade-requiring species. As a canopy of branches covers the flow, water no longer evaporates readily from the surface of the lava, and plants are increasingly favored.

Weeds introduced by man to the Hawaiian Islands can often be found on lava flows. Perhaps plant invaders of lava flows in prehuman times were also quite weedy. As the islands grew older and volcanoes became extinct, some plants of the Hawaiian flora appear to have become specialized for wet forest, and to have lost their original weediness. Thus, the ability a plant or animal now has to survive in pioneer conditions may or may not indicate similar qualities in its ancestors: they might once have grown successfully on new lava.

3. Environmental Degradation

Since the advent of man in Hawaii, profound changes in ecology have taken place. Large numbers of "weed" or "pest" species have been introduced, intentionally or accidentally. Many plants which are common garden ornamentals or hedges elsewhere have become serious weeds, blanketing large areas cleared of forest for grazing, and invading and exterminating native forest. Similarly various mammals and birds have been introduced, as escaped pets, or intentienally by organizations or local government agencies, for hunting pruposes. Cattle, horses, goats, sheep, deer, and pigs have devastated thousands of acres of natural vegetation and threaten some of the remaining stands. Mongooses and rats have helped reduce native birds. And many species of insects (an average of 16 species is accidentally introduced each year; Beardsley, 1962) and other invertebrates have also ravaged the native environment. The transformation of the biota from native to introduced is not restricted to the lowlands, but extends to mountain ridges, valleys, and summits, where hiking trails, sightseeing roads, radio, radar, and other developments have been introduced, many temperate plants such as Rubus have become established, ravaging large areas and exterminating native vegetation.

Nearly all elements of the native biota appear to lack genetic resilience or other qualities to successfully compete with the invading biota. Native plants have disappeared and been replaced by the invaders in practically all areas where towns, roads, agriculture, grazing, gardens, and other developments have materialized, except where special precautions such as fences (effective for only a few of the invaders), weed-control, or other special measures have been taken. Associated with the recession of the native vegetation from the lowlands and the mountains is the decrease in the numbers of native birds, insects, and snails, and the extinction of some of the more specialized members of these groups. It has become obvious that native animals cannot survive when the vegetation of their natural habitat is seriously disturbed.

Attempts at biological control, primarily stimulated by the desire to control agricultural or garden pests rather than to protect the native biota, have had further disrupting effects on the environment.

Many of the beneficial insects imported have successfully controlled pests and largely limited their feeding to these pests, but some have preyed upon native insects or plants. The introduction of two predaceous snails to control the giant African snail, a serious plant-feeding pest, has made inroads on populations of the endemic land snails. And associated with the giant African snail itself are pathogens which provide a potential threat to man and other animals.

The public health implications of introduced animals and plants is aggravated by the greatly increased air traffic between Hawaii and the entire Pacific basin. This calls for intensive basic studies on the biology of both endemic and introduced species and the interrelationships between them.

The recession of the native vegetation from the lowlands, mountaintops, and ridges (with a consequent decrease in the native birds, insects, and snails) has not only been alarming but associated with it is the greater tragedy of the extinction of some of the most specialized birds and other species. The continued threat of extinction has been accelerated in recent years, with the great growth in human population, tourism, resort development, planting of former native forests with theoretically potential timber trees, road-building, game introduction, and other incursions.

The solution of the diverse problems posed by the Hawaiian biota and ecosystems is directly relevant to many of the problems of the present day world. Hawaii fits the concept of a small relatively quarantined sample area, which might thus serve as a laboratory for the study of the future of mankind, particularly in terms of the conservation of natural resources, of ecology and evolution, and the proper use of land in terms of the over-population of the earth by man.

The native Hawaiian biota, which had evolved in the absence of man and of large grazing or carniverous mammals, seems to have been in particularly delicate balance within the ecosystem, and thus was especially sensitive to the changes which accompanied man to Hawaii. The Polynesians brought with them some 25 species of plants used for food, medicine, fiber, and other purposes. These included coconut, taro, banana, breadfruit, candlenut, paper mulberry, ti, sweet potato, and various yams. They also brought rats, dogs, pigs, and jungle fowl. The Polynesians, and the organisms which they brought with them, certainly influenced the native biota, but one can only speculate on the magnitude of their effects. Undoubtedly the impact of the Polynesians was greatest in areas where the Hawaiians lived and grew their crops. On the other hand, Hawaiians considered lands, plants, and animals as the property of, and to be held in trust for, the gods. This outlook resulted in a sort of practical conservation. When birds were trapped to obtain brightly colored feathers, this was said to be done without harming them, and they were later released to grow new feathers; fish and shellfish were collected only in season, etc. Thus, although the initial effects of Polynesian colonization on the native Hawaiian biota were great, they were certainly less drastic than the effects brought about by sustained contact with European cultures.

It is likely that new ecological equilibria were established at some time after the extensive colonization of the islands by the Polynesians, and that these equilibria were operative in 1778 when

Captain Cook arrived.

Cook released the goat and a second type of pig in 1778. In 1793 Captain Vancouver released cattle and sheep. Horses were introduced in 1803. Cats and rats probably arrived on some of the earliest ships. The last feral horses and cattle were not exterminated from Mauna Kea until the 1930's, and feral cattle are still to be found in some areas of the Kona coast of Hawaii today. Sheep, goats, and pigs today endanger the native forests on most of the main islands.

While the large hoofed animals were rapidly increasing in numbers and destroying the vegetation in large areas by grazing and trampling, many plants introduced, intentionally and otherwise, were aggressive, weedy species which occupied the areas newly opened up by animals. Since early records are so incomplete we cannot estimate the number of species in the native biota which became extinct in the century following Cook's visit. During the last hundred years better records are available. As extensive areas of land were cleared for agricultural purposes the native biota disappeared almost completely from these areas.

The delicate balances existing in the native biota were easily upset - as the plants disappeared the birds, insects, and terrestrial molluscs which associated with them also disappeared. Even after the unique biotic resources of Hawaii came to be appreciated by the scientific community, the desire for "progress" and economic development on the part of the general public has been so great that policies have still not been developed to protect and manage Hawaii's unique and precious natural resource, its native biota.

Even today areas of relatively undisturbed native forest are being bulldozed or treated with herbicides to permit the planting of introduced species of Eucalyptus or Pinus which might some day bring economic benefit to a few people. The introduction of the giant African snail was mentioned above. These are only two examples of the sorts of management practices underway today which result in further destruction of the native biota. Many more can be cited.

Hawaii affords an ideal area to study the interrelationships of invading and endemic biota but such studies must be made soon, or the endemic biota will have disappeared. If any of the unique members of the Hawaiian biota are to be preserved much more ecological data must be accumulated quickly. Such data will hopefully contribute to the development of management practices in areas which must be set aside for the preservation of unique Hawaiian ecosystems.

Introduced Flora:

The native flora is a disharmonic one, and several plant groups which are widespread in the tropics and might be expected to be native in Hawaii are not. Fosberg (1948) indicated some groups which he considered to be "significantly absent" as gymnosperms, Ficus, Cunoniaceae, mangroves, Piper, Bigoniaceae, and Araceae. All of these groups except the Cunoniaceae have been introduced to Hawaii in some numbers in recent years. Mangroves have been successful, probably because there were no other plants occupying their particular ecological niche, and in less than 50 years well-developed mangrove swamps have developed on Molokai and Oahu. A few species of Ficus (Moraceae) and Spathodea campanulata (Bignoniaceae) have become naturalized to some extent, but usually only in otherwise disturbed areas, and are not yet causing serious problems. Piper methysticum has persisted in the wild since its cultivation by the Polynesians. Other than these, the plants in the groups "significantly absent" from the native flora have not seemed to spread beyond cultivation.

The most successful members of the introduced flora, those which have become thoroughly naturalized, have occupied the most extensive areas, and which most often seem to be in competition with the native flora include: Prosopis pallida, Leucacna leucocephala, Acacia farnesiana (Leguminosae); Lantana camara, Stachytarpheta spp. (Verbenaceae); Rubus rosaefolius, R. penetrans (Rosaceae); Psidium guajava, P. cattleianum, Rhodomyrtus tomentosa, Eugenia cuminii (Myrtaceae); Melastoma malabathricum, Tibouchina semidecandra, Clidemia hirta (Melastomataceae); Opuntia megacantha (Cactaceae); Bidens pilosa, Pluchea spp., and many other genera (Compositae); Commelina diffusa (Commelinaceae); Andropogon glomeratus, A. virginicus, Panicum maximum, Paspalum conjugatum, Pennisetum clandestinum, P. setaceum, and many other genera (Gramineae).

Nearly all of these are species which are widespread throughout the tropics and have been aggressive colonizers in other areas as well as Hawaii. In Hawaii (with significant exceptions such as the species of Andropogon), they occur primarily in areas with a past history of disturbance by man or grazing and browsing animals, and most are unable to become established in undisturbed areas of native vegetation. However, once established many will persist even after the original cause of disturbance is removed. Little of the native vegetation is relatively undisturbed today, none is completely undisturbed since pigs can be found in even the most remote rain forests. Even in areas such as the Alakai Swamp or Kipahulu Valley the very act of making trails to permit scientific study may create openings in which weedy species can become established. Thus, precautions must be taken in any such study areas to prevent further spread of introduced species.

The most successful species in the introduced flora have little in common except an ability to compete well and to invade disturbed areas. They include a wide variety of species, some of which have relatives in the native flora, others of which do not. Aside from those species of value in agriculture and forestry, little work has been done on the introduced species, and we need to obtain much more information about their ecology, dispersal, and reproductive biology if we are to exercise effective controls on them.

The immigrant fauna, that which has come to the Hawaiian Islands since man arrived here, is now an important segment of the total fauna. It is of very great concern since it includes nearly all of the pests of agriculture, forestry, gardens and households, and those concerned with public health. From the economic standpoint, therefore, the immigrant fauna is of paramount concern, and from the standpoint of conservation it is of similar importance, because of its great success in competing with the native biota. A great part of the Subprogram will involve the assessment of the ecological impact, current status and potential of the immigrant biota. Since additional species of insects and other arthropods are accidentally introduced each year (Beardsley, 1962), this is a constantly growing and changing problem.

The disharmonic nature of the endemic fauna leaves numerous important ecological gaps, many of which have been conspicuously filled by immigrant fauna. For instance, ants, termites, and cockroaches are lacking in the endemic fauna, but several species of each are now all colonized, and have had great impact both on the human economy and the endemic biota. The conspicuous examples of the introduced hoofed animals have been mentioned above. Also the introduced rats, mongoose, cat and other animals have helped reduce the birds and other elements. Proposed introduction of deer to additional islands would have additional disastrous effect on the native vegetation, if not also on agriculture.

Among the insects proper, of 33 orders recognized, only 12 are included in the native fauna, but 15 additional have been introduced by man.

For other arthropods, the picture is similar. About 1,500 species of insects have been introduced to these islands. To these are to be added some 200 kinds of mites, plus other arthropods. Thus the study of the role of these many species in the ecology of the islands will form a major undertaking of the proposed studies.

C. Scope and Objectives of the Ecosystem Overview

To describe the Hawaiian ecosystem merely as complex and unique is to place it in the same category as all other ecosystems on this planet. Presumably the degree of organization and dynamic state that warrants the term "system" already implies some prescribed minimum level of complexity and continuity in terms of material and energy flow. Thus all ecosystems are complex.

Uniqueness is inherent in any biological system with the possible exception of a hypothetical construct based on precisely controlled physical environment populated by cloned life forms. Thus all (real world) ecosystems are unique.

The particular complexity and uniqueness exhibited in the Hawaiian ecosystems set is, in part, a reflection of the historic factors and in part a consequence of its current status in physical, biological terms. More than any other attribute, the diversity conferred by geography, geology and climate along with geobiological, biogeochemical and biotic interactions which are confined to a miniscule isolated land surface, create a kind of uniqueness - setting Hawaii apart even from the most closely similar tropical islands.

Some of the problems stimulating ecological research in Hawaii reflect this uniqueness:

What determines the fact that although speciation is a conspecuous feature of Hawaiian biota, some of its most successful organisms have not speciated?

What determines the simultaneous existence of extremely stable and extremely fragile ecosystems?

How are speciation and stability related to diversity, isolation, original gene poos, climatology, etc?

It is within the framework of the distinctive, multi-faceted Hawaiian ecosystem and the many as yet unanswered questions as to its nature that we seek to assess the consequences of geothermal resource development. To that end, we here assemble data pertaining to salient features of the principal Hawaiian Islands overall and to the Island of Hawaii in particular. To the extent that existing data prove sufficient, the regional consequences of geothermal field development will be assessed. Actual experience with the environmental impact of a geothermal facility in Hawaii is limited to one specific site, HGP-A in the Puna district, Island of Hawaii, and to a short observation period. Other relevant and useful experience derives from a more general review of the biological effects of natural geothermal processes and emissions associated with volcanism. The latter is limited to the active rift and caldera areas on the Island of Hawaii.

After assembling the elements of a necessarily general picture of the ecosystems of Hawaii and even more broadly of the other major islands, our next task will be to interface that data with information about geothermal processes, and effluents as they relate to living matter (geobiology, including geotoxicology and biogeochemistry). Data from domestic areas of geothermal development, e.g. California and Utah KGRA's or those in New Zealand and Italy can have but little relevance, as differences in contained ecosystems preclude all but the most superficial comparisons. Furthermore, Hawaii has all of the environmental complexity of an entire continent hence is totally unlike any KGRA overview study yet done.

As anticipated, therefore, attention will then be directed toward a brief statement of inadequacies and gaps in the current body of knowledge and data, and therefore, toward informational needs for the future.

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THE LAND

A 1. Soil Types and Associations* (done only partially for the Island of Hawaii as a demonstration of the uniqueness and where mainland counterparts are unknown)

The Island of Hawaii is one of the eight major islands of the State of Hawaii. It has an area of 2,579,000 acres or about 4,030 square miles. Although its land area is 62.7 percent of the State, its population of 65,941 is only 8 percent. The island is a county. Hilo, the county seat, is about 216 miles southeast of Honolulu, the State capital.

Farming is the main source of income, and the highly mechanized production of sugarcane has been the main industry. Farming is now diversified, however, and other enterprises, including the production of macadamia nuts, papaya, truck crops and one of the most extensive orchid cultures in the world are increasing rapidly. Anthuriums and ornamental foliage are also increasing rapidly. The only coffee grown in the United States is produced in the Kona district. The island leads the State of Hawaii in the production of cattle. Parker Ranch, the second largest in the United States, is in the Kohala District. Tourism also is a growing source of income.

The Island of Hawaii is commonly called the "Volcano Isle," the "Orchid Isle," or the "Big Island" (13). It has the only active volcanoes and the largest land mass in the State. Its lush, green rain forest, its warm, sunny coastal areas, and its snow-covered mountain peaks provide a variety of scenery and climate.

A soil association is a landscape that has a distinctive proportional pattern of soils. It normally consists of one or more major soils and at

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*Excerpted and condensed from Soil Survey of the Island of Hawaii, State of Hawaii. Soil Conservation Service, United States Department of Agriculture. United States Government Printing Office, December 1973, pp. 6-150.

least one minor soil, and it is named for the major soils. The soils in one association may occur in another, but in a different pattern.

A map showing soil associations is useful to people who want a general idea of the soils on the island, who want to compare different parts of the island, or who want to know the location of large tracts that are suitable for a certain kind of land use. Such a map is a useful general guide in managing a watershed, a wooded tract, or a wildlife area, or in planning engineering works, recreational facilities, and community developments. It is not a suitable map for planning the management of a farm or field or for selecting the exact location of a road, building, or similar structure, because the soils in any one association ordinarily differ in slope, depth, stoniness, drainage, and other characteristics that affect their management.

The soil associations on the Island of Hawaii are discussed in the following pages.

1. Lava flows association

Gently sloping to steep, excessively drained, nearly barren lava flows: on uplands.

This association consists of excessively drained, nearly barren lava flows and somewhat excessively drained and well-drained, coarse-textured and medium-textured soils that formed in volcanic ash, pumice, and cinders. These soils are on mountains at an elevation ranging from near sea level to 13,000 feet. They receive an annual rainfall of 10 to 250 inches. The mean annual soil temperature is between 49° and 76° F. The natural vegetation consists of lichen, moss, ohia, amaumau fern, mamane, naio, Kentucky bluegrass, and sweet vernal.

This soil association makes up about 50 percent of the island area, and most if it is in the saddle between Mauna Loa and Mauna Kea, near the summit of Mauna Kea, and near Pahala. Pahoehoe lava flows make up about 40 percent of this association, and Aa lava flows about 30 percent. The main soil series are Apakuie, Huikau, and Kilohana, each of which makes up about 3 percent of the association. The remaining 21 percent consists of Kilauea, Heake, and Keekee soils, and of Rock land, Rough broken land, Very stony land, Beaches, Cinder land, and Fill land.

Pahoehoe lava flows have a smooth, ropy surface. Aa lava flows are a mass of clinkery, hard, sharp lava fragments. Apakuie, Huikau, and Kilohana soils are near the summit of Mauna Kea. Apakuie soils have a dark reddish-brown and dusky-red very fine sandy loam surface layer underlain by dark reddish-brown very fine sandy loam and loamy sand. Huikau soils have a very dark brown loamy surface layer underlain by dark reddish-brown sandy loam and loamy sand and by slightly weathered volcanic ash, cinders, and pumice. Kilohana soils have a very dark brown loamy fine sand surface layer over dark-brown and very dark gray fine sand.

Beaches consist of coral sand, black sand, or olivine sand. Cinder land is a mixture of fine cinders, pumice, and volcanic ash. Rock land consists of very shallow soils where rock outcrop occupies 50 to 90 percent of the surface. Rough broken land is made up of very steep and precipitous areas broken by many intermittent drainage channels. Very stony land consists of very shallow soils that have stones covering 30 to 70 percent of the surface.

This soil association is used for grazing, wildlife habitat, and recreation. The carrying capacity for grazing and wildlife is low. The wildlife consists of goats, sheep, pigs, pheasants, and quails. Sheep are common near the summit of Mauna Kea. Goats are in the stony areas.

2. Kekake-Keei-Kiloa association

Very shallow, gently sloping to steep, well-drained organic soils over Aa or pahoehoe lava; on uplands.

This soil association consists of well-drained, very shallow soils that formed in organic matter over pahoehoe lava or fragmental Aa lava. These soils are on mountains at an elevation ranging from near sea level to 7,000 feet. The annual rainfall is 40 inches to more than 150 inches. The mean annual soil temperature is between 47° and 73° F. The natural vegetation consists of ohia, tree fern, koa, guava, and Christmas berry.

The total area of this association is about 21 percent of the island, and most of it is in the Kau, Kona, and Puna Soil and Water Conservation Districts. Kekake soils make up 20 percent of the association, Keei soils 15 percent, Kiloa soils 12 percent, and Kahaluu soils 10 percent. The remaining 43 percent consists of Kaimu, Keaukaha, Kealakekua, Kona, Lalaau, Malama, Mawae, Opihikao, Papai, Puna and Punaluu soils.

Kekake, Keei, Kahaluu, Keaukaha, Kona, Opihikao, and Punaluu soils are 2 to 12 inches deep over pahoehoe lava bedrock. Kekake soils have a black, mucky surface layer and a mean annual soil temperature of about 51° F. Keei soils have a very dark brown, mucky surface layer and a mean annual soil temperature of about 63° F.

Kaimu, Kiloa, Lalaau, Malama, Mawae, Papai, and Puna soils are 2 to 12 inches deep over fragmental Aa lava. Kiloa soils have an extremely stony, mucky surface layer and a mean annual soil temperature of about 65° F.

This association is used for pasture, woodland, watershed, and recreation. In addition, Kiloa, Malama, Papai, and Puna soils are used for macadamia nuts, and some areas of Kaimu and Punaluu soils are used for papaya. The wildlife consists mainly of wild pigs.

3. Hanipoe-Maile-Puu Oo association

Deep, gently sloping to steep, well-drained soils that have a medium-textured to moderately fine textured subsoil; on uplands.

In this soil association are medium-textured to moderately fine textured soils that formed in volcanic ash. These soils have a dark surface layer that is high in content of organic matter. They are on mountains at an elevation ranging from 2,500 to 8,000 feet and receive from 30 to 120 inches of rainfall annually. The mean annual soil temperature is between 54° and 62° F. The natural vegetation consists of ohia, koa, naio, mamane, tree fern, rattail, brome, kikuyugrass, and orchardgrass.

The total area of this association is about 6 percent of the island. Hanipoe soils make up 30 percent of the association, Maile soils 20 percent, and Puu Oo soils 10 percent. The remaining 20 percent consists of Kapapala, Laumaia, Manu, Manahaa, Palapalai, Puhimau, Punohu, and Umikoa soils.

Hanipoe soils are in the Mauna Kea, Kona, and Kau Soil and Water Conservation Districts. These soils have a surface layer of dark reddish-brown to very dark brown silt loam and a subsoil of dark-brown, dark reddish-brown, and very dark brown silt loam. Maile soils are in the Mauna Kea Soil and Water Conservation District. Their surface layer is dark reddish-brown to very dark brown silt loam, and their subsoil is dark-brown to dark yellowish-brown silty clay loam. Puu Oo soils are on the eastern slopes of Mauna Kea. They have a surface layer of dark reddish-brown and very dark gray silt loam and a subsoil of very dark brown to dark reddish-brown silty clay loam.

This association is used for pasture and woodland. It produces some of the finest pasture on the island and has some excellent stands of tree plantings. The soils are favorable for many kinds of vegetables, but most areas are too steep for intensive cultivation and erosion control. The wildlife consists of wild pigs, pheasants, doves, and quails.

4. Amalu-Kahua-Kehena association

Shallow to deep, gently sloping to steep, poorly drained to somewhat poorly drained soils that have a moderately fine textured subsoil; on uplands.

This soil association consists of moderately fine textured soils that formed in volcanic ash. These soils are on the Kohala Mountains at an elevation ranging from near sea level to 5,500 feet. They receive 80 inches to more than 200 inches of rainfall annually. The mean annual soil temperature is between 56° and 75° F. The natural vegetation consists of kikuyugrass, hilograss, sedges, ohia, and guava.

The total area of this association is about 2 percent of the island. Amalu soils make up 62 percent of the association, Kahua soils 24 percent, and Kehena soils about 8 percent. Mixed alluvial land and Tropaquepts make up the rest.

Amalu soils have a layer of partly decomposed moss and other organic matter over a surface layer of dark-gray mucky silt loam. Their subsoil is dark-brown to very dark grayish-brown silty clay loam. An ironstone seam occurs in them at a depth of 15 to 20 inches. Kahua soils have a very dark brown silt loam surface layer and a subsoil of dark-brown to very dark grayish-brown silty clay loam. A thin ironstone seam occurs in these soils at a depth of 8 to 40 inches. Kehena soils have a surface layer of dark-brown silty clay loam and a subsoil of dark-brown to very dark grayish-brown silty clay loam. Mixed alluvial land consists of very stony soil material derived from alluvium that washed from wet soils. Tropaquepts consist of very poorly drained soil material that varies in texture and is shallow over poorly sorted sandy and gravelly alluvium.

Kahua and Kehena soils are used for pasture, woodland, watershed, and wildlife. Amalu soils are used for watershed and wildlife. Tropaquepts are used for growing taro. Forage in this soil association has low nutritional value and very low content of dry matter. The wildlife consists mainly of wild pigs.

5. Kawaihae association

Moderately deep, gently sloping to moderately steep, somewhat excessively drained soils that have a medium-textured subsoil; on coastal plains.

In this association are medium-textured soils that formed in volcanic ash. These soils are on coastal plains at an elevation ranging from near sea level to 1,500 feet. They receive 5 to 20 inches of rainfall annually, and their mean annual soil temperature is between 74^{o} and 77^{o} F. The natural vegetation consists of kiawe, ilima, piligrass, uhaloa, and buffelgrass.

The area of this association is about 1 percent of the island. Kawaihae soils make up most of the association. Included with them are Kamaoa soils, Very stony land, and Rock land. Also included are small areas of the alluvial Kamakoa soils in drainage ditches.

Kawaihae soils have a surface layer of dark reddish-brown, extremely stony, very fine sandy loam. Their subsoil is dark reddish-brown and dusky-red silt loam. Bedrock is at a depth of 20 to 40 inches. Calcium carbonate is encrusted on rocks or is concentrated in a layer in the lower part of the profile.

6. Akaka-Honokaa-Kaiwiki association

Deep, gently sloping to steep, moderately well drained and well drained soils that have a moderately fine textured subsoil; on uplands.

This soil association consists of moderately fine textured soils that formed in volcanic ash. These soils are high in organic-matter content, are very porous, and are continuously wet. They are on mountains at an elevation ranging from near sea level to 6,000 feet. They receive from 80 inches to more than 200 inches of rainfull annually, and their mean annual soil temperature is between 54° and 75° F. Their natural vegetation is ohia, tree fern, koa, and false staghorn fern.

The total area of this association is about 11 percent of the island. Akaka soils make up about 40 percent of the association, the Hydrandept-Tropofolist association 15 percent, Honokaa soils 10 percent, and Kaiwiki soils 10 percent. The remaining 25 percent consists of Alapai, Kilea, Hilo, Honaunau, Kealakekua, Ohia, Olaa, Panaewa, Piihonua, and Puaulu soils.

Akaka soils are in the eastern part of the island between Glenwood and Laupahoehoe. They have a dark reddish-brown silty clay loam surface layer. Their subsoil is reddish-brown to dark reddish-brown silty clay loam. Hydrandept-Tropofolist soils are in the Kau Soil and Water Conservation District. These are deep soils in volcanic ash and shallow, wet, organic soils over fragmental Aa and pahoehoe lava flows. Honokaa soils are in the Honokaa area. They have a dark-brown silty clay loam surface layer and a silty clay loam subsoil that is dark brown, very dark brown, and very dark grayish brown. They have a dark-brown surface layer and a dark-brown and dark reddish-brown silty clay loam subsoil.

The major soils and some of the minor soils of this association are used for sugarcane. The Akaka soils and some of the minor soils are used for woodland, and the Honokaa and Kealakekua soils are used for pasture, truck crops, macadamia nuts, and coffee. Forage in this association has low nutritional value and very low content of dry matter. The potential for ember is high. The wildlife consists of wild pigs.

7. Waimea-Kikoni-Naalehu association

Very deep, nearly level to steep, well-drained soils that have a medium-textured to moderately fine textured subsoil; on uplands.

This association consists of medium-textured to moderately fine textured soils that formed in volcanic ash. These soils have a dark surface layer that is high in content of organic matter. They are on mountains at an elevation ranging from 750 to 6,000 feet. They receive from 25 to 70 inches of rainfall annually, and their mean annual soil temperature is between 66° and 72° F. The natural vegetation consists of bermudagrass, lantana, guava, rattail, kikuyugrass, and whiteclover.

The area of this soil association is about 2 percent of the island. Waimea soils make up 65 percent of the association, Kikoni soils 20 percent, and Naalehu soils 15 percent.

Waimea and Kikoni soils are in the Mauna Kea Soil and Water Conservation District. Waimea soils have a surface layer of very dark brown and dark-brown, very fine sandy loam and loam. Their subsoil is dark-brown silt loam. Kikoni soils have a surface layer of very dark brown very fine sandy loam. Their subsoil is dark-brown and dark reddish-brown very fine sandy loam and silt loam. Naalehu soils are in the Kau Soil and Water Conservation District. These soils have a very dark brown silty clay loam surface layer. The upper part of their subsoil is dark-brown silty clay loam, and the lower part is dark reddish-brown silt loam.

Waimea and Kikoni soils are used for pasture and, in small areas, for truck crops. Naalehu soils are used for sugarcane. The pastures of the Waimea and Kikoni soils provide habitat for pheasants, quails, and doves.

8. Puu Pa-Pakini-Waiaha association

Shallow to deep, nearly level to steep, well-drained to somewhat excessively drained soils that have a medium-textured subsoil or medium-textured underlying material; on uplands.

This soil association consists of moderately coarse textured to moderately fine textured soils that formed in volcanic ash. Most of these soils have a concentration of calcium carbonate that occurs as a soil layer or as coatings on rock fragments. These soils are on mountains and alluvial plains at an elevation ranging from near sea level to 4,000 feet. They receive 20 to 60 inches of rainfall annually and have a mean annual soil temperature that is between 63° and 76° F. The natural vegetation is lantana, natal redtop, Japanese tea, cactus, and kiawe.

The area of this soil association is about 3 percent of the island. Puu Pa soils make up about 60 percent of the association, Pakini soils 10 percent, and Waiaha soils about 10 percent. The remaining 20 percent is made up of Kaalualu, Kainaliu, Kamakoa, Kamaoa, and Waikaloa soils.

Puu Pa soils are in the northwestern part of the island. These soils have a very dark brown extremely stony very fine sandy loam surface layer. Their subsoil is dark-brown and dark yellowish-brown very stony very fine sandy loam. Pakini soils are in the southernmost part of the island. They have a very dark brown and dark-brown very fine sandy loam surface layer. Their subsoil is brown loam that contains an accumulation of calcium carbonate at a depth of 30 to 55 inches. Waiaha soils are mostly in the Kona Soil and Water Conservation District, except for small areas in the Kau district. They have a very dark brown extremely stony silt loam surface layer and a dark-brown very stony silt loam subsoil. These soils are less than 20 inches deep over bedrock.

This association is used mainly for pasture, and the pasture is excellent. Kainaliu soils are used for truck crops, coffee, macadamia nuts, and pasture. The wildlife consists of pheasants, quails, and doves.

9. Kukaiau-Ainakea-Paauhau association

Deep and moderately deep, gently sloping to steep, well-drained soils that have a moderately fine textured subsoil; on uplands.

This soil association consists of moderately fine textured soils that formed in volcanic ash and basic igneous rock. These soils are on mountains at an elevation ranging from near sea level to 2,500 feet. They receive from 50 to 140 inches of rainfall annually, and their mean annual soil temperature is between 66° and 71° F. The natural vegetation consists of bermudagrass, hilograss, molassesgrass, kikuyugrass, guava, and Christmas berry.

The area of this association is about 3 percent of the island. Kukaiau soils make up 25 percent of the association, Ainakea soils 20 percent, and Paauhau soils 18 percent. The remaining 37 percent consists of Honuaulu, Moaula, Niulii, Ookala, and Puukala soils.

Kukaiau and Paauhau soils are between Kukaiau and Kikuihaele. These soils have a very dark grayish-brown silty clay loam surface layer and a dark-brown silty clay loam subsoil. Ainakea soils are in the Mauna Kea Soil and Water Conservation District. They have a dark-brown silty clay loam surface layer and a dark-brown silty clay loam subsoil.

All of these soils, except Honuaulu and Puukala soils, are used for nonirrigated sugarcane. Small areas are used for truck crops, orchards, and pasture. Coffee is grown on the Honuaulu soils. Puukala soils are used for pasture and woodland. The wildlife consists of pheasants and wild pigs.

10. Kohala-Hawi-Mahukona association

Deep, gently sloping to steep, well-drained soils that have a moderately fine textured to fine textured subsoil; on uplands.

In this soil association are fine-textured soils that formed in basic igneous rock and volcanic ash. These soils have a concentration of manganese dioxide in the upper part of the profile. They are on the Kohala Mountains at an elevation ranging from near sea level to 1,500 feet. They receive from 20 to 60 inches of rainfall annually and their mean annual soil temperature is between 72° and 74° F. The natural vegetation consists of guava, lantana, bermudagrass, natal redtop, ilima, and kiawe.

The area of this association is about 1 percent of the island. Kohala soils make up about 45 percent of the association, Hawi soils 40 percent, and Mahukona soils 15 percent.

Kohala soils have a surface layer of very dark grayish-brown and dark-brown silty clay and a subsoil of dark-brown to dark yellowish-brown silty clay. Hawi soils have a very dark grayish-brown silty clay surface layer and a dark-brown to dark yellowish-brown stony silty clay subsoil. Mahukona soils have a dark reddish-brown very stony silty clay loam surface layer and a dark reddish-brown and dusky-red silty clay loam subsoil.

This association is used for irrigated sugarcane and for pasture. Small areas are used for irrigated truck crops and macadamia nuts. The wildlife consists mostly of pheasants, chukar, partridges, and doves.

Ainakea Silty Clay Loam, 12 to 20 percent slopes

This soil is similar to Ainakea silty clay loam, 3 to 12 percent slopes, except that it is moderately steep.

Included in mapping are about 90 acres of cinder cones about 1 mile south of Hawi. These cinder cones have a slope of 50 to 90 percent.

Descriptions of the Soils

This section describes in alphabetical order the soil series and mapping units of the Island of Hawaii. A general description of each series is followed by a technical description of the mapping unit that is representative of the series. This is followed by brief descriptions of the remaining mapping units of the series.

Three kinds of survey were made on the island. A high-intensity survey was made on all cultivated areas; a low-intensity survey was made of all grazing and forested land; and a reconnaissance survey was made on inaccessible areas. The composition of the low-intensity mapping units is more variable than that of the high-intensity units but the survey has been controlled well enough to allow interpretations for the expected uses of the soils.

Following the name of each soil or mapping unit, is a symbol in parentheses. This symbol identifies the soil on the soil map and indicates the intensity of the survey. For a soil within the high-intensity survey, the symbol consists of a combination of capital and lowercase letters (AaC). It includes a number if the soil is eroded. For a soil within the low-intensity survey, the symbol consists of capital letters (AFD). For a soil within the reconnaisance survey, the symbol consists of a lowercase "r" preceeding the capital letters (rAK). Only those areas wherein geothermal potential has been recognized will be given with full description.

Ainakea Series

Akaka Series

Alapai Series

Amalu Series

Apakuie Series

Beaches

Cinder Land

Cinder land (rCL) is a miscellaneous land type consisting of bedded cinders, pumice, and ash. These materials are black, red, yellow, brown, or variegated. The particles have jagged edges and a glassy appearance and show little or no evidence of soil development.

Cinder land commonly supports some grass, but it is not good pasture land because of its loose consistency and poor trafficability. This land is a source of material for surfacing roads (Capability subclass VIIIs, nonirrigated).

Fill Land

Hanipoe Series

Hawi Series (has potential geothermal sites)

The Hawi series consists of well-drained silty clays that formed in basic igneous rocks and were influenced by volcanic ash. These are nearly sea level to moderately sloping soils on uplands. They are at an elevation ranging from near sea level to 1,200 feet and receive 25 to 40 inches of rainfall annually mostly during the winter months. Their mean annual soil temperature is between 72° and 75° F. The natural vegetation consists of lantana, uhaloa, ilima, natal redtop, and bermuda grass. These soils are in the same general area as Kohala and Mahukona soils.

Hawi soils are used for pasture and irrigated sugarcane.

Hawi silty clay, 0 to 3 percent slopes (HaA).— This soil is on the lower parts of the Kohala Mountains.

In a representative profile the surface layer is very dark grayish-brown silty clay about 15 inches thick. The subsoil is very dark grayish-brown to dark yellowish-brown stony silty clay about 53 inches thick. The substratum is soft, weathered basic igneous rock. The surface layer is slightly acid, and the subsoil is neutral. The surface is extremely stony in places.

The hue of the solum ranges from 7.5 YR to 10 YR, and the texture from silty clay to silty clay loam. The structure of the A horizon ranges from moderate to strong granular.

Permeability is moderate, runoff is slow, and the erosion hazard is slight. The available water capacity is about 1.5 inches per foot of soil. Roots can penetrate to a depth of 4 feet or more.

This soil is used for irrigated sugarcane. (Capability class I, irrigated, and capability subclass IIc, nonirrigated; sugar cane group 1; pasture group 3).

Hawi silty clay, 3 to 12 percent slopes (HaC).-- This soil is similar to Hawi silty clay, 0 to 3 percent slopes, except that it is moderately sloping. Runoff is medium, and the erosion hazard is moderate.

This soil is used for irrigated sugarcane and for pasture. (Capability subclass IIIe, irrigated, and IIIe, nonirrigated; sugarcane group 1; pasture group 3).

Hawi extremely stony silty clay, 6 to 12 percent slopes (HeC).-- This soil is similar to Hawi silt loam, 0 to 3 percent slopes, except that stones cover 3 to 15 percent of its surface, and it is moderately sloping. Runoff is medium, and the erosion hazard is moderate.

This soil is used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 3).

Heake Series

Hilea Series

Hilo Series (has potential geothermal sites)

The Hilo series consists of well-drained silty clay loams. These soils formed in a series of Volcanic ash layers that give them a banded appearance. They are gently sloping to steep soils on uplands at an elevation ranging from near sea level to 800 feet. They receive from 120 to 180 inches of rainfall annually, and their mean annual soil temperature is between 72° and 74° F. The natural vegetation consists of hilograss, californiagrass, guava, ohia, and tree fern. These soils are in the same general area as Kaiwiki, Olaa and Ookala soils.

Hilo soils are used for sugarcane, truck crops, orchards and pasture.

Hilo silty clay loam 0 to 10 percent slopes (HoC).-- This soil is low on the windward side of Mauna Kea and is dissected by steep, narrow gulches.

In a representative profile the surface layer is dark-brown silty clay loam about 12 inches thick. The subsoil is about 48 inches thick and consists of dark-brown, dark reddish-brown, and very dark grayish-brown silty clay loam. The surface layer is very strongly acid, and the subsoil is strongly acid to medium acid. This soil dehydrates irreversibly into fine gravel-size aggregates.

Included in mapping are small areas of shallow soils over pahoehoe lava bedrock.

Permeability is rapid, runoff is slow, and the erosion hazard is slight. Roots can penetrate to a depth of 5 feet or more.

This soil is used mostly for sugarcane. Small areas are in truck crops, orchards and pasture. (Capability subclass IIIe, nonirrigated; sugarcane group 2; pasture group 9; woodland group 7)

Hilo silty clay loam, 10 to 20 percent slopes (HoD).-- This soil is similar to Hilo silty clay loam, 0 to 10 percent slopes, but is steeper. Runoff is medium, and the erosion hazard is slight to moderate.

This soil is used for sugarcane. (Capability subclass IVe, nonirrigated; sugarcane group 2; pasture group 9; woodland group 7).

Hilo silty clay loam, 20 to 35 percent slopes (HoE).-- This soil is similar to Hilo silty clay loam, 0 to 10 percent slopes, but it is steeper. Runoff is medium and the erosion hazard is moderate.

Most of this soil is used for sugarcane. Small areas are used for pasture. (Capability subclass VIe, nonirrigated; sugarcane group 2; pasture group 9; woodland group 7).

Honaunau Series

Honokaa Series

Honuaulu Series

Huikau Series

Hydrandept-Tropofolist Association

Kaalualu Series (has possible geothermal sites)

The Kaalualu series consists of well-drained loamy sands that formed in volcanic ash. These are gently sloping to moderately sloping soils in coastal areas at an elevation ranging from near sea level to 1,000 feet. They receive from 20 to 40 inches of rainfall annually, and their mean annual soil temperature is between 73° and 75° F. The natural vegetation consists of lantana, bermudagrass, indigo, and Japanese tea. These soils are in the same general area as Kaimu, Kamaoa, Pakini, and Punaluu soils.

Kaalualu soils are used for pasture.

Kaalualu extremely loamy sand, 2 to 12 percent slopes (KBC).-- This soil is in low coastal areas on Mauna Loa at South Point.

In a representative profile the surface layer is dark-brown cobbly loamy sand and loam about 5 inches thick. The subsoil is dark-brown cobbly silt loam about 19 inches thick. The substratum is fragmental Aa lava. This soil is neutral throughout the profile.

Included in mapping are small areas of Kamaoa and Pakini soils.

Permeability is rapid, runoff is slow, and the erosion hazard is slight. Roots can penetrate to a depth of 20 to 30 inches.

This soil is used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 2)

Kahaluu Series

The Kahaluu series consists of well-drained, thin, organic soils overlying pahoehoe lava bedrock. These soils are moderately sloping to moderately steep. They are on uplands at an elevation ranging from 3,500 to 7,000 feet and receive from 90 to 150 inches of rainfall annually. Their mean annual soil temperature is between 55° and 57° F. The natural vegetation consists of ohia, tree fern, amaumau fern, uluhe fern, and puakeawe. These soils occur with Kealakekua, Keei, Kiloa, Kona, and Lalaau soils.

Kahaluu soils are used for woodland and pasture.

Kahaluu extremely rocky muck, 6 to 20 percent slopes (rKAD).— This soil is at intermediate elevations on Mauna Kea and Mauna Loa. Rock outcrop occupies 30 to 50 percent of the surface area.

In a representative profile the surface layer is very dark brown muck about 5 inches thick. It is underlaid by pahoehoe lava bedrock. This soil is very strongly acid.

Included in mapping are small areas of Rock land.

The soil above the bedrock is rapidly permeable. The bedrock is very slowly permeable, although water moves rapidly through the cracks. Runoff is rapid. Roots extend only to the bedrock or to a depth of a few feet where the bedrock is fractured. There is little or no erosion hazard.

This soil is too shallow and rocky for cultivation. Most of it is in native woodland. A few areas are cleared and used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 10)

Kahua Series

Kaimu Series

Kainaliu Series

Kaiwiki Series

Kamakoa Series

Kamaoa Series

Kapapala Series

Kawaihae Series

The Kawaihae series consists of somewhat excessively drained extremely stony soils that formed in volcanic ash. These soils have a very thin surface layer of fine sandy loam over silt loam and loam. They are gently sloping to moderately sloping soils on coastal plains at an elevation ranging from near sea level to 1,500 feet. The annual rainfall is 5 to 20 inches, most of which falls during the winter months. The mean annual soil temperature is between 74° and 77° F. The natural vegetation consists of kiawe, piligrass, ilima, and fingergrass. These soils and Mahukona, Puu Pa, and Waikaloa soils are in the same general area.

Kawaihae soils are used mainly for pasture, recreation areas, wildlife habitat, and homesites. Small acreages are used for truck crops.

Kawaihae extremely stony very fine sandy loam, 6 to 12 percent slopes (KNC).-- This soil is on the leeward coastal plains of Mauna Kea.

In a representative profile the surface layer is dark reddish-brown extremely stony very fine sandy loam about 2 inches thick. Below this is dark reddish-brown and dusky-red stony silt loam and loam. Hard pahoehoe lava bedrock is at a depth of about 33 inches. The surface layer is neutral, and the subsoil is neutral to mildly alkaline.

The depth to pahoehoe bedrock ranges from 20 to 40 inches. The surface layer ranges from platy to weak, granular in structure and from 2.5 YR to

7.5 YR in hue. The B horizon ranges from silt loam to loam in texture. In some places calcium carbonate has accumulated in the lower part of the profile or is coated on rocks.

Included in mapping are areas that are underlain by fragmental Aa lava. These inclusions comprise 10 to 20 percent of this mapping unit.

Permeability is moderate, runoff is medium, and the erosion hazard is moderate. Roots can penetrate to bedrock.

This soil is used mostly for pasture, wildlife habitat, and recreation areas. Small areas, less than an acre in size, have been cleared of stones and are used for irrigated truck crops. (Capability subclass VIIs, nonirrigated; pasture group 1)

Kawaihae very rocky very fine sandy loam, 6 to 12 percent slopes (KOC).— This soil is similar to Kawaihae extremely stony very fine sandy loam, 6 to 12 percent slopes, except that rock outcrops occupy 10 to 20 percent of the surface.

Included in mapping are severely eroded areas in which small gullies are forming and the vegetation is sparse. These areas make up as much as 10 percent of this mapping unit.

This soil is used for pasture. (Capability subclass VIs, nonirrigated; pasture group 1)

Kealakekua Series

Keei Series

Keekee Series

Kehena Series

Kekake Series

Kikoni Series

Kilauea Series

Kiloa Series

Kilohana Series

Kohala Series

The Kohala series consists of well-drained silty clays that formed in material from basic igneous rock influenced by volcanic ash. These soils are nearly level to steep. They occupy the coastal areas of the Kohala Mountains at an elevation ranging from near sea level to 1,500 feet. They receive from 40 to 60 inches of rainfall annually, and their mean annual soil temperature is between 72° and 74° F. The natural vegetation consists of Koa haole, lantana, guava, and Christmas berry. These soils and Ainakea and Hawi soils are in the same general area.

Kohala soils are used mostly for sugarcane. Small areas are used for pasture, orchards, and truck crops.

Kohala silty clay, 0 to 3 percent slopes (KhA).--This soil is on the windward side of the Kohala Mountains. It is dissected by a few, deep, narrow gulches.

In a representative profile the surface layer is very dark grayish-brown and dark-brown silty clay about 14 inches thick. The subsoil is about 25 inches thick and consists of dark-brown to dark yellowish-brown silty clay loam and silty clay. The substratum is weathered basic igneous rock. The profile is slightly acid in the surface layer, slightly acid and neutral in the subsoil, and neutral in the substratum.

The depth to weathering basalt is more than 36 inches. The hue of the solum ranges from 7.5 YR to 10 YR. In the A horizon effervescence with hydrogen peroxide ranges from moderate to strong.

Kona Series

Kukaiau Series

Lalaau Series

Laumaia Series

Lava Flows, Aa (have possible geothermal site)

Lava flows, Aa (rLV), has been mapped as a miscellaneous land type. This lava has practically no soil covering and is bare of vegetation, except for mosses, lichens, ferns, and a few small ohia trees. It is at an elevation ranging from near sea level to 13,000 feet and receives from 10 to 250 inches of rainfall annually. It is associated with pahoehoe lava flows and many soils.

This lava is rough and broken. It is a mass of clinkery, hard, glassy, sharp pieces piled in tumbled heaps. In areas of high rainfall, it contributes substantially to the underground water supply and is used for watershed. (Capability subclass VIIIs, nonirrigated)

Lava Flows, Pahoehoe

Lava flows, pahoehoe (rLW), has been mapped as a miscellaneous land type. This lava has a billowy, glassy surface that is relatively smooth. In some areas, however, the surface is rough and broken, and there are hummocks and pressure domes.

Pahoehoe lava has no soil covering and is typically bare of vegetation except for mosses and lichens. In the areas of higher rainfall, however, scattered ohia trees, ohelo berry, and aalii have gained a foothold in cracks and crevices.

This miscellaneous land type is at an elevation from sea level to 13,000 feet. The annual rainfall ranges from 10 inches to more than 140 inches.

Some flat slabs of pahoehoe lava are used as facings on buildings and fireplaces. In areas of higher rainfall, this lava contributes to the ground-water supply. (Capability subclass VIIIs, nonirrigated)

Mahukona Series

The Mahukona series consists of well-drained silty clay loams that formed in volcanic ash and basalt residuum. These are undulating to rolling soils that occupy leeward coastal areas of the Kohala Mountains. They are at an elevation ranging from near sea level to 550 feet and receive from 20 to 30 inches of rainfall annually. Their mean annual soil temperature is between 72° and 75° F. The natural vegetation consists of kiawe, uhaloa, ilima, swollen fingergrass, and bermudagrass. These soils and Hawi, Kawaihae, and Puu Pa soils are in the same general area.

Mahukona soils are used for pasture and irrigated sugarcane.

Mahukona very stony silty clay loam, 6 to 12 percent slopes (MKC).— This soil occupies coastal areas on the Kohala Mountains. The slope is dominantly 10 percent.

In a representative profile the surface layer is dark reddish-brown very stony silty clay loam about 6 inches thick. The subsoil is dark reddish-brown and dusky-red silty clay loam about 30 inches thick. The substratum is hard saprolite. The surface layer is medium acid. The subsoil is slightly acid to neutral.

The depth to saprolite is 32 to 42 inches. In places the A horizon has a weak, platy structure. The hue of the A horizon ranges from 5 YR to 7.5 YR.

Included in mapping are shallow soils in drainageways.

Permeability is moderate, runoff is medium, and the erosion hazard is moderate. The available water capacity is about 1.5 inches per foot of soil. Roots can penetrate to a depth of 3 feet or more.

This soil is used for pasture. (Capability subclass VIs, nonirrigated; pasture group 2)

Mahukona silty clay loam, 3 to 12 percent slopes (MHC).-- This soil is similar to Mahukona very stony silty clay loam, 6 to 12 percent slopes, except that it is nonstony. It is used for irrigated sugarcane and pasture. (Capability subclass IIIe, irrigated, and IIIe, nonirrigated; sugarcane group 1; pasture group 2)

Maile Series

The Maile series consists of well-drained silt loams that formed in volcanic ash. These are nearly level to moderately steep soils on uplands. They are at an elevation ranging from 2,500 to 4,000 feet and receive from 60 to 90 inches of rainfall annually. Their mean annual soil temperature is between 57° and 60° F. The natural vegetation consists of ohia, tree fern, alapaio fern, kikuyugrass, and white clover. These soils and Honokaa, Kahua, Kikoni, Palapalai, Puu Oo, and Umikoa soils are in the same general area.

Maile soils are used for pasture and woodland.

Maile silt loam, 6 to 20 percent slopes (MLD).-- This soil is at intermediate elevations on the windward side of Mauna Kea. It has a dominant slope of about 15 percent.

A representative profile has a surface layer of dark reddish-brown to very dark brown silt loam about 14 inches thick. The subsoil is about 46 inches thick. It consists of dark yellowish-brown and very dark brown silty clay loam. The subsoil dehydrates irreversibly into fine sand-size aggregates. The profile grades from medium acid in the surface layer to slightly acid and neutral in the subsoil.

The A horizon has a chroma and value of 2 or 3 when moist. The B horizon has a hue of 5 YR to 10 YR and weak to strong, subangular blocky structure. Thin bands of hard ash occur erratically throughout the solum. The B horizon dehydrates irreversibly into dark-brown or black, very hard aggregates the size of sand and silt.

Included with this soil in mapping are small, steep drainageways and gullies.

Permeability is moderately rapid, runoff is slow, and the erosion hazard is slight. Roots can penetrate to a depth of 5 feet or more.

This soil is used for pasture and woodland. (Capability subclass IVe, nonirrigated; pasture group 11, woodland group 8)

Maile silt loam, 0 to 3 percent slopes (MaA).-- This soil is similar to Maile silt loam, 6 to 20 percent slopes, except that it is nearly level. Runoff is very slow, and the erosion hazard is none to slight. This soil is used for truck crops and pasture. (Capability class I, nonirrigated; pasture group 11; woodland group 8)

Malama Series

The Malama series consists of well-drained, thin extremely stony organic soils over Aa lava. These soils are undulating to rolling. They are on mountains at an elevation ranging from near sea level to 1,000 feet, and receive from 60 to 90 inches of rainfall annually. Their mean annual soil temperature is between 72° and 74° F. The natural vegetation consists of guava, waiwe, mango, hala, noni apple, and ohia. These soils and Keei, Opihikao, Puna, and Punaluu soils are in the same general area.

Malama soils are used for woodland, pasture, and orchards.

Malama extremely stony muck, 3 to 15 percent slopes (rMAD).-- This soil overlies relatively young Aa lava flows on the windward side of Kilauea Crater.

In a representative profile the surface layer is very dark brown extremely stony muck about 3 inches thick. It is underlain by fragmental Aa lava. This soil is strongly acid.

The depth of fragmental Aa lava ranges from 2 to 8 inches. The hue of the 02 horizon ranges from 7.5 YR to 10 YR.

Included in mapping are small areas of Opihikao soils.

Permeability is rapid, runoff is very slow, and the erosion hazard is slight. Roots can extend to a depth of 24 inches into cracks of the lava.

This soil is used for woodland, pasture, and orchards. (Capability subclass VIIs, nonirrigated; pasture group 7; woodland group 13)

Manahaa Series

Manu Series

The Manu series consists of well-drained silt loams that formed in volcanic ash, cinders, and pumice. These soils are nearly level to gently sloping. They are on uplands at an elevation ranging from 3,000 to 4,000 feet and receive from 80 to 120 inches of rainfall annually. Their mean annual soil temperature is between 58^{o} and 62^{o} F. The natural vegetation consists of ohia, tree fern, amaumau fern, and rattail. These soils and Heake, Kilauea, Kona, Puaulu, and Puhimau soils are in the same general area.

Manu soils are used mostly for woodland. Small areas are used for pasture and truck crops.

Manu silt loam, 2 to 6 percent slopes (rMUB).-- This soil is at intermediate elevations on the windward side of Mauna Loa in the Volcano area.

In a representative profile the surface layer is very dark brown silt loam about 3 inches thick over about 5 inches of very dark grayish-brown fine sandy loam. It is underlain by stratified layers of very dark grayish-brown coarse sand, fine sandy loam, and loamy fine sand and dark yellowish-brown pumice. Hard pahoehoe lava bedrock is at a depth of about 36 inches. The profile grades from medium acid in the surface layer to neutral in the lower part of the subsoil.

The depth of pahoehoe lava bedrock ranges from 27 to 47 inches. The A11 horizon is 3 to 5 inches thick and ranges from 7.5 YR to 10 YR in hue.

Included in mapping are small areas of Puhimau soils.

Permeability is rapid, runoff is slow, and the erosion hazard is slight. Roots can penetrate to the pahoehoe lava bedrock.

Most of this soil is in native forest. A small acreage is used for truck crops and pasture. (Capability subclass IIe, nonirrigated; pasture group 9; woodland group 7)

Mawae Series

Mixed Alluvial Land

Mixed alluvial land (MT) is a miscellaneous land type consisting of recent stream deposition that varies widely in texture. This land is in the Waipio, Pololu, and Waimanu Valleys. It is on bottoms at the mouth of the valleys and is subject to frequent flooding. The surface is littered with stones and boulders.

Mixed alluvial land is at an elevation ranging from sea level to 500 feet and receives from 50 to 100 inches of rainfall annually. The mean annual soil temperature is about 73° F. The vegetation consists of hilograss, guava, honohonograss, and monkey pod.

Included with this land in mapping are areas of talus material along the base of the steep valley sides. It consists of rock debris and soil material.

Mixed alluvial land is used for grazing and for wildlife habitat. (Capability subclass VIs, nonirrigated; pasture group 7; woodland group 5)

Naalehu Series

Niulii Series

Ohia Series

Olaa Series

Ookala Series

Opihikao Series

The Opihikao series consists of well-drained, thin organic soils over pahoehoe lava bedrock. These soils are gently sloping to moderately steep. They are on uplands at an elevation ranging from near sea level to 1,000 feet and receive from 60 to 90 inches of rainfall annually. Their mean annual soil temperature is between 72° and 73° F. The natural vegetation consists of guava, waiwe, and ohia. These soils and Keei, Kona, Malama, Papai, and Puna soils are in the same general area.

Opihikao soils are in native forest or are used for pasture.

Opihikao extremely rocky muck, 3 to 25 percent slopes (rOPE).-- This soils is in the Puna district. Rock outcrops occupy 30 to 50 percent of the area.

In a representative profile the surface layer is very dark brown muck about 3 inches thick. It is underlain by pahoehoe lava bedrock. The muck is strongly acid.

The depth to pahoehoe lava bedrock is 2 to 5 inches. The hue of the 02 horizon ranges from 7.5 YR to 10 YR.

The muck is rapidly permeable. The lava is very slowly permeable, but water moves rapidly through the cracks. Runoff is slow, and the erosion hazard is slight. Roots are matted over the pahoehoe lava, but they can penetrate the cracks to a depth of 2 feet.

This soil is in native forest or is used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 7)

Paauhau Series

Pakini Series

Palapalai Series

Panaewa Series

Papai Series

The Papai series consists of well-drained, thin, extremely stony organic soils over fragmental Aa lava. These soils are gently sloping to moderately steep. They are on uplands at an elevation ranging from near sea level to 1,000 feet and receive from 90 inches to more than 150 inches of rainfall annually. Their soil temperature is between 72° and 74° F. The natural vegetation consists of ohia, tree fern, uluhe fern, and guava. These soils and Keaukaha, Kiloa, Olaa, Opihikao, and Panaewa soils are in the same general area.

Papai soils are used mostly for woodland. Small areas are used for pasture, orchards, and truck crops.

Papai extremely stony muck, 3 to 25 percent slopes (rPAE).-- This soil is low on the windward side of Mauna Kea.

In a representative profile the surface layer is very dark brown extremely stony muck about 8 inches thick. It is underlain by fragmental Aa lava. This soil is slightly acid.

The depth to fragmental Aa lava ranges from 3 to 12 inches. The hue of the surface layer ranges from 7.5 YR to 10 YR.

Permeability is rapid, runoff is slow, and the erosion hazard is slight. (Capability subclass VIIs, nonirrigated; pasture group 9; woodland group 13)

Piihonua Series

Puaulu Series

Puhimau Series

Puna Series

The Puna series consists of well-drained, thin, extremely stony organic soils over fragmental Aa lava. These soils are gently sloping to moderately steep. They are on uplands at an elevation ranging from 1,000 to 3,500 feet and receive from 60 to 90 inches of rainfall annually. Their mean annual soil temperature is 63° F. The natural vegetation consists of ohia, guava, Christmas berry, and alapaio fern. These soils and Kona, Malama, and Opihikao soils are in the same general area.

Puna soils are used for woodland, pasture, and orchards.

Puna extremely stony muck, 3 to 25 percent slopes (rPXE).— This soil is at intermediate elevations on Mauna Loa and Hualalai.

In a representative profile the surface layer is very dark brown extremely stony muck about 5 inches thick. It is underlain by fragmental Aa lava. This soil is neutral in reaction.

The depth to fragmental Aa lava is 2 to 6 inches.

Permeability is rapid, runoff is slow, and the erosion hazard is slight. Roots are matted in the surface layer, but some roots extend to a depth of 20 inches into the cracks in the lava.

This soil is used for woodland, pasture, and orchards. (Capability subclass VIIs, nonirrigated; pasture group 7; woodland group 13)

Punaluu Series

The Punaluu series consists of well-drained, thin organic soils over pahoehoe lava bedrock. These soils are gently sloping to moderately steep. They are on uplands at an elevation ranging from near sea level to 1,000 feet and receive from 60 to 90 inches of rainfall annually. The mean annual soil temperature is between 72° and 74° F. The natural vegetation consists of koa haole, Christmas berry, guineagrass, natal redtop, and sand bur. These soils and Kaalualu, Kaimu, Kainaliu, Malama, Pakini, and Waiaha soils are in the same general area.

Punaluu soils are used for pasture.

Punaluu extremely rocky peat, 6 to 20 percent slopes (rPYD).-- This soil is low on the leeward side of Mauna Loa. Rock outcrops occupy 40 to 50 percent of the surface.

In a representative profile the surface layer is black peat about 4 inches thick. It is underlain by pahoehoe lava bedrock. This soil is medium acid.

The 02 horizon ranges from 3 to 8 inches in thickness and from 5 YR to 10 YR in hue.

The peat is rapidly permeable. The pahoehoe lava is very slowly permeable, although water moves rapidly through the cracks. Runoff is slow, and the erosion hazard is slight. Roots are matted over the pahoehoe lava.

This soil is used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 3)

Punohu Series

Puukala Series

Puu Oo Series

Puu Pa Series

The Puu Pa series consists of well-drained stony very fine sandy loams that formed in volcanic ash. These soils are gently sloping to extremely steep, and most areas are extremely stony. They are on uplands at an elevation ranging from 1,000 to 2,500 feet and receive from 20 to 35 inches of rainfall annually. Their mean annual soil temperature is between 69° and 71° F. The natural vegetation consists of bermudagrass, swollen fingergrass, lantana, ilima, and cactus. These soils and Kamakoa, Kawaihae, Mahukona, Waikaloa, and Waimea soils are in the same general area.

Puu Pa soils are used for pasture.

Puu Pa extremely stony very fine sandy loam, 6 to 20 percent slopes (PVD).— This soil is low on the leeward side of Hualalai, Mauna Kea, and the Kohala Mountains.

In a representative profile the surface layer is very dark brown extremely stony very fine sandy loam about 6 inches thick. The next layer is dark-brown and dark yellowish-brown very stony very fine sandy loam about 34 inches thick. It is underlain by fragmental Aa lava. The reaction is medium acid to slightly acid in the surface layer and neutral in the substratum. In places the surface layer is silt loam.

The depth to fragmental Aa lava ranges from 20 inches to more than 40 inches. The depth to soft podery lime ranges from 20 to 40 inches. In some places this lime encrusts the gravel and stones. The A horizon has a value of 2 or 3 and a hue of 10 YR to 5 YR. Below the A horizon, the chroma and value range from 2 to 4.

Included in mapping near Puuwaawaa Hill are small, nonstony areas. Also included are cinder cones.

Permeability is moderately rapid, runoff is medium, and the erosion hazard is moderate. Roots penetrate to the fragemental Aa lava.

This soil is used for pasture. (Capability subclass VIIs, nonirrigated; pasture group 2)

Puu Pa extremely stony very fine sandy loam, 70 to 100 percent slopes, severely eroded (PVF3).— This soil is near the Puuwaawaa Ranch. The average slope is about 90 percent. This soil is so severely eroded that in most areas only a thin soil layer is left over weathering trachyte. The hazard of further erosion is very severe. Runoff is very rapid.

This soil is used for wildlife habitat and watershed. (Capability subclass VIIIs, nonirrigated)

Puu Pa silt loam, 12 to 20 percent slopes (PWD).-- This soil is near Puuwaawaa Ranch. The dominant slope is about 13 percent. The depth to weathering trachyte is more than 48 inches. Runoff is medium, and the hazard of erosion is moderate.

This soil is used for pasture. (Capability subclass IVs, nonirrigated; pasture group 2)

Rock Land

Rough Broken Land

Tropaquepts

Umikoa Series

Very Stony Land

Waiaha Series

The Waiaha series consists of shallow, well-drained silt loams that formed in volcanic ash. These soils are nearly level to moderately steep and most areas are extremely stony. They are on uplands at an elevation ranging from near sea level to 1,000 feet. They receive from 20 to 40 inches of rainfall annually, most of which falls during the summer months, except in the Pahala area. The mean annual soil temperature is between 72^{o} and 74^{o} F. The natural vegetation consists of kiawe, koa haole, natal redtop, lantana, guineagrass, and bermudagrass. These soils and Kaimu, Kainaliu, and Punaluu soils are in the same general area.

Waiaha soils are used for pasture.

Waiaha extremely stony silt loam, 6 to 12 percent slopes (WHC).-- This soil is low on the leeward side of Hualalai and Mauna Loa.

In a representative profile the surface layer is very dark brown extremely stony silt loam about 4 inches thick. The subsoil is dark-brown very stony silt loam about 14 inches thick. The substratum is pahoehoe lava bedrock. The surface layer is slightly acid. The subsoil is neutral to mildly alkaline. In places the surface layer is nonstony.

The depth to underlying pahoehoe lava bedrock ranges from 15 to 20 inches. The structure of the A horizon ranges from weak to moderate. Near sea level, calcium carbonate encrusts the rocks or extends into the cracks of the bedrock.

Waikaloa Series

Waimea Series

GLOSSARY

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates such as crumbs, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging. See structure.

Available water capacity (also termed available moisture capacity). The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil.

Base saturation. The degree to which material that has base-exchange properties is saturated with exchangeable cations other than hydrogen, expressed as a percentage of the cation-exchange capacity.

Bulk density. The mass of dry soil per unit of bulk volume. Bulk volume is determined before drying to constant weight at 105 degrees centigrade. A unit of measure, usually grams per cubic centimeter or pounds per square foot.

Cation exchange capacity. The sum total of exchangeable cations that a soil can adsorb, expressed in milliequivalents per 100 grams of soil or of other adsorbing material, such as clay.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Consistence, soil. The feel of the soil and the ease with which a lump can be crushed by the fingers. Terms commonly used to describe consistence are:

Loose.--Noncoherent when dry or moist; does not hold together in a mass.

Friable.--When moist, crushed easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.

Firm.--When moist, crushed under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

Plastic.--When wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.

Sticky.--When wet, adheres to other material, and tends to stretch somewhat and pull apart, rather than to pull free from other material.

Hard.--When dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.

Weakly smeary.--When strong pressure is applied, soil material exhibits only weak thixotropic properties as evidenced by changing suddenly to fluid; the fingers "skid," and the soil smears. After the soil smears there is little or no evidence of free water on the fingers.

Moderately smeary.--Under moderate to strong pressure, soil material changes suddenly to fluid; the fingers "skid," and the soil smears and is slippery. After the soil smears, there is evidence of free water on the fingers.

Strongly smeary.--Under moderate pressure the soil material changes suddenly to fluid; the fingers "skid," and the soil smears and is very slippery. After the soil smears, free water is easily seen on the fingers.

Drainage, surface. Runoff, or surface flow, of water from an area.

Erosion. The wearing away of the land surface by wind (soil blowing), running water, and other geological agents.

Flood plain. Nearly level land, consisting of stream sediments, that borders a stream and is subject to flooding unless protected artificially.

Horizon, soil. A layer of soil, approximately parallel to the surface, that has distinct characteristics produced by soil-forming processes. These are the major horizons:

O horizon.--The layer of organic matter on the surface of a mineral soil. This layer consists of decaying plant residue.

A horizon.--The mineral horizon at the surface or just below an O horizon. This horizon is the one in which living organisms are most active and therefore is marked by the accumulation of humus. The horizon may have lost one or more of soluble salts, clay, and sesquioxides (iron and aluminum oxides).

B horizon.--The mineral horizon below an A horizon. The B horizon is in part a layer of change from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics caused (1) by accumulation of clay, sesquioxides, humus, or some combination of these; (2) by prismatic or blocky structure; (3) by redder or stronger colors than the A horizon; or (4) by some combination of these. Combined A and B horizons are usually called the solum, or true soil. If a soil lacks a B horizon, the A horizon alone is the solum.

C horizon.--The weathered rock material immediately beneath the solum. In most soils this material is presumed to be like that from which the overlying horizons formed. If the material is known to be different from that in the solum, a Roman numeral precedes the letter C.

R horizon. Consolidated rock beneath the soil. The rock usually underlies a C horizon but may be immediately beneath an A or B horizon.

Igneous rock. Rock that has been formed by the cooling of molten mineral material. Examples: Granite, syenite, diorite, and gabbro.

Mottles. Irregular markings of different colors that vary in number and size. Mottling in soils usually indicates poor aeration and drainage. Descriptive terms are: Abundance--few, common, and many; size--fine, medium, and coarse; and contrast—faint, distinct, and prominent.

Parent material. The disintegrated and partly weathered rock from which soil has formed.

Permeability. The quality of a soil horizon that enables water or air to move through it. Terms used to describe permeability are as follows: very slow, slow, moderately slow, moderate, moderately rapid, rapid and very rapid.

Plinthite. The sesquioxide-rich, humus-poor, highly weathered mixture of clay with quartz and other dilutants that commonly shows as red mottles, usually in platy, polygonal, or reticulate patterns. Plinthite changes irreversibly to hardpan or to irregular aggregates on repeated wetting and drying or it is the hardened relicts of the soft, red mottles. It is a form of the material that has been called laterite.

Profile, soil. A vertical section of the soil through all its horizons and extending into the parent material.

Reaction, soil. The degree of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is precisely neutral in reaction because it is neither acid nor alkaline. The degrees of acidity or alkalinity are expressed thus:

	pH		pH
Extremely acid	Below 4.5	Mildly alkaline	7.4 to 7.8
Very strongly acid	4.5 to 5.0	Moderately alkaline	7.9 to 8.4
Strongly acid	5.1 to 5.5	Strongly alkaline	8.5 to 9.0
Medium acid	5.6 to 6.0	Very strongly alkaline	9.1 and higher
Slightly acid	6.1 to 6.5		
Neutral	6.6 to 7.3		

Residual material. Unconsolidated partly weathered mineral material that accumulates over disintegrating solid rock. Residual material is not soil but is frequently the material in which a soil has formed.

Runoff (hydraulics). The part of the precipitation upon a drainage area that is discharged from the area in stream channels. The water that flows off the land surface without sinking in is called surface runoff; that which enters the ground before reaching surface streams is called ground-water runoff or seepage flow from ground water.

Sand. Individual rock or mineral fragments in soils having diameters ranging from 0.05 to 2.0 millimeters. Most sand grains consist of quartz, but they may be of any mineral composition. The textural class name of any soil that contains 85 percent or more sand and not more than 10 percent clay.

Silt. Individual mineral particles in a soil that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). Soil of the silt textural class is 80 percent or more silt and less than 12 percent clay.

Soil. A natural, three-dimensional body on the earth's surface that supports plants and that has properties resulting from the integrated effect of climate and living matter acting on parent material, as conditioned by relief over periods of time.

Solum. The upper part of a soil profile, above the parent material, in which the processes of soil formation are active. The solum in mature soil includes the A and B horizons. Generally, the characteristics of the material in these horizons are unlike those of the underlying material. The living roots and other plant and animal life characteristic of the soil are largely confined to the solum.

Structure, soil. The arrangement of primary soil particles into compound particles of clusters that are separated from adjoining aggregates and have properties unlike those of an equal mass of unaggregated primary soil particles. The principal forms of soil structure are: platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are (1) single grain (each grain by itself, as in dune sand) or (2) massive (the particles adhering together without any regular cleavage, as in many claypans and hardpans).

Subsoil. Technically, the B horizon; roughly, the part of the solum below plow depth.

Substratum. Technically, the part of the soil below the solum.

Surface soil. The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, about 5 to 8 inches in thickness. The plowed layer.

Terrace (geological). An old alluvial plain, ordinarily flat or undulating, bordering a river, lake, or the sea. Stream terraces are frequently called second bottoms, as contrasted to flood plains, and are seldom subject to overflow. Marine terraces were deposited by the sea and are generally wide.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The sand, loamy sand, and sandy loam classes may be further divided by specifying "coarse," "fine," or "very fine."

Water table. The highest part of the soil or underlying rock material that is wholly saturated with water. In some places, an upper, or perched, water table may be separated from a lower one by a dry zone.

A 2 Land Use Patterns and Ratings*

Use and Management of the Soils

Soils are used for the production of plants and support of animals and as structural material for engineering purposes. Thus, this section has two main parts - management of soils for farming and related uses, which include woodland and wildlife habitat, and management of soils for the construction of highways, the support of buildings, and other engineering uses.

Farming and related uses

This section discusses the suitability and management of the soils for crops and pasture, for woodland, and for wildlife habitat.

Management groups

For convenience in planning the management of soils, they are placed in management groups according to their suitability for specific uses. One grouping described in this section is the capability system used by the Soil Conservation Service (21). This system is adapted to soils throughout the country to show their suitability for most kinds of crops. Other groupings described are those for sugarcane, pasture, and woodland and for wildlife habitat. These groupings are adapted to the specialized uses of the soils of the island. In the description of each group the soil features that affect management are given, as well as estimated yields and suggested practices. Only the soils suited to these specific uses have been placed in these groups. Some of the stony soils and the land types, for example, have not been placed in the sugarcane groups because they are unsuited or are too variable.

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* As for Part IIA1, pp. 150-203.

Crops and pasture

Many factors affect the use of soils for crops and pasture. Some important factors are temperature, relief, drainage, depth of soil, stoniness, availability of water, amount of solar insolation, and accessibility and suitability for use of mechanized equipment. These factors are reflected in the grouping of the soils and in the management suggested. Management refers to such practices as soil preparation, selection of crops, application of fertilizer, use of crop residue, and control of soil and water loss. Practices vary, but generally a high level of management is practiced in Hawaii.

Capability grouping

Capability grouping shows, in a general way, the suitability of soils for most kinds of field crops. The groups are made according to the limitations of the soils when used for field crops, the risk of damage when they are used, and the way they respond to treatment. The grouping does not take into account major and generally expensive landforming such as change slope, depth, or other characteristics of the soils; does not take into consideration possible but unlikely major reclamation projects; and does not apply to special management crops such as rice, cranberries, horticultural crops, or others.

Those familiar with the capability classification can infer from it much about the behavior of soils when used for other purposes, but this classification is not a substitute for interpretations designed to show suitability and limitations of groups of soils for range, for forest trees, or engineering.

Soils are grouped at two levels, the capability class, and the subclass. The classification is designated in the "Guide to Mapping

Units" for all soils on the island, both irrigated and nonirrigated soils. The classification is described in the following pages.

CAPABILITY CLASSES, the broadest groups, are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use, defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.

Class III soils have severe limitations that reduce the choice of plants, require special conservation practices, or both.

Class IV soils have very severe limitations that reduce the choice of plants, require very careful management, or both.

Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use largely to pasture, range, woodland, or wildlife.

Class VI soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland or wildlife.

Class VII soils have very severe limitations that make them unsuited to cultivation and that restrict their use largely to pasture or range, woodland, or wildlife.

Class VIII soils and landforms have limitations that preclude their use for commercial plants and restrict their use to recreation, wildlife, or water supply, or to esthetic purposes.

CAPABILITY SUBCLASSES are soil groups within one class; they are designated by adding a small letter, e, w, s, or c, to the class numeral, for example, IIe. The letter e shows that the main limitation is risk of erosion unless close-growing plant cover is maintained; w shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); s shows that the soil is limited mainly because it is shallow, droughty, or stony; and c, used in only some parts of the United States, shows that the chief limitation is climate that is too cold or too dry.

In class I there are no subclasses, because the soils of this class have few limitations. Class V can contain, at the most, only the subclasses indicated by w, s, and c, because the soils in class V are subject to little or no erosion, though they have other limitations that restrict their use largely to pasture, range, woodland, wildlife, or recreation.

Sugarcane

Sugarcane is the principal crop on the Island of Hawaii. It is grown on the windward slopes of Mauna Kea and the Kohala Mountains and on the southern slopes of Mauna Loa. Sugarcane generally is not irrigated, except for the acreage on the Kohala, Honokaa, and Paauhau soils at low elevations where the rainfall is relatively low and solar insolation is high.

Sugarcane is harvested every 20 to 36 months, depending on the variety of cane and the climate. Replanting generally is not necessary, because after the cane is harvested the root system sends up new sprouts, or shoots, to produce the next crop. Replanting is common, however, to introduce a new variety, alter the irrigation or field layout, relieve undue compaction of the soil, or change the cropping system.

The sugarcane industry is highly mechanized. The use of heavy equipment permits the production of sugarcane in some areas that otherwise would be considered unsuited for cultivation.

The present method of harvesting sugarcane consists of burning the cane fields to remove excess leaves. Immediately after burning, a mechanical push rake pushes the cane stalks into piles. Large cranes load the stalks into trucks that transport the cane to the mill. These operations disturb the soil and increase the erosion hazard, but the hazard can be minimized by harvesting the crop during periods of low rainfall and by allowing time for regrowth of the crop before periods of high rainfall. Soil erosion can be controlled by constructing grassed waterways, irrigating and planting on the contour, lining ditches and canals, and using diversion ditches.

To establish a new planting of sugarcane, the fields are smoothed, subsoiled, or disk-plowed, and harrowed. If the field is to be irrigated, the irrigation, drainage, and road systems are installed. Terraces, diversions, grassed waterways and roads are installed in non-irrigated areas. After these operations are completed, the seed stalk is planted by machine or by hand. The stalk is planted in the bottom of a machine-opened furrow and covered with a few inches of soil. The furrows are laid out on the contour to minimize erosion. After harvest the common practice is to reshape and repair the furrows, terraces, diversions, roads, waterways, and ditches.

Fertilizer is applied by hand, machine, or airplane or in irrigation water. The soils respond readily to applications of nitrogen, phosphorus, and potassium. Lime is needed on some soils. The kind and amounts of fertilizer are best determined by soil tests, tissue analysis, field trials, and experience.

Insecticides are applied as needed to control insects. Weeds are controlled by herbicides and hand weeding.

Sugarcane Group 1

This group consists of well-drained to somewhat excessively drained silty clay loams and silty clays that have a slope of 0 to 35 percent. These soils have moderate to moderately rapid permeability, slow to rapid runoff, and a slight to severe hazard of erosion. They hold about 1.5 to 1.8 inches of water available per foot of soil. Their rooting depth is 36 to 60 inches or more. They receive 20 to 80 inches of rainfall annually. The amount of solar insolation is high. The mean annual soil temperature is 72° F. or more.

Those soils are irrigated by sprinkler systems or by furrows from ditches or aluminum and concrete flumes. The furrows have a gradient of 0.5 to 1.5 percent. The field layout and tillage practices are across the slope, nearly on the contour. Diversions and secondary field roads are also across the slope and serve to remove runoff water. Young cane is alternated with old cane in strips. The width of the strips and the spacing of diversions are determined by the kind of soil, the length and gradient of slope, and the intensity and frequency of rainfall.

On soils that have a slope greater than 20 percent, special equipment and special land preparation, planting, and harvesting are required to minimize field damage and soil and water losses.

Yields are 8 to 12 tons per acre per crop.

Sugarcane Group 2

This group consists of well-drained silty clay loams that have a slope of 0 to 35 percent. These soils have moderately rapid to rapid permeability, slow to rapid runoff, and a slight to severe erosion hazard. Their rooting depth is 10 to 60 inches or more.

They receive 35 to 180 inches of rainfall annually, and the soils in the lower rainfall areas become droughty during the summer. The total solar insolation is relatively high. The mean annual soil temperature is 72° F. or more.

These soils are not irrigated. The field layout and tillage practices are across the slope, nearly on the contour. The diversions and secondary field roads are also across the slope and serve to remove runoff water. Young cane is alternated with old cane in strips. The width of the strips and the spacing of diversions are determined by the kind of soil, the length and gradient of the slope, and the intensity and frequency of rainfall.

On soils that have a slope greater than 20 percent, special equipment and special land preparation, planting, and harvesting are required to minimize field damage and soil and water losses.

Yields are 7 to 11 tons of sugar per acre per crop.

Sugarcane Group 3

This group consists of well-drained silty clay loams that have a slope of 0 to 35 percent. Some of these soils dehydrate irreversibly into fine sand-size aggregates. Permeability is moderately rapid to rapid, runoff is slow to rapid, and the erosion hazard is slight to severe. The rooting depth is 30 to 60 inches or more. The annual rainfall is 60 to 100 inches. The amount of solar insolation is relatively low, and the mean annual soil temperature is between 68° and 71° F.

These soils are not irrigated. The field layout and tillage practices are across the slope, nearly on the contour. Diversions and secondary field roads are also across the slope and serve to remove runoff water. Young cane is alternated with old cane in strips. The width of the strips and the spacing of diversions are determined by the kind of soil, the length and gradient of the slope, and the intensity and frequency of rainfall.

On soils that have a slope greater than 20 percent, special equipment and special land preparation, planting, and harvesting methods are required to minimize field damage and soil and water losses.

Yields are 6 to 9 tons of sugar per acre per crop.

Sugarcane Group 4

This group consists of moderately well drained to well drained silty clay loams that have a slope of 0 to 35 percent. Some of these soils dehydrate irreversibly into very hard, fine gravel-size aggregates. Trafficability is poor. Permeability is rapid, runoff is slow to rapid, and the erosion hazard is slight to severe. The rooting depth is 10 to 60 inches or more. The annual rainfall is 80 to 300 inches or more. The amount of solar insolation is low, and the mean annual soil temperature is between 56° and 70° F.

These soils receive more than adequate rainfall to produce sugarcane without irrigation. The field layout and tillage practices are across the slope, nearly on the contour. Young cane is alternated with old cane in strips. Diversions and secondary field roads are also across the slope and serve to remove runoff water. The width of the strips and the spacing of the diversions are determined by the kind of soil, the length and gradient of slope, and the intensity and frequency of rainfall. Harvesting is scheduled during the dry months to minimize field damage and to allow the regrowth of sugarcane before the wetter season begins.

On soils that have a slope greater than 20 percent, special equipment and special land preparation, planting, and harvesting are required to minimize field damage and soil and water losses.

Yields are 6 to 9 tons of sugar per acre per crop.

DIVERSIFIED CROPS

Truck crops, papaya, bananas, macadamia nuts, and coffee are some of the important crops grown in addition to sugarcane. In 1967 about 18,540 acres were used for such crops. About one-fourth of this was used for coffee and one-fourth for macadamia nuts.

TRUCK CROPS. - Lettuce, cucumbers, tomatoes, snap beans, daikon (white radish), and Chinese cabbage are grown for the Honolulu market, for home use, and to supply other areas when vegetables are out of season. Broccoli, corn, eggplant, peppers, ginger root, onions, and taro are also grown, but in small quantities. Vegetables are grown mainly in the Waimea, Kona, and Volcano districts. Because of the tropical climate, there is an all-year growing season, and in most areas at least two crops of vegetables can be grown in a year.

In preparation for truck crops, the soil is first disk harrowed to chop plant residue. This is followed by plowing, disking, harrowing, and smoothing. Areas of extremely stony mucky soils are cleared with a dozer, then smoothed and rolled. Sugarcane bagasse is spread over the area for a mulch. Soil fumigants are used before planting to control nematodes.

The soils used for vegetables respond readily to nitrogen, phosphorus, and potassium. The amount and kind of fertilizer and the time to apply it depend on the soil and the crop. Fertilizer is applied in dry form or by foliar application. Minor elements and lime are added as needed. The rate and kind of fertilizer to apply are best indicated by soil tests, field trials, and experience.

Vegetable crops are irrigated by overhead sprinklers or by furrows, and they generally require frequent irrigation.

Weeds are controlled by pre-emergence herbicides soon after planting. Contact herbicides are applied after the crop begins to grow. Mechanical and hand weeding are also common methods of weed control.

Insects and fungus are controlled by seed treatment and by insecticides applied by spraying or dusting.

PAPAYA. - This is a herbaceous plant commonly referred to as a tree. It has a single, erect, hollow stem surmounted with a crown of large leaves. The melonlike fruit is spherical to oblong in shape.

The tree grows rapidly, requiring only 10 to 14 months from the time of germination of the seed to the harvesting of the first ripe fruit.

Papaya grows well along the coastal plains and the foothills where temperature and solar insolation are high. Most of the papaya plantings are in the Kapoho area where the soils are extremely stony and shallow over fragmental Aa lava. The solo papaya is the most common variety grown.

Preparation for planting consists of clearing the forest of ohia trees, shaping and smoothing, and rolling with a heavy roller or drum. On fragmental Aa, a small hole is made and a few handfuls of soil are placed in the hole together with fertilizer and a few seeds. Plantings are usually spaced 8 by 10 feet apart.

Weeds are controlled by herbicides. A complete fertilizer is applied at planting time and at intervals of 2 or 3 months.

Control of insects and plant diseases is essential for maximum yields. Phytoptera and anthracnose are the principal diseases of papaya. Mites and fruit flies need to be controlled. Yields ar 40,000 to 60,000 pounds per acre per year.

BANANAS. - Bananas are among the most commonly grown fruits in Hawaii. Commercial banana plants generally do not produce seeds. New plants are usually started from large suckers removed from the parent plant or from sections taken from old banana stumps. The time required to grow a crop is normally one year but depends on climate, soil, and other factors.

The two most important commercial varieties grown are Cavendish (Chinese) and Gros Michel (Bluefield). Bananas require adequate moisture throughout the year and good drainage.

The Cavendish banana can be planted as close as 6 to 8 feet apart, but the Bluefield requires a spacing of 12 to 18 feet. A surface mulch and shallow cultivation help to control weeds. Supplements of manure or commercial fertilizers are applied three or more times a year, the rate depending on the kind and depth of soil, the amount of rainfall, and the size of plants.

Excess suckers are removed at least four times a year. If soil fertility is high, a new sucker can be allowed to develop every 3 months so that no more than four stalks make up a mat at any one time.

Windbreaks are planted to protect bananas in areas exposed to the trade winds. The fruit fly and other insects, in addition to nematodes, diseases, and rats, must be controlled. Bananas ripen best when they are picked green. Yields are about 20,000 pounds per acre per year.

MACADAMIA NUTS. - Macadamia nuts are produced in the Hamakua and Kau districts and on lava soils in Hilo, Puna, and Kona. Macadamia trees grow at an elevation from sea level to about 2,500 feet (fig. 12). These trees grow in deep soils as well as in shallow soils over Aa lava. They grow best where the annual rainfall is 50 to 120 inches.

Only grafted trees of the best varieties should be planted in new orchards. The three most promising varieties are Kakea, Ikaika, and Keauhou. Macadamia trees take aobut 7 years to come into commercial production. Yields vary from 2,500 to 3,500 pounds per acre, depending on climate and soil.

A complete fertilizer is applied three to five times a year, the amount and frequency depending on soil, amount of rainfall, and size of plants.

Herbicides are used to control weeds. Control of anthracnose, nut borer, and rats is also essential.

COFFEE. - The production of coffee is the island's third largest industry. Coffee is grown primarily on the Kona coast at an elevation of 800 to 2,500 feet. The annual rainfall is 40 to 125 inches and occurs mostly during the summer.

Guatemala (Coffea arabica) is the main variety planted. Seedlings are planted about 6 feet apart. The trees produce coffee berries after 3 years and may continue to bear for many years. Yields are about 20 to 25 bags of parchment per acre per year.

A complete fertilizer is applied aobut three times a year. Herbicides are used to control weeds.

PASTURE

Approximately 743,000 acres are used for cattle grazing on the Island of Hawaii. Ranches vary in size from 250,000 acres to small units operated by part-time ranchers. Nearly all ranches are cow-calf operations.

The beef animals are generally marketed as yearlings, although some weaners are sold as feeders.

SUGGESTED PRACTICES. - In areas of low rainfall, forage production varies extremely from year to year. When the rainfall is adequate, the green-feed period sometimes lasts from November to July. When the rainfall is low, the green-feed period is much shorter, and when there is a drought the grasses sometimes do not green up. In areas of higher rainfall, forage production is consistent from year to year. Those who manage pasture should consider the length of the green-feed period and make full use of the feed when it is most nutritious. They should also consider the consistent variation in forage production from season to season and vary the stock numbers and grazing time accordingly.

Livestock graze selectively. They seek the more palatable and nutritious plants. If grazing is not controlled the desirable plants will be eliminated and less desirable plants will increase. Pasture rotation, periodic deferment of grazing, and a good fertilization program will help maintain the desirable forage plants.

Weeds can be controlled by applying chemicals, by clipping or mowing, or by controlled grazing.

Carefully controlled grazing of newly seeded pasture is necessary to prevent destruction of the seedlings. During the first year it is desirable to allow bunch grass to produce a seed crop.

Stockwater ponds and troughs, properly located and constructed, help to control grazing. The ponds should be lined with impervious material to prevent seepage.

Most pasture eventually needs reseeding, depending on the kind of plants and management.

Establishing pasture is expensive. If pasture is to be seeded, the native rain-forest vegetation is bulldozed (fig. 16) and a seedbed is prepared. If preparing a seedbed is impractical, pasture can be established by controlling the existing vegetation. Chain dragging, brush raking, controlled burning, and applying chemicals are methods of controlling vegetation. On shallow soils over Aa or pahoehoe lava, the surface layer of organic matter should not be removed. Establishing pasture on extremely stony soils is difficult, because seeding, fertilizing, and controlling weeds and brush must be done by hand or by aerial methods. Stony soils are placed in the same management groups as nonstony soils, however, because the adapted pasture plants and the methods of maintaining the pasture are the same.

Nitrogen or a nitrogen-phophorus fertilizer is generally necessary to establish grasses. Phosphorus or a combination of phosphorus and lime is usually necessary to establish a grass-legume pasture. These should also be applied periodically to maintain yields. The application rate and timing depend on the kind of pasture plants, the soil, the climate, and the season of use.

The best planting stock available should be used for seeding pasture. Clean seed that has a high percentage of germination insures a good stand. Legumes should be inoculated with the proper rhizobium.

All of the present improved varieties of pasture plants on the island have been introduced. In the following paragraphs some improved grasses and legumes are discussed.

IMPROVED GRASSES AND LEGUMES. - Koa haole (<u>Leucaena</u> <u>leucocephala</u>) is a deep-rooted, leguminous, long-lived shrub or small tree. It is adapted to areas that receive 25 to 60 inches of rainfall annually and are at an elevation from sea level to 1,500 feet. Koa haole is established from seed. For best results is should be mechanically planted in a prepared seedbed. It can be planted with guineagrass or green panicgrass, and it should be managed according to the growth cycle of the companion grass.

Big trefoil (Lotus uliginosus) is a long-lived semi-prostrate legume that produces rhizomes and a large fibrous root system. It has a weak, succulent stem that roots at the leaf axis. The stem grows to a length of more than 36 inches. This legume is adapted to areas that receive more than 60 inches of rainfall annually and are at an elevation above 1,000 feet. It grows in open sunlight or partial shade. It can be established from seed or sprigs and can be planted with kikuyugrass or pangolagrass. Big trefoil has a regrowth cycle of 30 days during the warmer months and 45 days during the cooler months. It can withstand grazing to a 2-inch stubble if the grazing is rotated.

Intortum (Desmodium intortum) is a long-lived legume that has a long, decumbent stem. The stem sometimes roots at the leaf axis and forms new plants. Intortum is adapted to areas that receive 60 to 120 inches of rainfall annually and are at an elevation from sea level to 3,000 feet. It can be established form seed or sprigs. For best results the seed should be mechanically planted in rows in a prepared seedbed. This legume is generally planted with pangolagrass but is managed according to its own growth cycle. When the leaves have been stripped from the stems, cattle should be removed from the pasture and the intortum allowed to regrow. The regrowth cycle is aobut 60 days in summer and 90 days in winter.

Kikuyugrass (Pennisetum clandestinum) is a long-lived deep-rooted, sod-forming grass that spreads by stolons and forms a dense turf. This is an excellent grass for pasture and for controlling erosion. It is adapted to all elevations that receive 40 to 80 inches of rainfall annually. Kikuyugrass is established from sprigs. It has a regrowth cycle of 30 days during the warmer months and 45 days during the cooler months. It can be grazed to a 2-inch stubble.

Pangolagrass (Digitaria decumbens) is a long-lived grass that grows 2 to 3 feet tall and produces long stolons that root at the nodes and form an open turf. It is a good forage producer and provides excellent ground cover that helps control erosion. This grass is adapted to areas that receive 60 to 120 inches of rainfall annually and are at an elevation from sea level to 3,000 feet. Pangolagrass does not produce viable seed. It is propagated by sprigging. For best results the sprigs should be planted less than 2 inches deep in a prepared seedbed. Established pangolagrass has a regrowth cycle of 30 days during the warm months and 45 days in the cool months.

Guineagrass (Panicum maximum) is a long-lived bunch grass that grows 6 to 8 feet tall. It is adapted to areas that receive 25 to 60 inches of rainfall annually and are at an elevation from sea level to 2,000 feet. The large fibrous root system is a good soil binder and helps control erosion. Guineagrass is easily established from seed in a prepared seedbed. Thin stands can be improved by deferred grazing that permits the growth of a seed crop. Established guineagrass pasture is ready to graze 40 to 60 days after the end of the dry season. If soil moisture is sufficient, guineagrass can be grazed on a 60-day rotation during the hot months and a 90-day rotation during the cool months. To maintain a good stand, this grass should not be grazed closer than 8 to 10 inches.

Paragrass (Brachiaria mutica sy. Panicum Purpurascens) is a long-lived, sod-forming grass. It has a coarse, trailing stem that roots at the nodes. The flower stem grows as much as 6 feet tall. Paragrass is particularly adapted to poorly drained soils that are at an elevation of less than 2,000 feet. This grass is a poor seed producer and is usually propagated from sprigs. Established paragrass has a regrowth cycle of 60 days during the warmer months and 90 days during the cooler months. Locally, it is used mainly as green-chop forage.

White clover (Trifolium repens) is a shallow-rooted, creeping, perennial legume that has trigoliolate leaves and stolons that root at the nodes. It is adapted to areas that receive 35 to 80 inches of rainfall. It grows at an elevation from sea level to 10,000 feet but is commonly grown at 2,000 to 7,000 feet. White clover is always established from seed and should be planted in a prepared seedbed with a mechanical planter. This is an excellent pasture legume, but good management is required to keep it in the pasture mixture. It has a regrowth cycle of 30 days in the warm season and 45 days in the cooler months.

Dallisgrass (Paspalum dilatatum) is a deep-rooted, long-lived perennial semibunch grass that has short rhizomes. It is adapted to areas that receive 30 to 100 inches of rainfall annually, and it grows at an elevation from sea level to 6,000 feet. It is best established from seed in a prepared seedbed. Dallisgrass is particularly good for erosion control. It grows best during the warm season and has a regrowth cycle of about 40 days.

Cocksfoot, or orchardgrass (Dactylis glomerata) is a long-lived bunch grass adapted to areas that receive 40 to 100 inches of rainfall annually and are at an elevation of 3,000 to 8,000 feet. Cocksfoot has a large fibrous root system that helps control erosion. It is easily established from seed. It should be planted mechanically less than 1 inch deep in a prepared seedbed. It can be planted with a companion legume. The companion legume can be seeded as recommended or mixed and planted with the cocksfoot seed. Cocksfoot generally has a regrowth cycle of 30 days during the warmer season, but as much as 60 days during the cooler season. In drier areas the stands can be improved by deferred grazing that allows the growth of a seed crop.

Perennial ryegrass (Lolium perenne) is a short-lived, perennial bunch grass that forms a turf under grazing. It is adapted to areas that receive 40 to 100 inches of rainfall annually and are at an elevation of 2,500 to 7,000 feet. The plant is always established from seed and should be planted in a prepared seedbed. Perennial ryegrass has a regrowth cycle of 30 days during its most rapid growth, but it may require 45 days during cool weather.

Buffelgrass (Cenchrus ciliare) is a long-lived bunch grass, well suited to areas that receive 10 to 40 inches of rainfall annually and are at an elevation of less than 2,000 feet. This grass has a large, fibrous root system that helps control erosion. It is readily established from seed, and is best established by shallow seeding with a mechanical planter in a prepared seedbed. Thin stands can be improved by deferred grazing that allows a seed crop to grow. Buffelgrass is ready to graze from 21 to 30 days after rain. If enough soil moisture is available, this grass can be grazed on a 30-day rotation, but it should never be grazed closer than 2 to 3 inches.

Green panicgrass (Panicum maximum var. trichoglume) is a medium-tall

(3 to 6 feet), long-lived bunch grass. It is adapted to areas that receive 22 to 60 inches of rainfall annually and are at an elevation of less than 2,000 feet. This productive forage plant makes a good ground cover that helps to control erosion. It is easily established from seed. For best results it should be mechanically planted in a prepared seedbed. This grass has excellent seedling vigor and established faster than guineagrass. Grazing can be deferred to produce a seed crop or to provide forage during the dry season. Established green panicgrass pasture is ready to graze 30 to 40 days after the end of the dry season. It has a regrowth cycle of 30 days during the warm months and 45 days during the cool months. Green panicgrass should not be grazed closer than 4 to 6 inches.

Pasture Group 1

In this group are soils of the Kawaihae series. These soils occupy leeward coastal areas in the drier parts of the island. They have a slope of 6 to 12 percent. They are at an elevation ranging from sea level to 1500 feet and receive from 5 to 20 inches of rainfall annually, most of which occurs during the winter. The mean annual soil temperature is between 74° and 77° F.

These soils formed in volcanic ash. They are extremely stony, somewhat excessively drained, and 20 to 40 inches deep over basalt. They are moderately permeable.

Unimproved pasture consists mostly of Hawaiian piligrass, feather fingergrass, swollen fingergrass, ilima, uhaloa, zinnia, and kiawe. Kiawe trees grow in thick stands along the coastal flats and in open stands on the uplands. During the summer the main source of food along the coastal flats is the kiawe pod. Unimproved pasture produces 1,100 to 1,400 pounds of air-dry forage per acre annually. About three-fourths of the forage is produced during the riany season. During the dry summer months, most of the annuals die and the perennials are dormant.

Forage plants for improved pasture are buffelgrass, white piligrass, and giant bermuda. Buffelgrass is particularly well adapted. It spreads rapidly and provides ground cover that helps control erosion. Improved pasture produces 1,700 to 2,600 pounds of air-dry forage per acre annually.

Pasture Group 2

In this group are Fill land and soils of the Kaalualu, Mahukona, Pakini, and Puu Pa series. These soils occupy southern coastal areas of Mauna Loa and low, leeward areas of Mauna Kea and the Kohala Mountains. They have a slope of 2 to 20 percent. They are at an elevation ranging from near sea level to 2,500 feet and receive from 10 to 40 inches of rainfall annually, most of which falls during the winter. The mean annual soil temperature is between 69° and 75° F.

These soils formed in volcanic ash and basic igneous rocks. They are well drained, are moderately to rapidly permeable, and are 20 inches to more than 60 inches deep.

Unimproved pasture on these soils consists mostly of piligrass, sandbur, natal redtop, bermudagrass, ilima, cactus, klu, Japanese tea, kiawe, and fingergrass. Winter forage production is about three times that of su-mer production. The total annual production is about 700 to 1,300 pounds of air-dry forage per acre.

Forage plants for improved pasture on these soils are guineagrass, and koa haole. Improved pasture produces 1,400 to 2,600 pounds of air-forage per acre annually.

Pasture Group 3

This group consists of soils of the Hawi, Waiaha, and Punaluu series. These soils are on coastal plains and low uplands. Their dominant slope is 0 to 20 percent. They are at an elevation ranging from near sea level to 1,200 feet and receive from 20 to 90 inches of rainfall annually. In the Kona district most of the rain falls from July through September. The mean annual soil temperature is between 72° and 75° F.

These soils formed in volcanic ash, basic igneous rock, and organic matter. They are well drained and have moderately rapid and rapid permeability. Hawi soils are more than 48 inches deep. Waiaha soils are less than 20 inches deep over pahoehoe lava. Punaluu soils, which formed in organic matter, are less than 10 inches deep over pahoehoe lava.

Unimproved pasture consists mostly of kiawe, koa haole, klu, cactus, lantana, ilima, opiuma, natal redtop, and bermudagrass. On the Hawi and Punaluu soils about two-thirds of the forage is produced during the winter. On the Waiaha soils, four-fifths of the forage is produced during the summer. The annual production is 1,000 to 1,500 pounds of air-dry forage per acre.

Forage plants for improved pasture are buffelgrass, guineagrass, green panicgrass, and koa haole. Improved pasture produces 2,000 to 3,000 pounds of air-dry forage per acre annually.

Pasture Group 4

This group consists of soils of the Kamakoa, Kamaoa, Waikaloa, and Waimea series. These soils are on the leeward side of Mauna Kea. Their dominant slope is 0 to 20 percent. They are at an elevation ranging from 1,000 to 6,000 feet and receive from 20 to 60 inches of rainfall annually, most of which falls from November through February. The mean annual soil temperature is between 59° and 69° F.

These soils formed in alluvium and volcanic ash. They are well drained or somewhat excessively drained, and are moderately to rapidly permeable. These soils are more than 30 inches deep, except for the Kamakoa soils, which are 20 to 50 inches deep over hard, consolidated sand.

Unimproved pasture consists mostly of cactus, ilima, aalii, bermudagrass, and natal redtop, and the annual production is 1,000 to 2,000 pounds of air-dry forage per acre. About two-thirds of the forage is produced during the riany season.

Kikuyugrass, green panicgrass, buffelgrass, bermudagrass, white clover, and bur clover are adapted for improved pasture. The annual production is 3,000 to 4,000 pounds of air-dry forage per acre.

Pasture Group 5

This group consists of soils of the Kohala, Naalehu, Kainaliu, and Kaimu series. These soils are on low uplands and their slope is 0 to 35 percent. They are at an elevation ranging from near sea level to 1,800 feet and receive from 35 to 60 inches of rainfall annually. Their mean annual soil temperature is between 71° and 75° F.

These soils formed in volcanic ash, basic igneous rock, and organic matter. They are well drained and have moderately rapid to rapid permeability. They are more than 36 inches deep, except for the Kainaliu and Kaimu soils. The Kainaliu soils are 20 to 40 inches deep over Aa lava. The Kaimu soils formed in organic matter and are less than 8 inches deep over gragmental Aa lava.

Unimproved pasture consists mainly of natal redtop, bermudagrass, lantana, Christmas berry, guava, Japanese tea, and bush indigo. Monkey pod, silk oak, and ohia trees are also common in some areas. Two-thirds of the forage is produced during the winter, except in the Kona area where four-fifths of the forage is produced during the summer. The annual production is 2,000 to 3,200 pounds of air-dry forage per acre.

Guineagrass, koa haole, kikuyugrass, and kaimi clover are adapted plants for improved pasture, and the annual production is 4,000 to 7,000 pounds of air-dry forage per acre per year.

Pasture Group 6

Tropaquepts are the only soils in this group. These soils are on alluvial valley bottoms. Their slope is 0 to 6 percent. They are at an elevation ranging from near sea level to 500 feet and receive from 60 to 100 inches of rainfall annually. Their mean annual soil temperature is between 72° and 75° F.

These soils formed in alluvium, and they are 20 inches to more than 40 inches deep. Their dominant properties are the result of poor drainage induced by man. These soils have poor workability. They are subject to frequent flooding. The depth to the water table is less than 20 inches.

Unimproved pasture consists mostly of hilograss, honohonograss, and wetland sedges and guava and monkey pod. These soils are on sites that have a 12-month growing season. The annual production is about 3,000 to 4,000 pounds of air-dry forage per acre.

Pangolagrass, kikuyugrass, big trefoil, and intortum are adapted plants for improved pasture. The annual production is 4,000 to 5,000 pounds of air-dry forage per acre.

Pasture Group 7

This group consists of Mixed alluvial land and soils of the following series:

Ainakea	Niulii
Honuaulu	Ookala
Kona	Opihikao
Kukaiau	Paauhau
Malama	Puna
Moaula	

These soils are on low uplands. Their slope ranges from 0 to 35 percent. They are at an elevation ranging from near sea level to 3,500 feet and receive from 60 to 120 inches of rainfall annually. Most of the rainfall on the Honuaulu soils comes during the summer. The mean annual soil temperature is between 63° and 74° F.

Mixed alluvial land is forming in young alluvium and has variable properties. Kona, Malama, Opihikao, and Puna soils formed in organic matter over lava. Kona and Opihikao soils are less than 7 inches deep over pahoehoe lava. Malama and Puna soils are less than 10 inches deep over fragmental Aa lava. The other soils formed in volcanic ash and are more than 20 inches deep. They are well drained and have moderately rapid permeability.

Unimproved pasture consists of hilograss, glenwoodgrass, yellow foxtail, carpetgrass, and guava. Ohia, silk oak, eucalyptus, and kukui trees also grow on these soils. The pasture sites have a 12-month growing season. The annual production is about 3,000 to 4,000 pounds of air-dry forage per acre.

Pangolagrass, kikuyugrass, big trefoil, and intortum are adapted plants for improved pasture. The annual production is 4,000 to 5,000 pounds of air-dry forage per acre.

Pasture Group 8

This group consists of soils of the Akaka, Kahua, Kehena, Piihonua, and Puaulu series. These soils are on uplands of Mauna Kea, Mauna Loa, and the Kohala Mountains. They are at an elevation ranging from 1,000 to 6,500 feet and have a slope of 0 to 20 percent. They receive from 60 to 300 inches of rainfall annually, and it is well distributed throughout the year. Their mean annual soil temperature is between 55° and 68° F. There is considerable fog and cloud cover, especially during the winter.

These soils formed in volcanic ash and have a depth ranging from 20 inches to more than 60 inches. They are well drained to somewhat poorly drained and rapidly to slowly permeable.

Unimproved pasture consists mostly of yellow foxtail, carpetgrass, rice-rass, glenwoodgrass, rattail, tarweed, and wetland sedges. Tree fern, koa and ohia grees grow in uncleared areas. About four-fifths of the forage is produced during the summer. The annual production is 2,000 to 3,000 pounds of air-dry forage per acre.

Kikuyugrass, pangolagrass, big trefoil, white clover, and intortum are among the adapted plants for improved pasture. The annual production is 4,000 to 5,000 pounds of air-dry forage per acre.

Pasture Group 9

Alapai
Hilea
Hilo
Honaunau
Honokaa
Kaiwiki
Kealakekua
Keaukaha
Keei
Kiloa
Manu
Ohia
Olaa
Panaewa
Papai

These soils are on uplands and have a slope range of 0 to 35 percent.

They are at an elevation ranging from near sea level to 5,000 feet. They receive from 80 to 200 inches of rainfall annually, and it is well distributed throughout the year. The mean annual soil temperature is between 58° and 74° F.

These soils are moderately well drained to well drained and are rapidly permeable. Keaukaha, Keei, Kiloa, and Papai soils formed in organic matter and are not more than 10 or 12 inches deep over pahoehoe or fragmental Aa lava. The other soils formed in volcanic ash and are 20 inches to more than 60 inches deep, except for the Hilea and Panaewa soils, which are less than 20 inches.

Unimproved pasture on these soils consists mostly of californiagrass, carpetgrass, ricegrass, and honohonograss. Ohia, tree fern, waiwi, and melastome grow in uncleared areas. The pasture sites have a 12-month growing season, but the best quality of forage is produced during the summer. The annual production is 3,000 to 5,000 pounds of air-dry forage per acre.

Pangolagrass, kikuyugrass, big trefoil, and intortum are adapted plants for improved pasture (fig. 17), and the annual production is 8,000 to 14,000 pounds of air-dry forage per acre.

Pasture Group 10

This group consists of soils of the Heake, Puukala, Kahaluu, Lalaau, and Puhimau series. These soils are on uplands of Mauna Loa and Hualalai and have a slope range of 0 to 20 percent. They are at an elevation ranging from 2,000 to 7,000 feet and receive from 60 to 150 inches of rainfall annually. Their mean annual soil temperature is between 55° and 65° F.

These soils are well drained and are rapidly permeable. The Heake, Puhimau, and Puukala soils formed in volcanic ash, pumice, and cinders. They are less than 20 inches deep over pahoehoe lava. The Kahaluu and Lalaau soils formed in organic matter and are less than 10 inches deep. The Kahaluu soils are over pahoehoe lava, and the Lalaau soils are over fragmental Aa lava.

Unimproved pasture consists mostly of carpetgrass, ricegrass, glenwoodgrass, puu lehua, tarweed, and wetland sedges. The main trees are tree fern, koa, mamani, and ohia. About four-fifths of the forage is produced during the summer. The annual production is 500 to 1,500 pounds of air-dry forage per acre.

Kikuyugrass, dallisgrass, orchardgrass, big trefoil, and white clover are adapted palnts for improved pasture. The annual production is 1,000 to 3,000 pounds of air-dry forage per acre.

Pasture Group 11

In this group are soils of the Maile, Manahaa, Punohu, and Puu Oo series. These soils are on uplands of Mauna Kea, Hualalai, and the Kohala Mountains. They have a slope of 0 to 20 percent. They are at an intermediate elevation ranging from 2,500 to 6,500 feet and receive from 50 to 100 inches of rainfall annually. Their mean annual soil temperature is between 53° and 60° F. There is considerable fog and cloud cover during the winter.

These soils formed in volcanic ash, and their depth ranges from 20 inches to more than 60 inches. They are well drained and have moderately rapid permeability.

Unimproved pasture consists of bermudagrass, rattail, sweet vernal, kukaipuaa, white clover, and alapaio fern. Koa, ohia, and tree fern grow on uncleared areas. About two-thirds of the forage is produced during spring and fall. The annual production is 4,000 to 6,000 pounds of air-dry forage per acre.

Kikuyugrass, pangolagrass, orchardgrass, ryegrass, white clover, and big trefoil are adapted plants for improved pasture, and the annual production is 8,000 to 12,000 pounds of air-dry forage per acre.

Pasture Group 12

In this group are soils of the Kikoni, Palapalai, Umikoa, Kekake, and Mawae series. These soils are on uplands of Mauna Kea, Kohala, and Hualalai. They have a slope range of 0 to 20 percent. They are at an elevation ranging from 2,000 to 7,000 feet and receive from 35 to 90 inches of rainfall annually. Their mean annual soil temperature is between 52° and 66° F.

All except the Kekake and Mawae soils formed in volcanic ash and are more than 42 inches deep. The Kekake and Mawae soils formed in organic material over lava and are less than 10 inches deep. Kekake soils overlie pahoehoe lava, and the Mawae soils overlie fragmental Aa lava. The soils of this group are well drained and have moderately rapid to rapid permeability.

Unimproved pasture consists mostly of hilograss, carpetgrass, yellow foxtail, bermudagrass, and rattail and an overstory of ohia and tree fern. About two-thirds of the forage is produced during spring and fall. Short, droughty periods and a lowering of the temperature may influence forage production. The annual production is 2,000 to 5,000 pounds of air-dry forage per acre.

Pangolagrass, kikuyugrass, orchardgrass, big trefoil, and intortum are adapted plants for improved pasture, and the annual production is 4,200 to 8,000 pounds of air-dry forage per acre.

Pasture Group 13

In this group are soils of the Hanipoe, Kapapala, and Laumaia series. These soils are on the high uplands of Mauna Kea and Mauna Loa. Their slope is 0 to 20 percent. They are at an elevation ranging from 2,000 to 8,000 feet and receive from 30 to 70 inches of rainfall annually. Their mean annual soil temperature is between 50° and 61° F.

These soils formed in volcanic ash and have a depth of 36 inches to more than 60 inches. They are well drained and have moderately rapid permeability.

Unimproved pasture consists mostly of bromegrass, rattail, and kukaipuaa and an overstory of koa, ohia, and mamani. Because of the cool temperature and dry periods, forage production is seasonal. It is slightly higher during the summer. The annual production is 2,200 to 3,500 pounds of air-dry forage per acre.

Kikuyugrass, puulehua, orchardgrass, white clover, and big trefoil are adapted plants for improved pasture, and the annual production is 4,200 to 8,000 pounds of air-dry forage per acre.

Pasture Group 14

In this group are soils of the Apakuie, Keekee, Kilohana, and Huikau series. These soils are on high uplands of Mauna Kea and Hualalai. Their slope is 0 to 20 percent. They are at an elevation ranging from 5,000 to 9,000 feet and receive from 15 to 40 inches of rainfall annually. Their mean annual soil temperature is between 47° and 53° F.

All except the Keekee soils formed in volcanic ash, cinders, and pumice. Keekee soils are forming in young alluvium. The soils of this group are 36 inches to more than 60 inches deep. They are well drained or somewhat excessively drained and are rapidly or very rapidly permeable.

Unimproved pasture consists mostly of puakeawe, ohelo, aalii, hardstem lovegrass, mountain pili, and sweet vernal and an overstory of koa, ohia, and mamani. Forage production is slightly higher during spring and fall. The annual production is 1,000 to 1,500 pounds of air-dry forage per acre.

Orchardgrass, alta fascue, tall meadow outgrass, velvetgrass, Parker Ranch bluestem, burclover, and black medic are prospective plants for improved pasture, and the annual production is 2,000 to 4,000 pounds of air-dry forage per acre.

WOODLAND

In the 1930's the Civilian Conservation Corps planted trees on the Island of Hawaii, primarily for watershed protection. Many of these stands are now ready to be harvested (fig. 18). According to the "Forest Resources of Hawaii - 1961" (9), the volume of timber on the island was about 602 million board feet, which was about 84 percent of the volume of timber in the State. The "Conservation Needs Inventory of 1967" (unpublished) lists 704,000 acres, or 28 percent of the total acreage of the island, in commercial forest.

The native forests are generally well stocked with ohia, koa, eucalyptus, and other trees. There are about 82 million board feet of robusta eucalyptus, which is used increasingly for furniture manufacturing, home construction, and other purposes (9).

Most of the trees that are planted are for timber, windbreaks, or watershed, but Norfolk-Island-pine is planted for Christmas trees (fig. 19), which are marketed locally and on the mainland.

WOODLAND CONSERVATION. - Conservation practices are needed to develop a woodland enterprise on the Island of Hawaii. Before trees can be planted, many areas need clearing to remove competing plants and prepare the soil. On shallow soils over Aa or pahoehoe lava, the organic material should be disturbed as little as possible.

Normally, seedlings are planted in spacings that range from 8 by 8 feet to 12 by 12 feet. To insure tree survival and good form, initial plantings of trees are usually closer than needed.

When the trees are 5 to 20 years of age, the stands are thinned to improve the growth and quality of the crop. Periodic commercial thinning increases income and maintains a fast growth rate of the remaining trees. The trees left for cutting are pruned.

When the stand has reached a desired size, it is harvested by clear cutting or by some type of shelterwood cutting. After the harvest, regeneration of the stand begins, and competing vegetation is removed until the seedlings are well established.

Proper construction of access roads and control of erosion are important. Roads should be constructed on grades of less than 12 percent and protected from erosion by water bars, culverts, and ditches.

WOODLAND GROUPS. - The soils of theisland have been placed in woodland groups on the basis of adapted species of trees, estimated annual productivity per acre, seedling mortality, plant competition, equipment limitations, erosion hazard, and windthrow hazard.

ADAPTED SPECIES are trees that are best suited for planting or for favoring in existing stands. On the Island of Hawaii, most of the trees that are grown commercially are exotics that have been introduced. Ohia and koa are the main native trees that are satisfactory for commercial production.

ESTIMATED ANNUAL PRODUCTIVITY PER ACRE is the estimated annual production of board feet per acre measured according to the international ¼-inch rule. At present there are no site or yield tables for any species of trees grown in Hawaii, but many stands of trees that have a known age have been measured and yields have been estimated on the basis of a harvesting cycle of 30 to 60 years, using robusta eucalyptus as a standard. One reason for the wide range in productivity within a group is the variation in growth rate between species of trees.

SEEDLING MORTALITY is the mortality of naturally occuring or planted seedlings, as influenced by soil, topography, and climate. The rating is slight if the expected mortality is less than 25 percent, moderate if it is between 25 and 50 percent, and severe if it is greater than 50 percent.

PLANT COMPETITION is the invasion or growth of undesirable plants. Slight competition does not prevent natural regeneration or the growth of planted seedlings. Moderate competition delays but does not prevent the eventual establishment of adequately stocked stands. Severe competition prevents establishment of stands unless the site is intensively prepared and weeded.

EQUIPMENT LIMITATIONS are limitations imposed by the characteristics of the soils that restrict or prevent the use of equipment in tending and harvesting trees. The limitation is slight if it does not restrict the kind of equipment or the time of year in which it can be used. The limitation is moderate if the use of equipment is moderately restricted by slope, stones, seasonal wetness, or physical characteristics of the soils. The limitation is severe if special equipement is needed and its use is restricted by slope, stones, wetness, or soil characteristics.

EROSION HAZARD depends on slope, soil stability, permeability, water-holding capacity, and extent of past erosion. Erosion in woodland seldom occurs until vegetation is disturbed or destroyed by fire or by excessive grazing, logging, or road building. The hazard is slight if there are only minor problems, moderate if some control measures are necessary, and severe if intensive control measures and special equipement are needed.

WINDTHROW HAZARD is the possibility of trees being blown over by wind. The hazard is slight if trees are not expected to be blown down by commonly occurring winds, moderate if some trees growing on wet or shallow soil are likely to be blown down by high wind, and severe if most of the trees growing in a stand on wet or shallow soil are expected to be blown down by moderate or high wind.

Woodland Group 1

This group consists of well-drained and somewhat excessively drained very fine sandy loams that formed in volcanic ash. These soils have a slope range of 0 to 20 percent. They are at an elevation of 1,000 to 6,000 feet and receive 20 to 60 inches of rainfall annually. The mean annual soil temperature is between 59^{o} and 69^{o} F.

Loblolly pine, slash pine, and gray ironback eucalyptus are the adapted species. The estimated annual production is 100 to 200 board feet per acre. Seedling mortality is moderate to severe. Plant competition is slight from bermudagrass, aali, and cactus. The equipment limitation is slight except in stony areas. The erosion hazard is slight to moderate, and the windthrow hazard is slight.

Woodland Group 2

This group consists of well-drained silty clay loams that formed in volcanic ash. These soils have a slope range of 0 to 35 percent.

They receive from 35 to 60 inches of rainfall annually and are at an elevation of 750 to 1,800 feet. Their mean annual soil temperature is between 71° and 75° F.

The adapted species are saligna eucalyptus, gray ironbark eucalyptus, red ironbark eucalyptus, silk oak, and Norfolk-Island-pine. The estimated annual production is 200 to 400 board feet per acre. Seedling mortality is moderate. Plant competition is moderate from bermudagrass, kikuyugrass, hilograss, and rattail. The equipment limitation is slight to moderate, the windthrow hazard is slight, and the erosion hazard is slight to severe.

Woodland Group 3

This group consists of moderately deep, poorly drained soils that formed in recent alluvium. These soils have a slope range of 0 to 3 percent. They receive from 60 to 100 inches of rainfall annually and are at an elevation of 0 to 500 feet. The mean annual soil temperature is between 70° and 76° F.

Monkey pod, robusta eucalyptus, saligna eucalyptus, and albizzia are the adapted species on these soils. The estimated annual production is 500 to 800 board feet per acre. Seedling mortality is slight. Plant competition is moderate from hilograss, californiagrass, guava, and ferns. The equipment limitation and windthrow hazard are severe. The erosion hazard is slight. These soils are subject to frequent flooding.

Woodland Group 4

This group consists of well-drained silty clays that formed in residuum from basic igneous rock. These soils have a slope range of 0 to 35 percent. They receive from 40 to 60 inches of rainfall annually and are at an elevation ranging from sea level to 1,500 feet.

The mean annual soil temperature is between 72° nad 74° F.

Norfolk-Island-pine, robusta eucalyptus, silk oak, and monkey pod are the adapted species. Estimated annual production is 200 to 400 board feet per acre. Seedling mortality is moderate to severe. Plant competition is moderate from bermudagrass. The equipement limitation is slight to moderate, the erosion hazard is slight to severe, and the windthrow hazard is slight.

Woodland Group 5

This group consists of well-drained silty clay loams that formed in volcanic ash. These soils have a slope range of 0 to 35 percent. They receive from 60 yo 120 inches of rainfall annually and are at an elevation ranging from near sea level to 2,500 feet. The mean annual soil temperature is between 65° and 74° F.

Saligna and robusta eucalyptus, Australian toon, Queensland maple, monkey pod, silk oak, Norfolk-Island-pine, and albizzia are the adapted species on these soils. The estimated annual production is 500 to 800 feet per acre. Seedling mortality is slight. Plant competition is moderate from hilograss, californiagrass, guava, Christmas berry, and kikuyugrass. The equipment limitation is slight to moderate, the windthrow hazard is slight, and the erosion hazard is slight to severe.

Woodland Group 6

This group consists of well-drained to somewhat poorly drained soils that formed in volcanic ash and have a silt loam or silty clay loam texture. These soils have a slope range of 0 to 20 percent and are more than 20 inches deep. They are on uplands at an elevation ranging from 1,000 to 6,500 feet and receive from 90 to 300 inches of rainfall annually. The mean annual soil temperature is between 55° and 68° F.

Robusta eucalyptus, Nepal alder, tropical ash, and the native ohia are the adapted species. The estimated annual production is 500 to 900 board feet per acre. Seedling mortality is slight. Plant competition is severe from tree fern, false staghorn fern, melabar melastome, downy myrtle, and kikuyugrass. The equipment limitation is severe because of the low bearing capacity of these soils. The erosion hazard is slight to moderate, and the windthrow hazard is slight.

Woodland Group 7

This group consists of well drained and moderately well drained silt loams and silty clay loams that formed in volcanic ash. These soils have a slope range of 0 to 35 percent. They are at an elevation ranging from near sea level to 5,000 feet and receive from 80 to 200 inches of rainfall annually. Their mean annual soil temperature is between 58° and 74° F.

The adapted species are saligna and robusta eucalyptus, Nepal alder, Norfolk-Island-pine, Australian toon, Queensland maple, tropical ash, blackwood, sugi, redwood, and monkey pod. Ohia and koa are native trees that are well adapted. The estimated annual production is 700 to 1,000 board feet per acre. Seedling mortality is slight. Plant competition is severe from tree fern, false staghorn fern, melabar melastome, downy myrtle, and kikuyugrass. The equipment limitation is moderate to severe. The erosion hazard is slight to severe, and the windthrow hazard is slight.

Woodland Group 8

This group consists of well-drained silt loams that formed in volcanic ash. These soils have a slope range of 0 to 20 percent. They are at an elevation of 2,500 to 6,500 feet and receive from 50 to 100 inches of rainfall annually. Their mean annual soil temperature is between 53° and 60° F.

The adapted species are saligna and robusta eucalyptus, Australian toon, Queensland maple, tropical ash, slash pine, redwood, sugi, and the native ohia and koa. The estimated annual production is 500 to 800 board feet per acre. Seedling mortality is slight. Plant competition is slight, except where kikuyugrass grows. The equipment limitation is slight, except on the very stony soils where it is moderate. The erosion hazard is slight to moderate, and the windthrow hazard slight.

Woodland Group 9

This group consists of well-drained very fine sand loams, silt loams, and silty clay loams that formed in volcanic ash. These soils have a slope range of 0 to 20 percent. They receive from 35 to 90 inches of rainfall annually and are at an elevation of 2,600 to 5,000 feet. Their mean annual soil temperature is between 55° and 66° F.

The adapted species are saligna and robusta eucalyptus, Australian toon, Queensland maple, tropical ash and loblolly and slash pine. The estimated annual production is 500 to 700 board feet per acre. Seedling mortality is slight. Plant competition is severe from kikuyugrass and paspalum. The equipment limitation is slight, the erosion hazard is slight to moderate, and the windthrow hazard is slight.

Woodland Group 10

This group consists of well-drained loams and silt loams that formed in volcanic ash. These soils have a slope range of 0 to 20 percent. They receive from 30 to 70 inches of rainfall annually and are at an elevation of 2,000 to 8,000 feet. Their mean annual soil temperature is between 52° and 61° F.

The adapted species are saligna eucalyptus, sugi, tropical ash, loblolly pine, slash pine, and the native koa and ohia. The estimated annual production is 400 to 600 board feet per acre. Seedling mortality is slight. Plant competition is moderate from alapaio fern, dallisgrass, and kikuyugrass. The equipment limitation is slight, except on very stony soils where is is moderate. The erosion hazard is slight.

Woodland Group 11

In this group are shallow sandy loams and silt loams that formed in volcanic ash and pumice over pahoehoe lava. These soils are only 10 to 20 inches deep. They have a slope range of 0 to 20 inches deep. They receive from 60 to 125 inches of rainfall annually and are at an elevation of 2,000 to 4,000 feet. Their mean annual soil temperature is between 59° and 61° F.

Saligna eucalyptus, blackwood, sugi, tropical ash, and Nepal alder are the adapted species. The estimated annual production is 200 to 500 board feet per acre. Seedling mortality is slight. Plant competition is slight to moderate from tree fern and kikuyugrass. The equipment limitation is slight to moderate. The erosion hazard is slight to moderate, and the windthrow hazard is severe.

Woodland Group 12

This group consists of shallow silty clay loams that formed in volcanic ash and are only 10 to 20 inches deep over pahoehoe lava. These soils have a slope range of 0 to 20 percent. They receive from 100 to 200 inches of rainfall annually and are at an elevation of 300 to 2,000 feet. Their mean annual soil temperature is between 65° and 74° F.

Robusta and saligna eucalyptus, sugi, Australian toon, and the native ohia and koa are the adapted species on these soils. The estimated annual production is 500 to 900 board feet per acre. Seedling mortality is slight. Plant competition is slight to moderate from tree fern, hilograss, californiagrass and melabar melastome. The equipment limitation is moderate, the erosion hazard is slight, and the windthrow hazard is moderate to severe.

Woodland Group 13

In this group are mucky soils that formed in organic matter and are less than 10 inches deep over Aa lava. These soils have a slope range of 0 to 20 percent. They receive from 60 to 150 inches of rainfall annually and are at an elevation ranging from near sea level to 4,000 feet. Their mean annual soil temperature is between 63° and 75° F.

Saligna and robusta eucalyptus, blackwood, Queensland maple, Australian toon, and the native ohia are the adapted species. Estimated annual production is 700 to 1,000 board feet per acre. Seedling mortality is slight. Plant competition is severe from tree fern, guava, and kikuyugrass. The equipment limitation is severe. The erosion and windthrow hazards are slight.

Woodland Group 14

In this group are mucky soils that formed in organic matter and are less than 12 inches thick over Aa lava. These soils have a slope range of 0 to 20 percent. They receive from 50 inches to more than 150 inches annually and are at an elevation of 3,500 to 7,000 feet. Their mean annual soil temperature is between 53° and 59° F.

Saligna and robusta eucalyptus, tropical ash, blackwood, redwood, sugi, and the native ohia and koa are the adapted species. The estimated annual production is 500 to 700 board feet per acre. Seedling mortality is slight. Plant competition is moderate from tree fern and kikuyugrass. The equipement limitation is severe. The erosion hazard and windthrow hazard are slight.

Woodland Group 15

This group consists of well-drained silt loams that formed in volcanic ash and are 10 to 20 inches deep over pahoehoe lava. These soils have a slope range of 0 to 20 percent. They receive from 20 to 40 inches of rainfall annually and are at an elevation ranging from near sea level to 1,000 feet. Their mean annual soil temperature is between 72° and 74° F.

Silk oak, mango, and monkey pod are the adapted species. The estimated annual production is 100 to 300 board feet per acre. Seedling mortality is severe. Plant competition is severe from guineagrass. The equipment limitation and the erosion hazard are slight to moderate. The windthrow hazard is severe.

Woodland Group 16

In this group are well-drained and somewhat excessively drained very fine sandly loamy sands, and loamy fine sands that formed in volcanic ash or cinders. These soils have a slope range of 0 to 20 percent. They receive from 15 to 40 inches of rainfall annually and are at an elevation of 5,000 to 9,000 feet. Their mean annual soil temperature is between 47° and 53° F.

Loblolly and slash pine and gray ironbark eucalyptus are the adapted species. The estimated annual production is 100 to 200 board feet per acre. Seedling mortality is moderate to severe. Plant competition is slight from mamani, naio, aalii, and lovegrass. The equipment limitation is slight to moderate, the erosion hazard is slight to severe, and the windthrow hazard is slight.

WILDLIFE

Various kinds of wildlife thrive on the island, from the arid coastal plains to the very humid rain forests on themountain slopes. Nearly all the big game and the upland game birds were introduced. The first pigs were brought in by the early Polynesians as a source of food. Goats were introduced by Captain Cook in 1778. Captain Vancouver brought sheep and cattle as gifts to the royalty in 1794. Atabu was placed on them, however, and they went wild in the forest(23).

Since 1920 many kinds of birds have been introduced for hunting, for control of insects, and for esthetic value. Birds that have been brought in primarily for hunting are the Chinese ring-necked pheasant, California valley quail, Japanese quail, Indian chukar partridge,, barred dove, and lace-necked dove. The Rio-Grande turkey, Reeves' pheasant, Barbary partridge, Gambel's quail, and francolin partridge, have been introduced lately by the State Fish and Game Division of Hawaii (14).

Bass and bluegill are stocked in some reservoirs in Kohala.

Wild pigs are found from sea level to high up in the mountains. Goats are common on rocky areas throughout the island. Feral sheep are concentrated on the high slopes of Mauna Kea and Mauna Loa.

The hunting season extends year round for sheep, goats, and pigs. The game-bird season usually opens during the beginning of November and closes in the middle of January. Bow and arrow hunting for sheep and pigs is open all year in certain areas.

There are five public hunting grounds, or game management areas, on the Island of Hawaii. These are located within four soil associations described in the "General Soil Map" section of this publication.

The Puako game area is in the Saddle overlapping the Kekake-Keei-Kiloa and the Lava flows soil accociations. The vegetation in the Kekake-Keei-Kiloa soil association consists of ohia and tree fern forest. The Lava flows association has a sparse vegetation of ohelo berry, aalii, and mamani. Wildlife hunted in this area include goats, feral sheep, wild pigs, pheasants, California quail, Japanese quail, chukar partridge, and doves.

The Mauna Kea game area is within the boundaries of the Mauna Kea State Forest. The area extends from an elevation of about 6,000 feet to the top of the mountain. It is in the Lava flows soil association. The vegetation consists of ohelo berry, aalii, naio, and mamani trees. Wild pigs, goats, feral sheep, pheasants, quail, chukar partridge, doves, and pigeons live in this area.

The Horse Pasture game area occurs within the Waimea-Kikoni-Naalehu soil association, which has a vegetative cover of grass and brush. This area is open to upland game bird hunting.

The Pohakuloa game area is a semi-arid alluvial flat in the Saddle between Mauna Kea and Mauna Loa. All kinds of birds and big game common on the island are found in limited numbers.

CLASSIFICATION OF THE SOILS

The Island of Hawaii has a variety of soils as a result of extremes in the factors that are active in soil genesis; climate, vegetation, parent material, relief, drainage, and time. Annual rainfall ranges from 10 inches on the dry leeward coast to more than

300 inches in the wet windward mountain areas. Elevation ranges from sea level to more than 13,000 feet. The average annual temperature at sea level is about 75° F. and decreases on the average about 3°F. for each increase of 1,000 feet in elevation. The mean temperature difference between the coldest and warmest month does not exceed 9° F. at any location on record. Parent material ranges in age from Pliocene to present. It is dominantly volcanic ash and basic igneous rock. These differences in age, parent material, relief, and climate coincide closely with the patterns of vegetation and soil. Consequently, the morphology of each soil reflects the combined effects of the genetic factors responsible for its development.

Soils are classified according to their observable and measurable properties. The properties chosen are primarily those that permit the grouping of soils that are genetically similar. Soil classification enables us to understand the pattern of soils and the ways in which they relate to each other.

The scheme of classification used in this survey was developed in the early sixties. It was adopted for general use by the National Cooperative Soil Survey in 1965 and supplemented in March 1967 and September 1968. It replaces a system, adopted in 1938 and later revised, that was used in the Soil Survey of the Territory of Hawaii by Cline and others. The current system incorporates knowledge gained through research over the last 25 years and is much more precise and more complex than the older system. It is under continual study. Readers interested in the development of the system should refer to the latest literature available.

The current system of classification has six categories. Beginning with the most inclusive, these categories are the order, the suborder, the great group, the subgroup, the family, and the series. The placement of some soil series in the current system of classification, particularly in families, may change as more precise information becomes available.

Table 5 shows, according to the current system, the classification of each soil series on the island by family and by subgroup, which also reflects the great group. It also shows one category - the great soil group - of the 1938 system.

Several subgroups, particularly in the order Inceptisols, correspond approximately to soil families according to the classification by Cline.

Family. -Families are established within a subgroup on the basis of properties important to the growth of plants or the behavior of soils when they are used for engineering. Among the properties considered are texture, mineral composition, reaction, soil temperature, permeability, thickness of horizons, and consistence.

Names of soil families consist of a series of properties used with the subgroup name. For example, the Waimea soils are classified in the medial, isothermic family of Typic Eutrandepts. The following list shows the criteria used for classifying soils on the island in families and gives definitions of the class names:

Class name	Definition
Ashy	More than 60 percent (by weight) consists of volcanic ash, cinders, or pumice, and less than 35 percent (by volume) is 2 millimeters across or larger, and apparent texture after prolonged rubbing is sandy.

Class name	Definition
Ashy-skeletal	Rock fragments more than 2 millimeters across make up 35 percent or more by volume, and the fine earth fraction is as defined for ashy.
Fine	Clay portion constitutes 35 to 60 percent clay in the fine earth fraction.
Medial	Term used when the soil consists of a mixture of discrete mineral particles and gels, and there is less than 60 percent (by weight) volcanic ash, cinders, and pumice in the fine earth; less than 35 percent (by volume) is 2 millimeters across or larger, and the fine earth is not thixotropic, and apparent texture after prolonged rubbing is loamy.
Cindery	More than 60 percent (by weight) consists of volcanic ash, cinders, and pumice, and 35 percent or more (by volume) is 2 millimeters across or larger.
Medial over cindery.	Medial material over cindery material.
Medial over fragmental	Medial material over fragmental Aa lava.
Medial over thixotropic	Medial material over smeary material.
Thixotropic over fragmental	Smeary materal over fragmental Aa lava.
Isohyperthermic	Soils that have less than 5° C. (9° F.) difference between mean summer and mean winter temperature and a mean annual soil temperature of more than 22° C. (72° F.).
Isothermic	Soils that have less than 5° C. (9° F.) difference between mean summer and mean winter temperature, and a mean annual soil temperature between 15° and 22° C. (59° and 72° F.).
Isomesic	Soils that have less than 5° C. (9° F.) difference between mean summer and mean winter temperature and a mean annual soil temperature between 8° and 15° C. (47° and 59° F.).
Acid	A pH less than 5.0 in 0.001M $CaCl_2$ (1 :1) throughout the control section (about 5.5 in H_2O, 1 :1)
Dysic	A pH less than 4.5 (in 0.01M $CaCl_2$) in all parts of the control section of a Histosol.

Class name	Definition
Euic	A pH of undried sample is 4.5 or more (in 0.01M $CaCl_2$) in at least some part of the organic materials in the control section of a Histosol.
Kaolinitic	More than half by weight consists of kaolinite, dickite, nacrite, tabular halloysite, and smaller amounts of other 1 :1 or nonexpanding 2 :1 minerals or gibbsite.
Mixed	Mixed clay mineralogy that contains less than 40 percent of any one mineral other than quartz.
Oxidic	Less than 90 percent quartz or less than 40 percent of any single mineral and the ratio of: $\frac{\text{percent extractable iron oxide and gibbsite}}{\text{percent clay}} \geq 0.20$

Series.-Classification of soils in series is described in the section "How This Survey Was Made," and each soil series is described in "Descriptions of the Soils."

LABORATORY ANALYSIS OF THE SOILS

Table 6 contains analytical data for eight representative soil series in the survey area. Each of the soil series was sampled at two locations. All samples were collected from carefully selected pits. Soil fragments larger than 1 inch across were discarded in the field. Fragments larger than 2 millimeters across were discarded in the laboratory. Soil samples were kept moist, but all capacity measurements are reported on an oven-dry basis.

The content of organic carbon was determined by wet combustion using the Walkley-Black method (1 milliegquvalent $K_2Cr_2O_7$ equivalent to 3.9 milligrams carbon).

Total nitrogen was determined by the Kjeldahl method modified by the Association of Official Agricultural Chemists.

Free iron oxide was determined by dithionite-citrate extraction and orthophenanthroline colorimetry, modified by shaking overnight instead of heating.

Bulk density was determined from core samples oven dried at 105° C. Two samples each were taken at 3-inch increments to a depth of 60 inches. The reported values are the means for the horizons.

Moisture retention was determined at 1/3 and 15 atmospheres using the Richards pressure membrane apparatus.

The pH was determined by glass electrode, using soil-water and soil-potassium chloride ratios of 1 :5, except 1 :1 ratios were used for Pakini, Kawaihae, and Waikaloa soils.

Cation exchange capacity was determined by direct distillation of absorbed ammonia after saturation with ammonium acetate.

Extractable calcium, magnesium, sodium, and potassium were determined by extraction with neutral normal ommonium acetate. Calcium and magnesium were separated with alcohol and determined by EDTA titration. Sodium and potassium were determined on original extracts using flame photometry.

Total analysis was determined by standard methods used by the Hawaii Agricultural Experiment Station of the University of Hawaii.

GENERAL NATURE OF THE ISLAND

This section describes the giology, physiography, and climate of the island and gives general information about the transportation, population, recreational facilities, and farming.

Geology and Physiography

The Island of Hawaii is the largest and youngest island in the Hawaiian group. It was built from the ocean floor by voluminous outpourings of lava from five volcanoes - Kohala, Mauna Kea, Hualalai, Mauna Loa, and Kilauea. The volcanos are believed to have started in the Tertiary period.

The Kohala volcano on the northern end of the island, 5,505 feet high, became extinct in the Middle Pleistocene. This volcano was deeply eroded on the windward side near the end of the Pliocene time.

Mauna Kea, the highest mountain, reaches 13,784 feet above sea level. The volcano has not erupted during historic time. It is built up of olivine basalt and covered with layers of volcanic ash. These individual ash layers vary in thickness from less than an inch to about 4 or 5 feet. During the Wisconsin stage of glaciation in North America, Mauna Kea was capped by a small glacier.

Hualalai mountain, 8,251 feet high, is built up of basalts. A large trachyte pumice cone of Puuwaawaa occurs on the northern slope. The last eruption of Hualalai, in 1800-1801, produced olivine basalt.

Mauna Loa covers an area of 2,035 square miles or 50 percent of the island. It is 13,680 feet high and last erupted in 1950. Mauna Loa and Mauna Kea receive an annual blanket of snow that lasts for a couple of months during the winter.

The Kilauea volcano, 4,090 feet high, originated on the southern slopes of Mauna Loa. Its lavas are largely olivine basalt. The flows in recent years have not been of the exploxive type, and it has been possible to observe them safely at reasonably close range. The most spectacular eruption occurred in 1959 when Kilauea Iki erupted and sent fountains of lava shooting 1,900 feet in the air. The following year, a flank eruption engulfed the town of Kapoho. Since then, many eruptions of short duration have occurred along the fissure zone.

The topography of the island reflects the volcanic activity. In the northern and eastern sections where volcanic flows have not occurred recently, the terrain has been eroded by rivers and streams. The stream pattern is more or less radial. The spaces between drainages are narrow. In the southern section the terrain is undissected, is quite barren, and reveals large areas of exposed lava.

The valleys draining the rainy, windward slopes of Mauna Kea are younger and therefore smaller than those of the Kohala Mountains. The dry western slope of Mauna Kea is largely undissected by stream erosion. The prominent gulches in the upper slopes of Mauna Kea have a distinct relationship to the glaciers which covered the top of the mountain during the late Pleistocene time. Shallow gulches drain the south-western slopes of Mauna Loa.

The Waimea plains were formed by the Mauna Kea lava ponding against the older Kohala Mountains. The plains are covered with volcanic ash. The Interior Plateau at Pohakuloa is covered with fresh lava from Mauna Loa banking against Mauna Kea and Hualalai.

Wave actions have eroded the basic rock and formed high sea cliffs that extend along the entire windward coast from Hilo northward to Kohala. These nearly vertical cliffs range from 50 to 350 feet in height. Along the leeward coast where there is less action, the cliffs are generally less than 50 feet in height.

Bays and sandy beaches are scarce along the rugged coastline. Hilo, Kailua, and Kawaihae are the largest bays. There are black sandy beaches at Kalapana, Kapoho, and Punaluu and a few scattered coral sand beaches on the western side of the island.

B. VEGETATION ECOLOGY OF THE HAWAIIAN ISLANDS

The following descriptions are brief and generalized, and do not attempt to account for all of the local variations present in such a complex area. They provide an orientation and facilitate the descriptions of the ecological patterns found on the individual islands. The ecosystems classification presented here draws upon the schemes of Hillebrand (1888), Rock (1913), Hosaka (1937), Robyns and Lamb (1939), Ripperton and Hosaka (1942) and Selling (1948) but is directly based upon Fosberg's (1972) guide prepared for the Tenth Pacific Science Congress.

1. PRINCIPAL TERRESTRIAL ECOSYSTEMS

METROSIDEROS FOREST: A broad-leafed evergreen forest usually dominated by trees of the genus *Metrosideros*, the ohia lehua of the Hawaiian. It is usually referred to as lehua forest locally. It is found in moderately moist or wet situations at fairly low to middle altitudes on the six larger islands, showing considerable variation in composition and structure in different habitats. In its simplest form it is an almost pure stand of *Metrosideros collina* var. *incana*, a sparse to dense forest of erect straight trees, varying in height with age and with the amount of available moisture. In certain favorable situations, as in the wettest part of the Kona slopes on Hawaii, they may reach 35 to 40 m. Homogenous stands of *Metrosideros* are found in all stages of development on relatively young lava flows and ash beds on the island of Hawaii. The seedlings commonly establish themselves on relatively new, scarcely weathered lava; in older habitats they start on the fibrous trunks of ferns such as *Sadleria* and *Cibotium*, then send down aerial roots to the ground, surrounding and strangling their hosts. In sufficiently wet areas older stands of Metrosideros commonly develop a dense understory of tree ferns of the genus Cibotium. On older forests more and more other species of trees are found mixed with the Metrosideros, also shrubs and epiphytes become very abundant. In dry areas of Hawaii and Maui, dwarfed open stands of Metrosideros are an important component of the dryland sclerophyll forest, described below.

Lehua forests are found on the slopes of the other islands, where they form a rather distinct zone above that dominated by Acacia koa. Here is the montane rainforest, a hallmark of tropical highlands. On the older volcanic domes, the lehua forest is more complex, with other genera, such as Bobea, Eugenia, Cheirodendron, and Elaeocarpus in places sharing dominance, and with many smaller trees, among them Psychotria, Antidesma, Xylosma, Tetraplasandra, Pittosporum, Coprosma, Ilex, Myrsine, Diospyros, Pelea, and Claoxylon making up a second tree layer. Groves and scattered individuals of Pritchardia palms are found. Shrubs of many genera such as Gouldia, Hedyotis, Dubautia, Clermontia, Cyanea, Cibotium, Cyrtandra, Touchardia, Rollandia, Pittosporum, Broussaisia, and Coprosma, form a prominent lower layer, and ferns, Peperomia, and a few other herbs, along with abundant mosses, cover the ground. Ferns of a number of genera, as well as a few other vascular epiphytes, climbers, such as Freycinetia, Alyxia, and Smilax and an abundance of bryophytes and some lichens are found on the trunks and branches of the trees. Leaf epiphytes are abundant. Openings tend to be filled with a Gleichenia. Recent disturbances, such as trails, are occupied by Paspalum conjugatum, Rubus rosaefolius, Eupatorium riparium, and other weeds. Landslide scars are occupied by ferns, sedges such as Machaerina, various weeds, and bryophytes.

Locally this forest becomes so mixed that _Metrosideros_ no longer can be regarded as the dominant species. Such genera as _Psychotria_, _Cheirodendron_, _Elaeocarpus_, _Eugenia_, and those listed above as making up the second tree layer form a mixture with no one species dominant, a usual situation in the tropics. This mixed montane rain forest merges upward with the cloud forest.

CLOUD FOREST: Above the _Metrosideros_ belt, on many of the mountains of the Hawaiian Islands, there is a cloud forest zone (Hosaka 1937). This is a mixed evergreen forest that is characterized by gnarled, spreading, much-branched trees, abundance of shrubs and great masses of epiphytic mosses, hepatics, ferns and vascular forms such as _Astelia_. Here _Psychotria_, _Metrosideros_, _Scaevola_, _Ilex_, _Pipturus_, _Eugenia_, _Dubautia_, _lobeloids_ of various sorts, _Myrsine_, _Cheirodendron_, _Pritchardia_, _Broussaisia_, _Cibotium_, and many other genera make up an endlessly varying vegetation that in sheltered places is of forest stature, while on exposed slopes, ridges, and crests it may be dwarfed and wind-sheared to a tangled scrub. In some places on wet crests it may even be reduced to grassy bogs, with dwarf shrubs and herbs approaching the open bogs described below. _Anoectochilus_, _Habenaria_, _Viola_, _Sanicula_, _Panicum_, _Peperomia_, _Phyllostegia_, _Vaccinium_, _Plantago_, _Lycopodium_, and various ferns are among the herbs and dwarf shrubs occuring here.

The cloud forest is confined to areas where cloud layers rest or blow by the greater part of the time, mostly on the windward slopes, upper ridges, crests and tops of the cliffs that face the trade winds. It is likely to be underlain by a gray soil not found in other situations and probably resulting from the low temperatures and percolating humic acid characteristic of this situation.

BOGS: In high, very rainy regions, especially on flat or gently sloping ground, true bogs are found. These are, according to Selling (1948, p. 46) both of the ombrogenous (fed by rain water) and soligenous (fed by both rain and ground water) types. They mostly have a substantial accumulation of peat and are underlain by light gray relatively impervious basal clays (Skottsberg 1940). Bogs occur at altitudes between 600 and 1765 m (Selling 1948, pp. 46-47), usually above 1200 m. Local distribution of those on Maui is well shown by Stearns (1946, Pl. 19).

The vegetation of most of the bogs is basically an irregular cushion of sedges, mostly *Rhynchospora lavarum* and *Oreobolus furcatus*. *Rhacomitrium lanugionosum*, a gray trailing moss, widely distributed in the world, and also found colonizing dry bare lava fields, is frequently abundant in the bogs. Grasses, especially dwarf species of *Panicum* and *Deschampsia*, ferns, such as *Sadleria*, *Polypodium*, *Hymenophyllum*, *Athyrium*, and *Schizaea* and other herbs such as *Lycopodium*, *Selaginella deflexa*, *Drosera* (Kauai only), *Plantago*, *Lagenophora*, *Viola*, and *Machaerina* are present, as well as shrubs or dwarf shrubs of *Vaccinium*, *Styphelia*, *Geranium*, *Ilex*, *Metrosideros*, *Pelea*, *Myrsine*, *Santalum* and *Cheirodendron*. Some of these, such as *Metrosideros*, are dwarf forms of the same species as occur in the surrounding forests. Others are special bog species or varieties, e.g., *Vaccinium pahalae*, *Viola kauaiensis*, *Lobelia gaudichaudii* var. *koolauensis*,.

The vegetation of these bogs is low and hummocky, with muddy channels between the hummocks, or a dwarf shrub, usually with scattered emergent shrubs to 1 or 2 m tall. The thickness of peat accumulation varies from very slight to as much as 3.2 m (Selling 1948, p. 62).

Typical Hawaiian open bogs are known on Kauai, Maui, and Molokai. *Sphagnum* bogs are found only in the Kohala Mts. of Hawaii.

Many attempts have been made to explain the existence of bogs on these tropical mountains, the most comprehensive one, which summarizes previous work, by Selling (1948). Most have been on the basis of climate and none have heen very adequate or convincing.

For years it has been noticed that certain Hawaiian forests are in poor condition, with many dead or dying trees. In some areas these are accounted for by the activities of grazing animals. This is especially true in dry areas and on cliffs and rough steep slopes. However, decadence of forest is also observed in very wet areas where there is no particular grazing; these areas are on comparatively level or gently sloping ground. The larger trees are dead or almost so, but usually there is a well developed stand of smaller trees or shrubs, including some or all of the same species as in the original forest. The stands are of varied statures, but within a stand the height is fairly uniform. These low forests do not seem to be young associations, as some of the taller ones, 4-6 m. have an abundance of old dead or partially dead taller trees, while in some lower stands, 1-2 m. standing dead trees are uncommon or rare. The lowest of these forests have been referred to as incipient bogs, and have well developed basal clay layers. One such stand east of Hanalei Valley, Kauai, where traversed by a road, shows a striking white clay substatum.

It is suggested that these decadent forests are stages in the process leading to the formation of bogs. Weathering of the basalt under cool, very wet conditions that permit an accumulation of humus and thus percolation of humic acid solutions yields clay (Wentworth et al. 1939). Formation of clay on level or gently sloping ground gradually impedes drainage, and brings about the accumulation of perches water on top of the clay. This drowns the rootsystems of the large trees, causing them to die slowly, as is seen in the decadent forests. They are replaced by smaller trees, more shallowly rooted. As the clay layer becomes more impervious and perhaps more extensive, the accumulation of water may become greater and may even drown the shallow root systems of the small trees. This process repeats itself, until the low forest, the shrub bog, and finally the very low sedge bog vegetation, are formed.

This gradual diminution process might also have brought about the evolution of dwarf races of such forest trees as Metrosideros that are in full flower when only a few centimeters tall.

METROSIDEROS WOODLAND WITH GLEICHENIA: On the moister aspects of the Island of Hawaii, especially, on relatively young lava flows, not yet deeply weathered, occurs a vegetation composed of thick, more or less continuous, blanket of Gleichenia linearis var. tomentosa with widely spaced Metrosideros collina trees. These trees vary in size from place to place but in any one stand are fairly uniform. Depending on the site, the Gleichenia may be from 0.5 to 2 m. deep and in thin places Macherina angustifolia, Dianella, Sadleria, and Lycopodium cernuum, as well as a number of weed species are fairly common.

This is interpreted as a normal succession, on relatively moist lava flows, leading to Metrosideros forest.

MIXED MESOPHYTIC FOREST: In areas a little less wet than the rain forests but not suffering an actual moisture deficit, and usually where the lavas have been well weathered, are evergreen or partially deciduous sclerophyllous to orthophyllous forests of very diverse composition. They may be predominantly of one species, such as Diospyros ferrea or Sapindus oahuensis, but they are commonly of many species, including some of the rarest Hawaiian trees. Hatheway (1952) names them "semi-deciduous seasonal forest," and "evergreen seasonal forest," and the distinction seems to rest on the presence or absence of certain species, e.g., Reynoldsia sandwicensis and Erythrina sandwicensis, which lose their leaves in the dry season. Both types seem actually to be highly variable and to be mosaics of groves of distinctive composition. The semi-deciduous type usually includes Sapindus oahuensis, Diospyros ferrea, Erythrina sandwicensis, Rauvolfia sandwicensis, Eugenia cumini, and Osmanthus sandwicensis, plus many other less constantly present species. Lantana is usually common in the undergrowth. The evergreen type usually includes Diospyros ferrea, Acacia koa, Eugenia malaccensis, Metrosideros collina, Osmanthus sandwicensis, and Myrsine lessertiana, plus many rarer or less constant species. It usually has little undergrowth.

These forests now occur on steep slopes at moderate to low altitudes. Similar forests may once have comvered much of the lower forest zone of Oahu, but grazing has largely destroyed them, leaving only those on slopes that are not easily accessible to cattle.

Another well known forest that seems to fit the mixed mesophytic category is the tall rich forest found in Kipuka Puaulu, above Kilauea volcano, (Rock 1913) and probably in other similar kipukas on the Island of Hawaii. Here Sapindus saponaria is the most abundant tree, sharing the rather open canopy layer with Metrosideros and Acacia koa. Psychotria (Straussia) hawaiiensis var. hillebrandii is most abundant in the second story, but Myrsine lessertiana, Pisonia umbellifera, Sophora chrysophylla, Coprosma rhynchocarpa, Pipturus albidus, Osmanthus sandwicensis, Pelea sp., Gouldia terminalis are also common. Here originally occurred some of the rarest trees in the Hawaiian flora, and, indeed, in the world.

Of Hibiscadelphus giffardianus, for example, no more than two or three trees were ever known, all from this one small kipuka. These were destroyed, along with most of the ground flora, by cattle which were pastured in the kipuka. Now most of the ground is covered by a dense growth of introduced grasses, with some of the ferns which have persisted. These moist forests have been little studied and even their distribution is not well defined.

ACACIA KOA FOREST: The best known of Hawaiian trees is the koa, sometimes called Hawaiian mahogany, It has long been used for furniture and musical instruments, because of its striking color and grain. It belongs to the Austrailian group of Acacia with leaves modified to phyllodes, but its closest relative, from which it is distinguished with difficulty, is Acacia heterophylla of Reunion Island, inthe Indian Ocean.

Acacia koa and two very closely allied species (or varieties), A. koaia and A. kauaiensis, dominate a distinctive sclerophyllous forest type found on most of the larger islands. Because of the nature of the foliage and the branching habit of the trees, the canopy presents an open dull green, almost bluish, appearance. However, where the canopy is dense, undergrowth is largely thin or lacking. On the older islands this community occurs generally below the main montane rain forest or Metrosideros belt, usually on leeward slopes under conditions somewhat drier than those prevailing in the rain forest and on fairly deeply weathered lavas. Here it has a considerable number of associated native species. Important native trees other than Acacia are Santalum freycinetianum, Myrsine kauaiensis, Psychotria (Straussia) mariana, P. kaduana, Metrosideros collina, Osmanthus sandwicensis, Bobea elatior, Charpentiera obovata, Pisonia umbellifera, Sapindus oahuensis, and Dodonaea viscosa. Spontaneous introduced species are Psidium guajava and P. cattleianum. Shrubs are Scaevola gaudichaudiana, S. chamissoniana, Wikstroemia oahuensis, Pipturus albidus, Cibotium splendens, Styphelia tameiameiae, Lantana camara, Cordyline fructicosa, Canthium odoratum, Sadleria cyatheoides, and Schinus terebinthifolius. Ground vegetation is meager, with almost no bryophytes and only a few ferns, such as Pteridium, Sphenomeris, and Nephrolepis exalta, Psilotum nudum, and a few herbs, such as Oplismenus hirtellus, Paspalum orbiculare, P. conjugatum, Carex oahuensis, Commelina diffusa, Dianella sandwicensis, Hedychium spp., Peperomia reflexa, P. leptostachya, and a few weedy Compositae. Vines, such as Alyxia, Freycinetia, Dioscorea spp., Ipomoea spp. are occasional. Ephiphytes are few.

On steep gulch walls in this forest type are open areas, probably mostly landslide scars, occupied by mats of Gleichenia linearis. The rhizomes of this fern are prostrate, either on the surface of the ground or shallowly buried. The branching fronds arise from the rhizomes and form a bright green color of these patches makes them identifiable from a considerable distance.

On Hawaii the koa is most prominent in a zone above the montane rain forest on both windward and leeward aspects. Here also it occupies a drier habitat than the rain forest and occurs on fairly young lava and ash surfaces, though it does not seem to be as much of a pioneer as Metrosideros. It has far fewer associated species than on the older islands. Metrosideros collina var. incana is common, and locally, Sophora chrysophylla and Myoporum sandwicensis as well. Except in the more dense groves, the shrub species that form the scrub at comparable altitudes are found, along with their accompanying grasses and herbs. Grazing has greatly altered this vegetation, especially the herbaceous layer, and has in most places inhibited regeneration of the koa.

Although the koa first occupied a large area, especially in pre-European time, and appears quite stable where not disturbed, it may really represent a long continued successional stage, leading to a mixed mesophytic forest where the substratum is deeply weathered. On the older islands, at the altitudes where koa forest is found, the gulch bottoms are generally occupied by Aleurites forest, which may have replaced koa in pre-European times. In modern times a great proportion of the koa forest has been cleared and replaced by pastures and pineapple plantations, some of it later planted exotic trees such as Eucalyptus.

ALEURITES FOREST: In gulches and along stream courses at moderate to low altitudes, Aleurites moluccana (kukui) forms dense stands composed almost exclusively of this species. The canopy is usually complete, of a pale frosty green color. The trees are closely to widely spaced, depending on their size, with spreading crown, their height greater the deeper and narrower the gulch in which they grow. Undergrowth is scarce or lacking. Aleurites seedlings are locally abundant. A few ferns, such as Nephrolepis exalta, Thelypteris dentata and T. parasitica may occur with a very few other shade tolerant herbs, but these forest usually exhibit poor diversity.

PSIDIUM GUAJAVA FOREST AND SCRUB: One of the commonest vegetation types in moist to wet areas at moderate to low elevations in the islands is a dense solid stand of the guava, introduced many years for its edible fruits and scattered by birds and pigs. It is now likely to be found almost anywhere below middle altitudes where vegetation on moist or wet land has been disturbed sufficiently to permit its establishment. Spreading and reproducing very readily from root sprouts, it is extremely difficult to eradicate. The trees are generally crooked, and diffusely branched, with smooth trunks and branches, and broad thin leaves. Their height, up to 10 m or more, seems almost in direct proportion to the available moisture, though guava spreads so rapidly that there are frequent areas of scrub stature that will develop into forest. In places there is an admixture of Schinus terebinthifolius and Leucaena leucocephala. The ground is likely to be covered by Commelina diffusa, Oplismenus hirtellus, Paspalum conjugatum, or ferns, to a density more or less inversely proportional to that of the guava canopy. There is often an alternation between guava forest and #Aleurites forest on slopes, with the #Aleurites in the bottoms of draws and gullies. It has principally replaced koa, mixed mesophytic, and mixed lowland forests.

PSIDIUM CATTLEIANUM FOREST: In many wet or mist areas, especially in koa, lehua, and mixed lowland forest, Psidium cattleianum (strawberry guava), or in places, a related species, P. littorale (waiwī), has gained a foothold or been planted. P. cattleianum, especially, tends to spread rapidly and to form almost pure thickets or forests. It is well adapted to growth in the wet forests and its seeds are spread by birds and pigs. Structurally this type is about the same as the Psidium guajava forest, but the leaves are thicker and glossy, darker green. Where P. littorale is dominant the trunks are distinctly taller and straighter. Many shade tolerant species are able to establish themselves in this type and Psidium littorale is, by some, regarded as a valuable "nurse tree" in the process of restoring to abundance some of the native forest plants.

LANTANA SCRUB: A widespread scrub formation, found on all the large islands, especially in areas that are neither excessively rainy nor excessively dry, is made up of solid stands of Lantana camara, of tropical American origin. It has replaced large areas of Metrosideros, mixed mesophytic, mixed lowland, and dry sclerophyll forests. This aggressive, unpleasantly prickly aromatic plant varies in stature from 0.5 to 3 m or even more in favorable spots. Usually it forms a dense scrub 1-2 m tall, the stems are tough, up to 2-3 cm thick, with hooked prickles when young, making it exceedingly difficult to traverse. It may occupy otherwise open slopes or it may fill the spaces between scattered trees or in open forest. Thirty years ago this vegetation type was spreading and very aggressive. Since then a considerable number of insect parasites have been introduced to control it with some measure of success. On Oahu many areas formerly covered by Lantana scrub are now occupied by Leucaena leucocephala. On Maui and Hawaii large areas are defoliated and not in a healthy condition. Leucaena and Schinus terebinthiofolius both seem able, slowly, to replace Lantana as it is weakened by the parasites.

LEUCAENA SCRUB: In rather dry to moderately wet area at low to middle altitudes, especially in disturbed places, roadsides, abandoned fields, and dry sloped, in former koa forest, dry sclerophyll and mixed lowland forests, Leucaena leucocephala (usually incorrectly L. glauca) forms dense solid stands, usually 2-4 m tall. The fine, feathery, dark green, bipinnate leaves are produced in great profusion and made a dense shade. The tall straight stems reach 2-5 cm in thickness and grow very close together. The ground is often covered by a dense carpet of seedlings of the same species. On Oahu, Leucaena has been able to replace Lantana in recent years.

PASTURES: Articicial pastures in Hawaii are very diverse in species composition and somewhat diverse even in structure. Under the term pasture are here included those areas where the native vegetation has been largely removed and replaced by a herbaceous cover, principally of grasses but often with a considerable admixture of leguminous and other broadleaf herbs. Excluded are native grasslands at high altitudes and on coastal bluffs, as well as areas of scrub and scrub-forest that are used for grazing, and the coastal Prosopis forests that are an important source of forage. These are described under special headings. Most of the pasture grasses and herbs, especially in the moister areas, are exotics, mostly deliberately introduced and often specifically sown or planted. Frequently, overgrazing has favored species that are not considered desirable for forage. In none of the pastures can the vegetation be said to be in equilibrium with the environment, as there is frequent overgrazing and at the same time continual attempt at pasture improvement by planting desirable species and eliminating undesirable ones. In some areas erosion is a problem.

Pastures, in the sense used here, are found on all the larger islands (Ripperton and Hosaka 1942), but most extensively on the west slopes of Haleakala, Maui, and on the lower and middle northern and western slopes of Mauna Kea and in the Waimea Saddle, Hawaii. In regions wetter than these, especially along the windward coasts of Maui and Kauai, many areas have been cleared and converted to pasture, but they tend to be invaded by shrubs, especially guava, Lantana and Schinus, and to develop a scrub vegetation. Only constant effort and expense will prevent this, and the invasion is favored, in the long run, by overgrazing.

In regions that are at all moist or wet the grass cover is continuous, often forming a compact sod. In areas where Panicum maximum, P. Purpurascens, or Melinis minutiflora are dominant, the grass tends to be quite tall, if not heavily grazed. Generally the stature is low, Clandestinum are dominant, or where grazing is heavy, only 10-30 cm. Few other generalizations can be made. In dry areas, in the rain shadows of the islands, where grasslands occur, the cover is generally open, with substratum showing, the grasses tending to be tufted or straggly. Some native grasses, especially species of Panicum, persist and are even important components of the vegetation. On Hawaii, in such areas, Pennisetum setaceum (fountain grass), reported as rare 20 years ago (Ripperton and Hosaka 1942), has become widely dominant, changing the structure of the vegetation to one of large stiff moderately spaced tussocks. Locally, also, in these drier areas, Opuntia megacantha occurs in some abundance. Formerly it was much more abundant but the introduction of an insect parasite, Cactoblastus, has controlled it to some extent and reduced its competitive ability. Overgrazing, especially in the drier pastures, tends to encourage the development of a low scrub of Dodonaea viscosa, one of the few native plants that seems to hold its own against cattle.

Artificial pastures have replaced substantial areas in the koa forest the Metrosideros forest, the dryland sclerophyll forest, the mixed mesophytic forest, and the mixed lowland forest ecosystems, so far as can be determined now. Good historical records have not been available as to what was present on much of this land before the ranches were established, and only be inference from remnants of vegetation and from the physiographic situation can picture of the former conditions be reconstructed. It is probably safe to assume that with a change such as that from forest to pasture, ecological conditions have tended to become more xeric, and that the forest that formerly occupied a pasture areas was more mesophytic than the present environment would indicate.

In the northern part of East Maui at low elevations, in areas with 1500 mm or more rainfall per year, Paspalum conjugatum and P. orbiculare are usually dominant, except within 1 km of the seam where Digitaria henryi and Desmodium triflorum are more abundant. Setaria geniculata is locally replacing the dominants. Recently there has been much planting of Digitaria decumbens (pangola), Desmodium canum, and D. introtum. Other common species in this area are Centella asiatica, Nephrolepis exalta, Digitaria pruriens, Sporobolus africanus, Cassia leschenaultiana, Sacciolepis indica, Cuphea carthagenesis, and Cynodon dactylon.

On the lower west slopes of Haleakala, where the land is not planted to pineapples and sugar cane, but above the Prosopis belt, pastures are largely made up of Cynodon dactylon (Bermuda grass), with a considerable admixture of Tricholaena rosea, Medicago lupulina, and Desmodium uncinatum. Other important species are Chloris gayana (Rhodes grass), Medicago hispida (bur cover), Melilotus indica (yellow sweet clover), Digitaria violascens, Chloris virgata, Paspalum dilatatum, Anagallis arvensis (scarlet pimpernel), and Sida fallax (ilima).

On the same slopes of Haleakala, but above the areas just described between 760-900 to 1500 m, is a pasture of Sporobolus africanus and Trifoleum repens, with substantial areas of Cynodon dactylon, said to have been formerly the dominant species here. Important species associated with these are Hypochaeris radicata, Pteridium aquilinum (bracken), Eragrostis brownei, Vicia angustifolia (vetch), Anthoxanthum odoratum (sweet vernal grass), Holcus lanatus (Yorkshire fog or "mesquite"), Bromus catharticus, Plantago lanceolata, Melinis minutiflora (molasses grass), Rumex acetosella (sheep sorrel), Digitaria Pruriens, Poa pratensis, Danthonia pilosa (Wallaby grass), Lolium perenne (perennial rye grass), and Dactylis glomerata (orchard grass or cocksfoot).

Above this, between 1500 and 1900 m on the west and northwest slopes of Haleakala, where the land is not covered by scrub, the pastures are mostly dominated by Anthoxanthum odoratum and Holcus lanatus in varying proportions, with Trifolium repens, and Pteridium aquilinum present in considerable amounts. Also noticeable here are Dactylis glomerata, Sporobolus africanus, Trifolium procumbens, Poa pratensis, Prunella vulgaris, and Rumex acetosella.

On the Island of Hawaii, in the Waimea section of the vast Parker Ranch, plants commonly found in the pastures are Digitaria decumbens, Pennisetum clandestinum (kikuyu grass), Cynodon dactylon, Medicago hispida, Medicago lupulina, Trifolium repens, Dactylis glomerata, Lolium perenne (perennial rye brass), Bromus catharticus, Opuntia megacantha (panini or prickly pear), Pasapalum dilatatum, and Hypochaeris radicata.

In the Waikii area, higher up on the west slopes of Mauna Kea, the common species are Pannisetum clandestinum, Paspalum dilatatum, Cynodon dactylon, Poa pratensis, Lolium perenne, Dactylis glomerata, Trisatum glomeratum, Panicum tenuifolium, Eragrostis grandis, Sporobolus africanus, Tricholaena rosea, and Bromus catharticus.

PLANTED FORESTS: In many places in the islands are various types of planted forests. Frequently they are blocks composed of single species, especially Eucalyptus robusta and other species of this genus, Melaleuca quinquenodia, Grevillea robusta, Acacia dealbata, Cupressus macrocarpa, Araucaria excelsa, and other conifers. Certain planted species have become naturalized and have spread, such as Acacia dealbata, Casuarina stricta, and Citharexylum spinosum. In addition to these plantations made for purely forestry purposes, there are small orchards of Persea americana (avocado) and Macadamia integrifolia (macadamia nut or Queensland nut), and several species of bamboo.

Although much of the forest planting in Hawaii has been on pasture land, this land was originally occupied by all the major forest types the greater portion koa.

MIXED LOWLAND FOREST: Along wet lower slopes and in the mouths of all but the drier valleys there existed a moist mesophytic forest which has been mostly destroyed or so altered that its original composition is now quite uncertain. Metrosideros was doubtless a component. If Pandanus, Calophyllum and Hibiscus tiliaceus occurred in the pre-human Hawaiian flora they belonged here, if introduced by the Polynesians they have found their places in this belt, as did Eugenia malaccensis, Phyllostachys, Aleurites, and Cocos, and later arrivals such as Eugenia cumini, E. jambosa, Psidium guajava, P. cattlemanum, Persea, Samanea, and Terminalia catappa.

At present this forest presents an irregular aspect, more a mosaic of small patches of other forests than an integrated entity. However, Pandanus, Eugenia malaccensis, E. cumini, and Hibiscus tiliaceus and others of the above list reproduce themselves effectively and with their associates do form a recognizable forest belt.

The stature of this forest varies, but is considerable, Its shrub layer is likely to be of guava, Leucaena, Lantana, or a mixture, the density varying inversely with that of the canopy. The herb layer consists of a few weeds, especially Oplismenus, Commelina, Ruellia, and abundant seedlings of the tree and shrub species. Vines, such as Ipomoea spp., Mucuna, and Thunbergia alata are common in the margins. Epiphytes are uncommon. Native plants are not at all common, but doubtless a well developed indigenous flora once existed here, now replaced by late-comers.

FRESH WATER MARSH: On the windward sides of some of the older islands, are a few areas of fresh water marsh land. Most of these are now gone, those on Oahu being either filled in and changed into housing areas, or dredged out. Those on Kauai, in Hanalei valley have long since been converted to rice fields. It is quite probable that all or most of these areas were used for taro culture, as low spots on windward Maui are today. A few small areas of these marshes persist, mostly solid wet meadows of *Panicum purpurascens,* such as Kawainui Marsh, Kailua, Oahu, and a few patches of tall *Scirpus*.

DRYLAND SCLEROPHYLL FOREST: Large areas of dry coastal slopes and higher rain shadows, probably most of the relatively dry areas below 1500 m, were originally covered by an open scrub forest, principally of broad-sclerophyll trees. A few scraps and traces of this remain, mostly on rough lava flows, on the two largest islands, and even these are mostly in a sad state of degradation from overgrazing.

The simplest of these forests are almost pure stands of *Metrosideros collina* or of *Diospyros ferrea* var. *pubescens*. More generally they include mixtures of several species and some have a considerable number, including many of the rarest Hawaiian plants. The most notable forest of this type was at Puu Waa Waa on the Island of Hawaii. Many species were described from there and some have been found nowhere else. This has been used for many years as a cattle ranch and the forest is now very degraded.

In its best development this is a low closed forest, the trees with rounded crowns. More commonly it is open, the trees not touching. What occupied the spaces between them, originally, is not certain, but some of the native shrubs, such as *Abutilon*, *Gossypium*, *Euphorbia*, *Nototrichium*, *Chenopodium*, *Dodonaea*, *Wikstroemia*, and *Sida* occur in this sort of habitat, but usually now with *Prosopis.*

This is one of the most important of the original forests types of the Hawaiian Islands. It is the one that has suffered most from the activities of man, and is now almost gone.

PROSOPIS FOREST: In dry lowland areas around all the larger islands is a forest of Prosopis pallida (keawe). This flat-topped leguminous tree, related to the mesquite of northern Mexico and southwestern United States, was introduced in 1828. It was rapidly spread by cattle that eat the sweet pods and void the seeds.

The forest varies from dense to open, even to savanna, and from a scrub 2 m tall up to 10 m or more tall. The trees have flat-topped spreading crowns and tiny leaflets. Although many relatives of this species are deciduous in their native habitats, in the Hawaiian Islands, at least, it is nearly or quite evergreen. In open stands the spaces may be occupied by various grasses, herbs, and shrubs, especially Acacia farnesiana and Lantana camara. Even in closed stands there is often a ground cover of weedy herbs. Some forests are so dense as to shade out even these. Locally the Prosopis may be partly or even wholly replaced by Pithecellobium dulce (opiuma) of similar habitat.

This vegetation has replaced large areas of open dry grassland and of dryland sclerophyll forest. In all probability most of its present area was once sclerophyll forest. Here, in a few places, may still be found Abutilon incanum, with a remarkable distribution, Hawaii and southwestern North America, and Gossypium sandwicense, an endemic cotton.

HETEROPOGON GRASSLAND: On steep dry leeward lower slopes and cliffs, especially on truncated lava spurs where the soil is this or almost lacking, are grassy areas that may have been free of forest for a long time. Early records speak of the west side of Kauai as bare, and of grassy plains and hills around Honolulu. It is not known whether such places were already grassy before the coming of the Polynesians, but it seems certain that by the time of the first Europeans large dry lowland areas were treeless and mainly covered by Heteropogon contortus (pili grass), the material used by the Hawaiians in the construction of their houses. This is a pantropical species and may conceivably have been brought by the Polynesians, but may well have been here before their arrival.

At the present time most of the parts that were grassy 200 years ago are forested with Prosopis or covered by scrub of Lantana, Acacia, Schinus, Opuntia, or Leucaena. This is especially true of the flatter lands and gentle slopes, also wherever there is any significant depth of soil. Heteropogon is still dominant on very steep slopes, ledges on cliffs, and eroded areas, though it has in many places been invaded, and even crowded out, by such introduced grasses as Tricholaena rosea, Digitaria insularis, and Melinis minutiflora. A great many broadleaf weeds are common in these grassy ledges and slopes, also.

OPUNTIA SCRUB: On many leeward, dry areas, usually at rather low elevations, the vegetation is dominated by Opuntia megacantha. This huge, swollen, spiny plant, in places, forms dense thickets up to 3-4 m high, mixed with Lantana, Acacia, Prosopis and other xerophytic shrubs, as well as Heteropogon contortus and various dry land weeds. In some pasture areas at moderate to low elevations, these thickets, here mostly Opuntia, furnish an important supplementary forage for dry periods.

This formation resulted from the introduction by man of Opuntia, and has certainly replaced principally Heteropogon and dryland sclerophyll forest. The introduction of the moth, Cactoblastus cactorum, to control the cactus has already resulted in a considerable reduction of its vigor and degree of dominance in many areas. It is likely that this vegetation type will soon disappear from the islands.

WET CLIFFS: Along the windward sides of the islands, and even on leeward exposures in certain deep amphitheater-headed valleys, are great fluted wet basalt cliffs, up to a thousand meters in height, with almost no soil and little vegetation. Ferns and Selaginella are common, and Pilea, Artemisia, Eragrostis, Phyllanthus sandwicensis, Hedyotis, Lythrum maritimum grow in crevices. Dwarfed plants of Metrosideros, Vaccinium, and other cloud forest trees and shrubs, even Pritchardia, inhabit ledges. Very wet areas here are the habitat of Gunnera, the enormous-leafed ape-ape. However, recent years have seen striking changes in the vegetation even of these inaccessible places.

An interesting feature of some of these cliffs is the presence in tiny pockets, or hanging valleys, of colonies of Aleurites moluccana and even of Musa sapientum (bananas), the seeds and rhizomes of which could only have been brought down by torrents from above.

DRY CLIFFS: Even less is known of the vegetation of dry basalt cliffs, such as exist on the Waianae side of Oahu, on valley walls of southeast Oahu, on valley walls of southeast Oahu, the windward side of Lanai, around Haleakala "Crater," and in various other locations in the rain shadows of the islands. Wisps of grass occur on ledges - Heteropogon and Tricholaena at low altitudes, Deschampsia and Trisetum higher up. Such shrubs as Lantana camara, Leucaena leucocephala, Acacia farnesiana, Prosopis, Canthium odoratum, and several native Euphorbia species occur on ledges at lower altitudes. Artemisia, Plectranthus, and Peperomia may also be found here, along with many weeds.

In many areas, goats are very common on such cliffs, and have denuded surfaces of what vegetation was originally there.

STRAND: The strand -- the shoreline and the zone immediately back of it that is strongly influenced by the sea -- has in many parts of the Hawaiian Islands been so completely disturbed that it is hard to tell what it was originally like, but in other parts it seems to have preserved its physiognomy and even its native species remarkably well. It has been described by MacCaughey (1918).

Four main subdivisions may be made with little difficulty, which present quite different ecological characteristics and which exhibit striking differences in vegetation, though some of the same species occur in all of them. These are wet sandy, wet rocky, dry sandy and dry rocky strands. In some places they are rather intimately mixed, especially where sand has blown onto rocks. Also there are varied degrees of wetness and dryness.

The Hawaiian Islands have perhaps less than their expected share of the widespread strand plant species, naturally, though some have been introduced and have become naturalized, such as *Tournefortia argentea*, *Terminalia catappa*, *Batis maritima*, and perhaps *Paspalum distichum* (*P. vaginatum*). There are a number of locally endemic strand species, either developed from chance immigrants from elsewhere, such as *Nama sandwicensis* and *Jacquemontia sandwicensis*, or derived from Hawaiian upland genera, such as *Santalum ellipticum* var. *littorale*, *Achyranthes splendens*, *Euphorbia degeneri*, succulent forms of *Myoporum sandwicense*, and forms of *Chenopodium oahuense*.

The physiognomy of the Hawaiian strand vegetation is not strikingly different from that in similar habitats elsewhere. On rocky windward shores the vegetation tends to be low and wind- (or spray-) sheared, even the species that are normally trees become depressed to creeping shrubs with most of the branches on the side away from the wind. Rock cliffs are frequently bare except for tufted plants, such as Fimbristylis cymosa and Hedyotis insignis. If wooded, such cliffs are usually covered by Hibiscus tiliaceus, Pandanus tectorius or Scaevola taccada. Lower rock shores, above the waves but still within reach of the spray, may have a depressed scrub or Scaevola taccada, and locally Santalum ellipticum, with Sesuvium portulacastrum and Fibristylis cymosa forming patches and and tufts in bare areas. On dry cliffs and slopes of tuff or disintegrating lava, Jacquemontia sandwicensis, Sida fallax, Boerhavia mutabilis, B. repens, and Fimbristylis cymosa are common. On limestone, rock shores, elevated coral reefs, Capparis sandwichiana, with its beautiful nocturnal flowers, Portulaca lutea, Chenopodium oahuense, Sesuvium portulacastrum, Lycium carolinianum, and Fimbristylis cymosa form a depressed vegetation, and Thespesia populnea forms occastional low clumps of scrub.

On low sandy areas the Prosopis forest is likely to approach close to the top of the beach, especially on lee shores. The beach vegetation may have Ipomoea pes-caprae subsp. Brasiliensis, Ipomoea stolonifera, and a few other hardy weeds. Where the sand is piled up in dunes, Heliotropium anomalum, Vitex ovata, Sesbania tomentosa, Scaevola taccada, Nama sandwicensis, Tribulus cistoides, Euphorbia degeneri, Sida fallax, Jacquemontia sandwicensis, Sporobolus virginicus, and Atriplex semibaccata occur in varying smounts and proportions. All have some tendency to bind the sand. The sand is usually of coral, but locally there are beaches and small dunes of "black sand," which is volcanic material, largely olivine. Here the flora is extremely poor, Ipomoea pes-caprae and a few weeds being the only plants found binding the sand at Kalapana, Hawaii, for example.

In places just back of the beaches are depressions which contain marshes or ponds, either salt or brackish. The water level fluctuates with the tide and the salinity depends on whether they are on leeward or windward coasts, this because leewards coasts are much drier, so that less surface and ground water reaches the sea through these ponds. The leeward ponds tend to have a solid succulent dward scrub vegetation of Batis maritima around their margins and in very shallow water. On slightly ground is a belt of low scrub of Pluches indica, or on still higher ground, of Pluchea odorata, a remarkable shrub with an ecological amplitude that permits it to grow in almost any situation from these saline flats to the rain forest near the top of the Koolau Mts. Atriplex semibaccata and, locally, Atriplex rosea, dominate sandy or silty flats back of the Batis zone, sometimes sharing this situation with Sesuvium portulacastrum. Surrounding these areas of very halophytic vegetation are less saline belts of a more weedy herbaceous vegetation, including among many other plants, Achyranthes aspera, Cenchrus echinatus and its native variety hillebrandi, Reichardia tingitana, Chloris inflata, Plumbago zeylanica, Cressa truxillensis, and several species of Euphorbia. On the windward side similar marshes and ponds are much less saline. Growing in them may be seen Scirpus cf. lacustris, with Paspalum distichum, forming dense sod around the margins, also Bacopa monnieri.

Such ponds were formerly used and improved as fish ponds by the old Hawaiians, and were very important in the economy. Now there are almost none left. The introduction of mangroves has tended to change them to mangrove swamps, and the development of subdivisions, harbors, and marinas has eliminated completely many of the finest of them. These marshes are not only important as a part of the natural Hawaiian landscape, but as refuges, breeding and feeding grounds for numerous species of water and shore birds. The attitude that a marsh is necessarily waste land, means the end of these birds in the near future unless our educational process becomes rapidly more effective in creating a sense of values that has a place for nature.

MANGROVE SWAMPS: Mangrove swamps were lacking in the Hawaiian Islands prior to the beginning of this century. After several species of Rhizophoracceae were introduced they rapidly spread into favorable habitats and swamps developed at a number of places, especially at Heeia, Oahu and west of Kaunakakai, on the south coast of Molokai, where they filled fish ponds and occupied shallow muddy places (MacCaughey 1917a, Fosberg 1948). At least three species were introduced, Rhizophora mangle, Bruguiera gymnorhiza, and Bruguiera parviflora. The latter, while persisting, has never become common. B. gymnorhiza is common near the fresh-water end of the salinity gradient at Heeia, above the bridge. Rhizophora mangle is the abundant species on the seaward side in all the swamps and the one that has colonized many places around the coasts. Thus the mangrove formation here is very impoverished in species, compared with those in most tropical countries. However, physiognomically it is quite typical.

SOPHORA-MYOPORUM PARKLAND: On the Island of Hawaii, above the koa and lehua forests, and interfingering with them in places and up to an uneven timberline, is an interrupted belt of a vegetation dominated by Sophora chrysophylla (mamani) and Myoporum sandwicense (naio) with scattered clumps of Acacia koa in the lower parts. It varies from an open forest to a savanna, and in places is interrupted by areas of grassland, scrub, and bare lava. The trees are rather scrubby, or at least spreading, with full crowns. Between them once grew a rich herbaceous flora and many shrubs, especially Styphelia, Vaccinium and Chenopodium oahuense.

This complex has been called mountain parkland (Robyns and Lamb 1939). Apparently this was an open forest formation even in pre-European times, and probably also in pre-Hawaiian times, as no activity of the early Hawaiians would very likely have seriously changed anything on these high lava and ash slopes. This parkland has been degraded, and nearly destroyed by the unrestrained grazing of feral sheep.

2. VEGETATION PATTERNS OF THE HAWAIIAN ISLANDS

ISLAND OF HAWAII: Hawaii is the largest, the highest, the youngest, and the most complex of the Hawaiian Islands. It exhibits a corresponding environmental diversity, with altitudinal zonation from sea level to well above timber line; climatic variation from orographic rainy regions and soaking bogs to desert rain shadows; and a complete range of primary ecological successional stages from fresh lava to rain forest on deep ancient soil.

Its vegetation pattern reflects this environmental complexity. The vegetation is built from a relatively small flora and in no place does it exhibit the richness in composition found in many tropical continental areas. However, in spite of this rather restricted floristic composition, a remarkable diversity of physiognomic and structural types has developed. Present day vegetation includes many types and many species of plants not present before the advent of man. Of course, these have, over large areas, replaced the vegetation and species that were there before. Reconstructing past vegetation must, at best, rest largely on informed guessing and in many places there is not even any information on which to base a guess. It seems clear that, in spite of an initial increase in diversity with the arrival of new aggressive plants, the general trend is toward much greater uniformity, as the successful immigrants are mostly species of great ecological amplitude. A few species tend to cover great areas and to replace many local insular endemics. The present pattern, with some reference to the past is, in broad strokes, about as follows:

Along the windward coast of Hawaii mixed lowland forest once formed a continuous belt, except where high cliffs fell directly into the sea. Its original nature can scarcely be surmised, and its extent only guessed at. At present it exists as an extremely varied mosaic of stands of Aleurites, Pandanus, Calophyllum, Eugenia cumini, Eugenia malaccensis, Hibiscus, tiliaceus, Metrosideros collina, and various mixtures of these with each other and with other species. It extends from the Kalapana region around as far as Hilo, interrupted by new lava flows and villages. Its inner limits are doubtful and it merges with various inland types. In many areas it has been replaced by guava forest and thicket. From Hilo to the Waipio valley and in the Kohala area it has been replaced by a continuous belt of sugar cane plantation up to 500-600 m level, the forest persisting (unless replaced by guava scrub), only in the lower courses and mouths of the abrupt stream gorges and ravines that cut the lavas of this coast. The mixed forest is also found on the floors and lower slopes of the great gorges of the Kohala Mts., along the north coast, where it gives way in places to taro culture. The montane rain forest forms a strip above this to about 1200 to 1600 (or even 2000) m. It is a thick forest, generally dominated by Metrosideros and in many areas with a conspicuous understory of Cibotium (tree ferns). This rain forest extends from just west and north of Kilauea to the Kohala Mountains, but is largely replaced in the Waimea area by pasture. Where lava flows have cut across this forest they are mostly covered by open Metrosideros and Gleichenia.

Above the montane forest, still on the windward side, is a belt of Acacia koa forest, with considerable Metrosideros, varying from a closed forest to open park-like areas with patches of forest in grassland. This seldom reaches 2000 m, usually less. Over large areas it has been destroyed and replaced by pasture.

The leeward sides of the island below 2000 m are mostly a rain-shadow varying in degrees of dryness. At the lowest altitudes around the coast, from somewhat east of Kalapana to Upolu Point on the Kohala Peninsula, lies a belt of xeric forest and scrub, giving way to grass in places on rock ridges and exposed points. Prosopis pallida is the dominant tree over much of this woodland, locally mixed with or replaced by Pithecellobium dulce (opiuma). These trees, with Acacia farnesiana (klu) and Leucaena leucocephala (koa haloe) forming a shrub layer, make up a microphyllous, often spiny, closed to open forest or scrub, or a savanna. In certain areas the sclerophyllous Diospyros ferrea (lama) and associates, such as Erythrina sandwicensis (wiliwili) persist, usually as scattered individuals or open stands. In other areas the coast is covered by bare black lava flows. The highly xeric belt usually occurs on the relatively flat coastal strip, but locally on the northwest and southeast coasts it may reach 300-500 m elevation. Above this is a belt slightly more mesophytic, but still definitely xerophytic. In some areas there may occur an open sclerophyllous forest of native trees, mostly degraded by grazing. It may be a mixture but if often dominated by Diospyros or by a very sclerophyllous form of Metrosideros. Large areas have been covered by scrub of Lantana, Leucaena, Schinus terebinthifolia or Dodonaea, with Opuntia locally abundant. Other areas are grassy, with Heteropogon contortus, Pennisetum setaceum and other introduced grasses. Much of this vegetation is used as pasture and frequently overgrazed. It tends to be more and more mesophytic upward. First it is a belt of mesophytic to subsclerophyllous trees with few ferns or epiphytes. The latter become more numerous until in some areas true montane rain forest, some of it very well developed, prevails. Such forest, seemingly out of place in a rain shadow, results from frequent convection showers, which occur in the lee of very high mountains. The greater part of this forest, where the slopes are not too steep or the lava too rough, is cleared and replaced by coffee plantations, pastures, and small farms. Strips of new lava and older lava in various stages of vegetational development cut across this at frequent intervals. Metrosideros is the principal tree species in the succession on lava as it is in the mesophytic and montane rain forests. Upward the stature of the forest diminishes and the epiphytes vanish. The montane rain forest is replaced by an interrupted belt of open nesophytic forest. In places this is a forest of Acacia koa, in others of a mixture of trees, including Myrsine, Santalum, Dodonaea, and Metrosideros. At the lower edges, Metrosideros is dominant with a moist carpet of moss on the ground. Upward the character of the forest becomes more xerophytic and it is more or less continuous, at least on the southeast side of Mauna Loa, with the koa belt that extends around the windward side at middle altitudes. Here, especially in the Kilauea region, are "kipukas" or patches of a rich mixed mesophytic forest on old deeply weathered soil, surrounded by fields of newer lavas, with koa and Metrosideros forests and grass. A small kipuka of this sort exists, also, on Puu Huluhulu, in the Humuula saddle between Mauna Loa and Mauna Kea, at about 2000 m elevation.

In the Kilauea-Kau region, also, considerable sections in this belt are grassy or grassy with scattered trees, very possibly as the result of a long history of grazing. Another conspicuous feature in this same region, but at a somewhat lower altitude, is the Kau Desert, an elliptical area extending south and southwest from Kilauea Caldera and almost devoid of vegetation. Much of the desert is relatively fresh lava, pumice, and ash, but this is scarcely sufficient to explain the general paucity of vegetation. The long-continued effect of the sulphur dioxide fumes drifting down-wind from the volcano, or some peculiarity in the topography intensifying the rain-shadow effect, may be partly responsible. There is certainly a marked decrease in rainfall in the vicinity of Kilauea.

On the southwest side of the island, the north slope of Hualalai has open Metrosideros forest with a mossy ground cover at around 1200-1800 m. Below are extensive areas of rough lava with open xerophytic forest, once a very rich mixture of local endimic species, now much degraded by grazing between Hualalai and Mauna Loa and Hualalai and Mauna Kea, but little information is on record as to their character.

North of Hualalai, and extending over the Waimea Saddle, between Mauna Kea and the Kohala Mts., and up toward Humuula Saddle, is an enormous area of pasture, locally degraded to a low scrup of Dodonaea and Wikstroemia;

some areas are dominated by *Pennisetum setaceum; mostly it is a mixture of introduced pasture grasses. The pastures extend far up the slopes of Mauna Kea and well around on its windward slopes.

On the Humuula Saddle and down toward Waimea are areas of tussock grass and of open scrub of Chenopodium oahuense. This vegetation is now much torn up by military maneuvering with heavy equipment. Much of the area in the Saddle, itself, is covered by fresh lava flows, one as recent as 1935 and bare vegetation.

The four large mountains on the island are strikingly different in their vegetational aspects, as well as geologically.

The top of the Kohala range is covered by very low wet forests, bogs and incipient bogs. The windward side is cut by spectacular gorges. Sphagnum is abundant at the heads of these gorges, Gunnera, also, as well as a rich shrubby flora.

Hualalai is a clinkery mass of cinder and spatter cones, lava flows, and ash beds. The vegetation is an open high altitude scrub of Styphelia, Coprosma, Dodonaea, Wikstroemia, and Santalum, in varying proportions, with scattered Sophora, Myoporum, and Metrosideros trees, and patches of forest of these species. Some of the upper cones and lava are almost bare.

Mauna Kea is surrounded, between 2000 and 3000 m, by a belt of forest or open woodland or parkland of Myoporum and Sophora, vividly described, both in its original state and present degraded condition by Warner (1960, see above). Mixed with this woodland, and above it, are areas of scrub of Styphelia, Vaccinium, Geranium, Dodonaea, and Coprosma. The scrub reaches a higher altitude on this mountain than elsewhere, possibly because the substratum is principally of ash. Above the scrub is an almost bare volcanic landscape in the summit area (Hartt and Neal 1940).

Mauna Loa, on the other hand, has what is essentially a timber line between 2000 and 2300 m with occasional lobes of forest reaching a bit higher. The upper forest may be of koa, Metrosideros, or of Myoporum and Sophora. In some areas the typical scrub of high altitudes is well developed above the forest and in interruptions in it. Most of the vast dome of Mauna Loa, however, is covered by barren slag-like lava flows, with xerophytic moss, ferns and rufts of grass in the crevices (Fosberg 1959). In kipukas above the forest, surrounded by lava, are patches of scrub. On the newer flow surfaces plants are hard to find.

The most interesting vegetational feature on the Island of Hawaii is the great complex of successional stages on lava flows of different ages and different climatic exposures, on windward and leeward slopes, and in convection areas. These cannot be described briefly. Several preliminary studies have been made of them (Forbes, 1911; Robyns and Lamb, 1939; Doty, in progress), but the results have only indicated how diverse are the successions involved and how difficult it is to generalize effectively about them. It is clear that on moister aspects the development of vegetation is very much more rapid. The most common primary tree colonist is Metrosideros collina (lehua). Under many circumstances a population of lehua develops directly, preceded only by the very earliest pioneer stages of ferns, lichens, and mosses. This scrub or forest usually may be rather open, and ther intervening surface, where sufficiently moist, is commonly soon occupied by Sadleria and especially Gleichenia ferns. Where drier this may be replaced by scrub of Dodonaea, Vaccinium Styphelia and other shrubs. In a more advanced stage an understory of Cibotium (tree ferns) develops and may become very luxuriant, in wet areas. Gradually other, more meshophytic trees come in, and the typical mixed mesophytic forest develop on moist, and montane rain forest on wet, flows. In drier areas the original population of *Metrosideros* may persist indefinitely, or perhaps may be replaced by dry sclerophyll forest. There are no observations to substantiate any conclusions about succession on the dry flows except that it is exceedingly slow.

ISLAND OF MAUI: Maui, with its two high volcanic domes connected by a very low isthmus, might almost be regarded as two islands. West Maui is much older and more deeply eroded of the two, and is only 1762 m high. There has been no volcanic activity since late Pleistocene. East Maui, of Haleakala, on the other hand, reaches 3139 m and has been the site of lava flows probably as late as 1750. It still shows large exposures of scarcely or slightly weathered lava and ash. Its upper parts extend above the level of trade wind rain and on its leeward south slopes the rain-shadow effect is strongly developed.

The windward north and east slopes of Haleakala are wet and densely forested, up to altitudes of 1800 to 2100 m, with well developed montane rain forest, except below 300 m and above 1800 m, where the lehua forest is partly replaced by the somewhat less hygrophilous koa forest. This forested region extends around the east end of the island and on the south slope almost to the Kaupo Gap, where it gives way abruptly to grass. The gulches, in their lower parts are mostly filled with *Aleurites* (kukui) forest, and in their mouths by mixed lowland forest, which also extends all along this wet coast in the lower 100 m or so. Northwest of Hana there are some fine examples of the *Pandanus* forest phase of this mixed type. Considerable areas of these lower slopes, and in places up to 300 m, have been cleared and converted to pasture, much of which is strongly invaded or occupied by *Psidium guajava.* Near Keanae are lowland marshes used for *Colocasia* (taro) culture.

The west slopes of Haleakala, up to 1800 to 2000 m, have been almost completely converted to mesophytic pasture, mostly of exotic pasture plants, or, at very low elevations, to pineapple plantations. The south slopes, below 1500 m, are mostly barren lava beds, with sparse grass, and locally, a few sorry remnants of the once extensive dryland sclerophyll forest. These persist where the roughness of the lava has to some extent discouraged the hungry cattle. The lowest parts of these lava beds, on the southwest corner, even though much more gently sloping to the sea, are almost completely bare of vegetation. Going north along the coast to the Isthmus, the lowest slopes bear Prosopis forest, and above it much of the pasture is interspresed with areas of Lantana scrub and Opuntia. Above 1500 m on the leeward side and 1800 to 2000 m on the more moist exposures, is very sparse to well developed high altitude mixed microphyllous scrub, with some areas of tussock grassland and some of Sophora woodland with either grass or scrub in the space between the trees. The summit ridges and much of the inside of the "crater" are lava desert, dry cliffs, and desert ash and cinder slopes with almost no vegetation. On some of these slopes, though, are scattered rosettes of the spectacular silversword, Argyroxiphium, certainly the most famous vegetational feature of Maui. Locally in the "crater" are areas of sparse scrub, and near the bases of the cliffs, thin stands of Pteridium.

A large part of the Isthmus, the gentle lowest northwest slopes of Haleakala, and the lowest slopes of West Maui, up to the break where the steep slopes begin, also the lower 500 m on the west side, are planted to sugar cane, with only some of the ravines and gulches woodes. The lowest and driest parts of the Isthmus are covered by Prosopis forest, except for the towns and an area of salt marsh around Kealia Pond on the south side.

The lower north slopes of West Maui are in lush green pasture except for the deep wooded gulches which radiate out from the high mountain mass. The south slopes of West Maui, up to 1000 m or more, are extremely barren and seriously eroded. Some grass and bits of scrub retain a foothold, with brush in the gulches. This barren area extends around somewhat onto the east and west slopes. Above this, and above the plantations and pastures, the mountain is covered by thick, soaking montane rain forest, except where the wet cliffs are too steep for more than thin scrub, and on the flat or gently sloping summit and uppermost ridges, where there are extensively developed open bogs. These West Maui mountains exhibit stupendous erosion features, and form on of the richest botanical regions in the islands.

ISLAND OF OAHU: Oahu, third largest of the Hawaiian Islands, is made up to two old volcanic domes, both apparently down-faulted on their seaward sides, leaving tremendous cliffs facing the sea and gentler slopes toward the depression that separates them. The topographic expression of these domes takes the form of two roughly parallel mountain ranges, the Waianae Range on the west side, the Koolau Range on the east, trending northwest-southeast. The Waianae Range is older, higher, and much more rugged, almost skeletonized by headward erosion. Its highest peak, Puu Kaala, is flat topped and 1227 m high. The Koolau Range is lower, reaching 946 m in Puu Konahuanui, back of Honolulu. The fluted cliffs along its windward side, facing generally northeast, are truly spectacular. The vegetation of Oahu, except above about 500 m in the Koolau Range and on a few steep slopes in the Waianae, has been completely altered by man.

In the Koolau Range, at middle altitudes where the slopes are not actually cliffs, the forest is well developed montane rain forest, dominated by Metrosideros. Landslide scars, covered by Gleichenia Linearis, are very common and show all stages of succession back to forest. Above this, along the main crest and down some distance on the long ridges, is scrubby cloud forest, and on some peaks and crests, open peaty spots with dwarfed vegetation approaching bog conditions. At the head of Kaipapau Valley is a small bog that has some of the special bog plants otherwise found only on the other islands (Fosberg and Hosaka 1938).

The windward cliffs, continually drenched by orographic trade wind rain and covered by clouds, are too steep to have much vegetation except on ledges and in tiny hanging valleys. At their bases are pockets of Aleurites forest and Metrosideros with a rich undergrowth flora of such hygrophytic plants as Cyrtandra. Below this, in the valley bottoms, is mixed lowland forest, with Eugenia malaccensis abundant near the foot of the mountains, Mangifera indica (mango) locally abundant, Pandarus, Hibiscus tiliaceus, Psidium guajava, and Eugenia cumini nearer the coast. Ridges that separate these valleys, where they run down toward the coast, are mostly covered with guava forest and scrub, or closer to the coast, with Lantana and Leucaena scrub. At Heeia there is a small but well developed mangrove swamp. There were formerly good coastal dunes, with an interesting vegetation, at Kaneohe and Waimanalo, but they are largely gone, as is most of the lowland and beach vegetation, because of the development of residential areas and military installations. The tuff cone on Makapuu Peninsula, called Ulapau Head, is rather dry and the vegetation is a thin Lantana scrub. Most of the marshes and ponds along the windward coast thave been filled or dredged out, but Kawainui marsh is still fairly extensive. Its original vegetation, however, is entirely gone, replaced by a solid stand of Panicum purpurescens, which is grazed by cattle. A number of small islets along the windward coast, mostly tuff cones, but one or two remnants of elevated reefs, preserve bits of native vegetation or at least a few native species. Most of them are protected as bird refuges, though the protection is not very effective.

Toward the east end of the range conditions, on both sides of the mountains become drier and the vegetation becomes xerophytic. Lantana scrub, Heteropogon grassland, and Prosopis cover much of the ground (Egler 1947). Scarcely a trace remains of the dryland sclerophyll forest that formerly was dominant.

On the leeward side of the Koolau Range, below the lehua forest, koa forest and possibly extensive areas of mixed mesophytic forest formerly occupied large areas. A little koa remains in gulches and on some of the narrow ridges. The flatter remnants of original lava flow slopes have been almost entirely cleared for pineapple fields, and, in their lower parts, sugar cane. Some traces of native vegetation remain in the gulches. In the koa belt the gulches are filled with Aleurites forest, which stands out against the steep valley walls because of its pale green color. Large areas on the leeward slopes and on the flatter land below are now occupied by the City of Honolulu nad its suburbs, and other towns. Much of this land was formerly grassland, probably Heteropogon, which now only remains on steep lava cliffs and tuff cone slopes. Middle slopes, too steep for houses, have Leucaena and Schinus scrub. The lowest and dryest areas, where not covered by houses, are mostly Prosopis forest. Some, such as on Koko Head, are so eroded that almost no vegetation remains.

The Waianae Range, mostly in the rain shadow of the Koolau, is much drier and has montane rain forest only on the highest crests and on the small plateau and upper slopes of Puu Kaala. The top of Kaala is an almost swampy forest, but has been altered by military establishments and by the introduction of the blackberry, Rubus penetrans, which makes prickly tangles. Some of the steeper slopes and hanging valleys on the sides of the Waianae Mts. still retain fine mixed mesophytic forests. Most of them however, have been seriously altered by grazing and the forests are in a degraded condition or have been changed by attempts at reforestation. Large areas are covered by Lantana and guava scrub especially on the lower slopes. Aleurites occupies many of the gulches. The base, where not covered by military establishments or sugar and pineapple plantations, is mostly Prosopis forest. Dry spurs on the leeward side have Heteropogon and Opuntia where there is any vegetation. On the Ewa Coral Plain, southwest of Pearl Harbor, is extensive Prosopis forest with areas of Agave sisalana (sisal). Kaena Point, the western extremity of the island, has some fairly well developed sand dune strand vegetation, with a number of native plants.

ISLAND OF KAUAI: Kauai is principally a single enormous, deeply dissected volcanic dome, with several subsidiary domes and cones, and considerable flat or gently sloping land on the lower slopes. Its highest peak, Waialeale, 1576 m, does not reach high enough to be above the orographic rainfall levels, and receives an enormous precipitation. Kauai is the oldest of the larger islands of the group, and has the most highly evolved flora, with many endemic species. Its vegetation has been altered in many parts, but some of the higher areas are still in much their natural condition.

The top of the dome is covered by cloud forest, very decadent where the terrain is flat or gently sloping, and with extensive bogs (Selling 1948). Below the cloud forest is montane rain forest, and on the higher western slopes, some excellent koa forest. The valleys on the north side are the same sort of stupendous gorges that are seen on other high windward coasts, with wet cliff vegetation, in some of the valleys much damaged by goats. Kalalau Valley, especially, has suffered from the depredations of these feral animals. In the bottoms of the valleys are areas of mixed lowland forest, and its _Pandanus_ and _Hibiscus tiliaceus_ phases are also abundant on the bases of the cliffs above the shore. Hanalei Valley has extensive rice and taro fields occupying former marshes. Many of the more moist lower slopes on the eastern side of the island are of bauxitic soil, too sterile for successful plantation agriculture. They are covered by a poor pasture vegetation with much scrubby _Melastoma_, guava-scrub, and, especially in ravines, a phase of the mixed lowland forest with _Pandanus_, _Eugenia cumini_, _Psidium guajava_, and _P. cattleianum_, the two latter frequently forming pure forests. _Leucaena leucocephala_ is abundant, as is _Lantana camara_. The vegetation of these bauxitic soils is being studied by Moomaw and Takahashi (1960) and some experimental work is being done on revegetation of denuded areas.

The Haupu Range, one of the subsidiary domes, on the southeast corner of the island, is partially denuded, but has extensive _Lantana_ scrub and _Aleurites_ forest, as well as guava thickets. The south slopes of the mountains have pasture just below the forest, and the lower parts are extensive sugar cane plantations. The coastal strip is dry and has some large areas of _Prosopis_ forest. In places plantations approach very close to the shore. On the west side, back of a broad strip of _Prosopis_.

forest, rise bare grassy, eroded slopes. These were more or less bare, or perhaps covered by Heteropogon and xerophytic shrubs even in pre-European times. Now overgrazing and erosion have made the slopes far more barren. Upward the grassland gradually merges into scrub and into the koa forest.

The south slopes of the main mountain mass are cut by stream erosion into tremendous gorges, rivaling those on the north slope in size, but much drier and with less vegetation. Waimea Canyon has been referred to as the Grand Canyon of Kauai. The walls are thinly grassy, with wcrub on the ledges, tiny strings of kukui forest in ravines. In the bottom of the upper part of the valley are kukui forests and some mixed lowland forest. Further down, the walls are covered by thin Leucaena scrub, and Opuntia, and with some Heteropogon grass. In the lower parts of the valley bottoms are Prosopis forests and pastures, with, in some areas, cane plantations.

There has been much exploration of Kauai from a floristic standpoint, but very little has been written on its vegetation.

Representative Algal Genera

S. E. Oahu (Reef Area)

Cyanophyta

Brachytrichia
Catothrix
Entophysalis
Lyngbya
Phormidium
Rivularia

Chlorophyta

Acetabularia
Boodlea
Dictyopheria
Enteromorpha
Struvea
Udotea

Chlorophyta

Caulerpa
Cladophora
Codium
Halimeda
Neomeris
Siphonocladus
Ulva
Valonia

Phaeophyta

Colpomenia
Dictyota
Ectocarpus
Hydroclathrus
Padina
Ralfsia
Rosenvingea
Sargassum
Sphacelaria
Turbinaria
Zonaria (incl. Pocockiella)

Rhodophyta

Acanthophora
Actinotrichia
Amansia
Amphiroa
Asparagopsis
Botryocladia
Centroceras
Chondrococcus
Dasya
Galaxaura
Geldium
Haloplegma
Hemitrema
Hypnea
Jania
Laurencia
Liagora
Plocamium
Porolithon
Tolypoiocladia
Wurdemannia

S. Kona Coast Hawaii (No Reef)

Cyanophyta

Entophysalis
Scytonema
Calothrix
Rivularia
Brachrichia
Lyngbya

Chlorophyta

Enteromorpha
Ulva
Halimeda
Codium

Phaeophyta

Ectocarpus
Sargassum
Ralfsia
Dictyopteris
Chnoospera
Padina

Rhodophyta

Ahnfeltia
Caulacanthus
Porolithon
Actinotrichia
Hemitrenia
Gaacilaria
Gelidium
Peyssonelia
Acanthophora
Centroceras
Galaxaura
Asparagopsis

C. FAUNA

1. ANCIENT AND RECENT VERTEBRATE LIFE

The fact that the Hawaiian Archipelago is isolated by open ocean is the most important factor in the development of prehistoric animal life. Birds constituted the principal early immigrants, hence it is significant that the only unquestionably native mammal is the Hawaiian bat (Lasiurus semotus).

Ancient bird life originated from many points of the compass. The ancestors of the honey creepers probably arrived from South America, and the honey eaters are similar to those found in Australia and New Zealand. A later arrival, the predecessor of the present species of flycatcher, is also considered Australian in origin. The thrushes seem most closely related to Polynesian, Melanesian, and Malaysian species. The non-migratory goose (Branta sandvicensis) and duck (Anas platyrhynchos wyvilliana) closely resemble the Canada Goose and Mallard in structure. The sub-specific coot (Fulica americana alai) and gallinule (Gallinula chloropus sandvicensis) are similar to the North American types. The distinct Hawaiian stilt (Himantopus himantopus knudseni) is most likely derived from an American ancestor which in pre-historic times found it unnecessary to migrate to survive. The sea birds, and owl (Asio flammeus sandwichensis) are sub-species of birds with world-wide distribution. The native crow (Corvus tropicus) is similar in appearance to the Australian crow. The hawk (Buteo solitarius) is considered closely related to the Swainson's hawk of North America.

The establishment of these unique birds took place over a long period of time, and it is thought that all of the diverse forms of land birds may have evolved from as few as 16 original immigrants. The

Hawaiian honey creeper family (Drepaniidae), with members whose bill structures vary from thick and finch-like to sickle shaped, may have originated from a single ancestral type. Another factor in this unusual specialization is the extreme variety of habitats found in these islands.

It is certain that a central core of regular migrants return to Hawaii each year from the Pacific Coast of North America. Most of these birds are shovellers (Spatula clypeata) and pintails (Anas acuta) with a few Baldpates (Anas americana) and Scaups (Aythya sp.), turning up each year. A variety of chance migrants have been noted. The annual waterfowl census numbers between 1,500 and 5,000 birds with a high of 10,462 recorded in 1953. Numerous species of shore birds have been seen over the years, but the most common are the wandering tattler (Heteroscelus incanum), rudder turnstone (Arenaria interpres interpres), and Pacific golden plover (Pluvialis dominica fulva). The latter is noted for its spectacular 2,000-mile non-stop flight to and from the Aleutian Islands each year.

The early Polynesian navigators brought with them domestic animals as well as food plants. The aboriginal jungle fowl has been domesticated for years but soon went wild in the uninhabited forests. The pig, varying in color from white to red, striped to spotted, reverted readily to a wild state. At the present time it is a truly wild animal and, in remote areas, uniformly black in coloration with a distinct "razor-back." The dog, although usually preferring the company of man, has formed isolated wild packs which raid sheep flocks, and even roam near Honolulu. Although the Hawaiian rat (Rattus hawaiiensis) is termed native, it is believed that it arrived in the canoes of the first settlers along with the common house mouse (Mus musculus). Before the arrival of the first white explorer at least one species of gecko and one skink were extant on Hawaii. These were of a variety common to the South Sea area, and very likely arrived with the Polynesians.

The larger domestic animals were brought in primarily as gifts for royalty by the first explorers. In some cases the chiefs, not knowing of their usefulness, placed a "kapu" on them and they were free to revert to a wild state. Captain Cook introduced an English breed of goat in 1778, and at the same time left a type of pig which readily crossed with Hawaiian variety. Domestic sheep (probably a Merino breed) and cattle were landed at Kealakekua in 1794 by Vancouver. Horses were brought to the Island of Hawaii in 1803. In most cases these domestic animals were unrestricted by fences and with vast wild lands to roam in, soon multiplied and became serious problems in the native forests.

Frogs and toads were introduced from Japan and America as early as 1867 by the Royal Agricultural Society. There are no snakes in Hawaii except for a secretive blind snake and of course various species of sea snakes. Skinks and geckos in addition to those mentioned above were probably introduced accidentally on shipping and there are a total of 7 species now recorded.

Domestic cats probably arrived on the first shipping, and are common on all the major islands in a wild state. They are an important predator on ground nesting birds. The Indian mongoose (Herpestes griceus), the only weasel-like animal in Hawaii, was introduced from Jamaica, West Indies, in 1883 to rid the sugar cane fields of rodents. In a short time it was found that not only were they ineffective but that they were pests to poultry farms and wild birds. They are found on all the main islands except Kauai where they were prohibited entry. The Norway rat (Rattus norvegicus), black rat (Rattus rattus rattus) and white-bellied rat (Rattus rattus alexandrinus) arrived on the first shipping. As in other areas these animals are pests to foodstuffs and carriers of disease.

Although rabbits have been very carefully excluded from the main islands, Belgian Hares and other varieties have been established on "Rabbit Island" off Oahu since 1903.

Beginning in the middle 1800's, many birds were introduced for hunting, for the control of noxious insects, and for esthetic reasons. The earliest established game bird (1875) was the Chinese ring-necked pheasant (Phasianus torquatas) which is now common on all the major islands. A subsequent release of Japanese blue pheasants (Phasianus versicolor versicolor) about 25 years later filled a wetter habitat. The two types hybridize readily. From a release of 40 chukar partridge (Alectorus graeca chukar) on Hawaii in 1949, the population exploded to an estimated 35,000 in 10 years. It is found most abundantly in the mountainous areas of Hawaii and Maui. Other important game birds which are hunted include the California quail (Lophortyx californica californica), Japanese Quail (Coturnix coturnix japonica), Barred dove (Geopelia striata striata), lace-necked dove (Streptopelia chinensis chinensis) and feral pigeon (Columba livia). Domestic turkeys (Meleagris gallopavo), pea fowl (Pavo cristatus), and guinea fowl (Numida meleagris galeata) were introduced between 1815 and 1874 and are found in a semi-wild state on many islands.

Many birds have been brought in for economic purposes, the most common of which is the Indian Mynah (Acridotheres tristis) which was introduced to control cutworms (1865). Others, such as the ricebird (Munia nisoria) escaped from cages and have since become a nuisance to crops.

Almost a hundred birds have been introduced to Hawaii from all over the world with varying degrees of success. A few important establishments include the English skylark (Alauda arvensis arvensis) from New Zealand, white-eye (Zosterops palpibrosus japonicus) from Japan, Peking nightingale (Liothrix lutea) from China, linnet (Carpodacus mexicanus frontalis) from California, and, inevitably, the English sparrow (Passer domesticus).

The introduction of these birds had an undesirable effect on the native song birds, particularly the highly specialized honey creepers and honey eaters. Changing land usage and exotic diseases contributed to the extinction of many native forms. The mamo (Drepanis pacifica), oo (Moho nobilis), moho (Pennula sandwichensis) and probably others are considered extinct. However, on the Island of Kauai, it has recently been determined that there are no extinct species--an exciting discovery. The Islands at the present time number over 70 species of birds found nowhere else in the world including the hawk, crow, goose, thrush and flycatcher.

If left to time alont it is certain that many land forms of birds would never reach Hawaii. The introduction of exotic birds and animals to Hawaii continues in an effort to fill voids in the habitat for the benefit of sportsmen and agriculturists. The barn owl (tyto alba pratincola) has been released on the Island of Hawaii to further combat rodents. The cattle-egret (Bubulcus ibis) has been introduced to get rid of insects associated with livestock. A long list of game birds are being tried including the bobwhite (Colinus virginianus texanus). Gambel's quail (Lophortyx gambeli), Reeve's pheasant (Syrnaticus reevesi), Barbary partridge (Alectoris barbara barbara), Rio Grande trukey (Meleagris gallopavo), and various private interests are importing these birds from mainland game farms or directly from their native country, and none are considered established as yet.

Big game animal introductions are a little more difficult to plan, as landuse conflicts, disease, and availability often prohibit entry. However, the European Mouflon sheep (<u>Ovis musimon</u>) and North American prong horn (<u>Antilocapra americana</u>) have been successfully released recently on Island of Lanai and reproduction has occurred. Also, on Hawaii, the Mouflon is being hybridized with the local feral sheep in an attmept to upgrade the appearance and habits of present animals. On Mauna Kea, Hawaii's glaciated mountain peak, the formerly domestic sheep have ravaged many parts of the forest despite constant hunter pressure. It is hoped that the new hybrid will be less detrimental to the flora.

The most successful large mammalian import to date is the Axis deer (<u>Cervus axis</u>) introduced to Molokai in 1868, and to Lanai sometime after 1920. A beautiful spotted deer of the Indian variety, it soon adapted itself in most cases to the hot open lowland forests of these islands. Although transplanted to Maui in 1959, it is not yet established there. Except in isolated instances this animal is nowhere a problem and limited hunting seasons are opened each year.

In summary, the Hawaii Islands originally boasted one of the most unique, albeit limited, faunas to be found in the world. With the advent of man and all the ramifications of agriculture, introduced animals, and changing land uses, many of these animals became reduced in numbers, or even extinct. Fortunately government controls were put into effect before any further damage could be done. Through strict quarantine against disease, and research as to the effects of exotics on the existing wildlife, the prevention of further extinction of primitive forms if being effected.

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2. LAND MOLLUSCA

The endemic land molluscan fauna of Hawaii is represented by the families Zonitidae, Helicarionidae, Endodontidae, Succineidae, Achatinellidae including Tornatellininae, Amastridae, Pupillidae, Helicinidae, and Hydrocinidae. Over 1,000 endemic forms comprise these families.

A few forms which were introduced accidentally or on purpose compose a minor but economically important part of the lowland fauna. Standouts among these immigrants are Achatina fulica, Subulina octona, and six species of the old genus Opeas (Stenogyridae=Achatinidae); Euglandina rosea (Oleacinidae); Gonaxis kibeziensis, and G. quadrilateralis (Streptaxidae); Bradybaena (=Eulota) similaris (Helicidea); the zonitids Hawaii minuscula and Zonitoides arboreus; and the slugs Veronicella leydigi, Limax flavus, Limax maximus, Deroceral laeve, and Philomycus carolinianus. This is due to the fact that the natural balance between the flora and fauna has been upset severely through the introduction of plant and animal pests like the lantana and the rat, to name only two. As a consequence, endemic native snails, with certain exceptions, live only on certain native plants and this under forest conditions. When the plants go, so do the snails.

In most places, the native forest begins at ±1200 feet. The bulk of the native snails also begin showing at this level. The lowland has been deforested for agriculture and other human activities.

The principal and commonest host plants on which the arboreal snails live are as follows: olopua (Osmanthus), ha'a (Antidesma), kolea (Myrsine), lehua (Metrosideros), kukui (Aleurites), alani (Pelea), ti (Cordyline), olomea (Perrottetia), kalia (Elaeocarpus), kanawau (Broussaisia), manono (Gouldia), and pilo (Coprosma) among native plants; grava and waivi, two forms of Psidium, immigrant.

The ground-dwelling snails use the fallen dried leaves of these and other plants and their twigs and trunks in their decaying stages as shelter and feeding grounds besides the usual talus and other cover.

The endemic snails are thought to subsist on algae and fungi and the term "host plant" should not mislead the biologist.

The genus Achatinella is confined to Oahu where it may be found together with Auriculella, Leptachatina, Amastra and Philonesia. Its congeners Partulina, Perdicella, and Newcombia are scattered on all the remaining outer islands except Kauai, Niihau, and perhaps Kahoolawe.

3. MARINE FAUNA

OAHU EXAMPLES

The coastline of Oahu at Black Point consists of a basalt outcrop massive blocks fronting directly on the sea. The basalt blocks are interrupted by tidepools of varying size and small, rubble-surfaced coves.

The dominant faunal element of the spray zone are the molluscus. Populations of Littorina pintado Wood and Nerita picea Recluz are conspicuous, and occasional specimens of Siphonaria normalis Gould also occur here. The grapsid crabs, Grapsus grapsus tenuicrastatus (Herbst) and Pachygrapsus plicatus (Milne Edwards) scurry over the rocks, and associated with them seaward is Plagusia depressa tuberculata (Lamarck).

The tidepools harbor a rich and varied fauna. Of the coelenterates, the sea anemones Marchanthea cookei Verrill and Bunodactis nigrescens (Verrill), occupy sandy bottoms and crevices respectively; and the "soft" coral, Zoanthus nigrescens Verrill coats the sides of pools. Eichinoderms include the ophiuroids Distichophis clarcki Ely, Amphiura immira Ely, and, beneath small clumps of algae, Ophiactis savignyi (Muller and Troschel). Commonly found holothurians are the black Holothuria atra Jager and the brown and white Actinopyga mauritiana (Quoy and Gaimard). Tidepool molluscs include several species of Conus, C. abbreviatus Reeve, C. ebraeus Linn., C. pennaceus Brug., C. lividus Hwass, and C. flavidus Lam., and two species of Cymatium, C. chlorostoma Lam. and C. pileare Linn. Beneath loose rocks are the gastropods Peristernia chlorostoma Sowerby and Mitra litterata Lam. and the bivalve Isognomon costellatum Conrad. Occasional specimens of Cypraea caputserpentis Linn. are also encountered beneath loose rubble and in crevices. In sandy areas of the pools, the enteropneust Ptychodera flava laysanica Spengel occurs. Crustaceans are represented by the colorful bandana prawn, Stenopus hispidus (Olivier) and the snapping shrimp Alpheus pacificus (Dana) while empty gastropod shells are occupied by the hermit crab, Calcinus herbsti De Man. Several species of portunid crabs abound in the sand and among the rock rubble, Charybdis japonica (A. Milne-Edwards), C. orientalis Dana, and Thalamita arenata. Care should be exercised in handling loose rocks because of the presence of "fireworm", Eurythoe pacifica Kinberg.

The fish fauna of the tidepools is made up of a number of well known species. Istiblennius zebra (Vaillant and Sauvage) occurs in

REPRESENTATIVE BIRDS

FOREST AND HIGHLANDS

(Scientific names from Peterson, 1961, Field Guide to Western Birds)

Apapane (*Himatione sanguinea*)

Iliwi (*Vestiaria coccinea*)

Amakihi (*Loxops virens*)

Creeper (*Loxops maculata*)

Elepaio (*Chasiempis sandwichensis*)

Introduced Species

Red-billed Leiothrix (*Leiothrix lutea*), SE Asia

White-eye (*Zosterops japonica*), Japan

Spotted dove (*Streptopelia chinensis*), Asia

Barred dove (*Geopelia striata*), Malaysia

Booby colony at Ulupau Head; Moku Manu-Sea Birds

Booby (*Sula sula*)

Brown Booby (*Sula leucogaster*)

Frigate bird (*Fregata minor*)

Sooty tern (*Sterna fuscata*)

Possibly Albatross (*Diomedea nigripes*) and others

Shore and Water

Hawaiian Stilt (*Himantopus mexicanus*)

Golden Plover (*Pluvialis dominica*)

Turnstone (*Arenaria interpres*)

Tattler (*Heteroscelus incanum*)

Sanderling (*Crocethia alba*)

Black Crowned Night Heron (*Nycticorax nycticorax*)

Possibly ducks and others

MAMMALS AND REPTILES OF THE KONA AREA, HAWAII

MAMMALS

Hawaiian bat, Lasiurus semotus

House mouse, Mus musculus

Hawaiian rat, Rattus exulans hawaiiensis

Alexandrine rat, Rattus r. alexandrinus

Black rat, Rattus r. rattus

Norway rat, Rattus norvegicus

Mongoose, Herpestes griseus

REPTILES

Mourning gecko, Lepidodactylus lugubris

Fox gecko, Hemidactylus garnoti

Stump-toed gecko, Peropus mutilatus

Moth skink, Leiolopisma noctua

Azure-tailed skink, Emoia cyanura

Snake-eyed skink, Ablepharus boutonii poecilopleurus

CHECK LIST OF MARINE INVERTERBRATES KONA AREA, HAWAII

SPECIES	Tidepool	Inlet	Coast	Sub-tidal
Coelenterates				
Pocillopora damicornis	X			
Pocillopora meandrina				X
var. nobilis				
Porites sp.	X			
Dendrophyllia manni	X			
Cyphastrea ooellina	X			
Porifora				
Spirastrella keaukeha	X			
Black Sponge	X			
Annelids				
Terebellid	X			
Eruythoe sp.	X			
Mollusca - Gastropods				
Bursa bufonia	X			
Cerithium nesioticum	X			
Conus abbreviatus	X			
" distans	X			
" hebraeus	X	X		X
" imperialis	X			
" lividus	X			X
" nanus	X	X		
" rattus	X			
" vermiculatus	X			X
Cymatium chlorostoma	X			
" gemmatum	X			
" pileare	X			
Cypraea caputserpentis	X			
" isabella	X			
" moneta	X			
" reticulata	X			
Drupa morum		X		
" ricina		X		
Helcioniscus exaratus			X	
Littorina pintado	X	X		
Melanella cumingi	X			
" midpacifica	X			
Mitra litterata	X			
Morula ochrostoma		X		
" tuberculata		X		
Natica machrochiensis	X			
Nerita picea	X	X		

SPECIES	Tidepool	Inlet	Coast	Sub-tidal
Peristernia chlorostoma	X			
Phenacolepas sp.		X		
Rhizochilus madreporum	X			
Siphonaria sp.		X		
Strombus maculatus	X			
Thais harpa	X	X		
Turris sp.	X			
Vexilla taeniata	X			
Mollusca - Opisthobranchs				
Haminoea crocata	X			
Hexabranchus sp.	X			
Hydatina amplustre	X			
Micromelo gramensis	X			
Mollusca - Lamellibranchs				
Anomya nobilis	X			
Brachidontes cerebristriatus	X			
Ctena bella	X			
Isognomon costellatum	X			
" *incisum*	X			
Periglypta edmonsoni	X			
Spondylus hawaiensis	X			X
Echinodermata - Asteroids				
Asterope carnifera	X			
Linkia multiflora	X			
Unidentified small red sp.	X			
Echinodermata - Echinoidea				
Centrechinus paucispinus	X			X
Echinometra mathaei mathaei	X		X	X
" *mathaei oblonga*	X			X
Eucidaris metularia	X			
Heterocentrotus mamillatus	X			X
Lytechnius verraculatus	X			
Podophora atrata			X	
Tripneustes gratilis	X			X
Echinodermata - Holothuria				
Actinopyga mauritiana	X			X
Chiridota rigida	X			
Holothuria atra	X			X
Ophiodesoma spectabilis	X			
Stichopus sp.	X			

SPECIES	Tidepool	Inlet	Coast	Sub-tidal
Echinodermata - Ophiuroidea				
Ophiocoma erinaceus	X			X
" *pica*	X			X
Arthropoda - Crustacea				
Carpiloides bella	X			
Grapsus grapsus		X		
Leander debilis	X			
Leptodius sanguinensis	X			
Leptodius sp.	X			
Pachygrapsus minutus	X			
Platypodia eydouxi	X			
Pseudosquilla ciliata	X			
Stenopus hispidus	X			
Arthropoda - Cirripedia				
Cthalamus hembeli			X	
Unidentified purple sp.		X		
Bryozoa				
Loxoxoma sp.	X		X	
Fishes				
Abudefduf abdominalis	X			X
Acanthurus triostegus	X			X
Aprion virescens				X
Bothus sp.	X			
Cantherines sandwichensis				X
Chaetodon fremblii	X			X
Dascyllus albisella	X			
Myripustis murjan				X
Naso unicornis				X
Ostracion cubicus	X			X
Polydactylis sexfilis				X
Priacanthus cruentatus				X
Selar crumenopthalmus				X
Sphyraena helleri				X
Thalassonia umbrostigma				X

shoreward pools with the gobies Bathygobius fuscus fuscus (Ruppell) and Kellogella oligolepis (Jenkins). Entomacrodus marmoratus (Bennett) is found where there is some surf. Other forms commonly encountered are juvenild specimens of Acanthurus sandvicensis Streets, Abudefduf abdominalis (Quoy and Gaimard), A. sordida (Forskal), and Kuhlia sandvicensis (Steindachner).

A less varied fauna is found on the exposed portions of the coastline. On the algal-encrusted basalt is the purple shingle urchin, Colobocentrotus atrata (L. Agassiz), while two forms of the short-spined sea urchin, the black Echinometra mathei oblonga (Blainville) and the gray E. mathei mathei Blainville occur in small crevices and holes. Molluscs of this area include the limpet Helcioniscus exaratus Nuttall and the drupes, Drupa morum Roding, D. ricinus Linn., and Morula tuberculata Blainville.

4. HAWAII'S INSECT FAUNA

Insects probably first reached the Hawaiian Islands soon after plants became established more than 10 million years ago. Perhaps a stray bird or winds brought the first seeds to the new born islands. As the plants became established and suitable habitats developed, insects began to arrive from the west by accidental means. Through the succeeding years many changes took place. New plants, insects and other animals arrived, original immigrants evolved into endemic species, new islands grew from the ocean, old ones eroded and disappeared beneath the sea and the chain with its biota slowly grew to the southeast and died in the northwest.

The changes must have taken place at a slow, leisurely rate to produce one of the most unusual faunistic assemblages present upon the face of the earth. But recently, changes have come more rapidly as man has set upon the islands and turned the land to his own use. The effects upon the native plants and insects have been disastrous. They have been unable to withstand these changes — both physical changes of the land and the competition from introduced organisms. Today much of the original biota is irrevocably lost. It is in the higher mountains that the native Hawaiian plants and animals have managed to persist. Only a few native species have been able to withstand the onslaught of man's activity in the lower, accessible lowlands. To see the species that make Hawaii unique, one must now go to the mountain forests.

There are over 5000 species of insects in Hawaii. They are not representative of continental groups, but are random samples that were able to make the oceanic voyage and gain a foothold in the islands. The fauna is an unbalanced (or disharmonic) one with many orders not represented in the native lists. More than half the world orders of insects are not found naturally in Hawaii. Many of the larger, conspicuous families are lacking. There are no native phasmids, mantids, stoneflies, mayflies, dobsonflies, caddisflies, and many others, in Hawaii. This is disappointing to the general collector, but the uniqueness of many of the existing native forms should more than compensate for lack of easily collected specimens.

Most of the native insects on Hawaii have originated in Tropical Asia. Zimmerman lists more than 90% of the genera with Pacific affinities. The origin, spread and development of the Pacific fauna has recently been covered by Gressitt in Pacific Insects Monograph 2. The evidence presented by these two authorities on Pacific insects is overwhelmingly in favor of Asiatic origins of the Hawaiian insects and Gressitt feels that New Guinea may have been a primary source of insects in the Pacific. Both authors cited the means of oceanic dispersal used by insects. These are: 1) air currents, especially during storms when strong winds blow from the west to the east contrary to the usually westerly direction of the trade winds; 2) accidental transportation on the body of birds either in the feathers, in mud on the feet or with the eggs passing through the intestinal tract; and 3) rafting on floating logs. Of course, many have been brought in on boats, ships and planes both as accidental and purposeful introductions. The predominance of small insects with low specific gravity indicates the first method to be most important. Recent work under the direction of Doctors Gressitt and Yoshimoto of the Entomology Department, Bishop Museum, has taken insects far at sea in nets aboard surface vessels and in a specially designed airplane trap, demonstrating that insects are carried over the ocean by air currents.

That the native insect fauna of over 3000 species could have developed from chance immigrants is emphasized by Zimmerman. He calculates that the native insects could have originated from about 250 introductions. This means that if the islands are 5 to 10 million years old, one immigrant each 20,000 to 40,000 years would account for the present species.

For detailed accounts of Pacific insects, the reader is referred to Zimmerman (1948, Insects of Hawaii, vol. 1) and Gressitt (1961, Pacific Insects Monograph 2), both of which have been the chief references in drawing up the above account.

Most of the native insects have been replaced by immigrants in the lowlands below about 2,000 feet. The remaining native fauna is largely confined to the native forests in the mountains. The field trips have been planned to get entomologists to areas where they might find these, but limitations have been imposed by time considerations and other factors. The post-Congress tour will undoubtedly be more profitable than those on Oahu, for on the outer islands there has been less disturbance and destruction of the native vegetation and the native insect fauna is richer.

The lists of insects for each island include selected genera which may be taken in the various localities to be visited. Endemic genera or only those with native species are listed. Associated plants are indicated in parenthesis. Such orders as Thysanura, Thysanoptera, Psocoptera, Mallophaga and Lepidoptera have not been included.

There are only two native butterflies in Hawaii, Vanessa tameamea Eschscholtz and Vaga (=Lycaena) blackburni (Tuely) and they are found on all major islands. Collectors will probably find them on several of the field trips. V. tameamea, the Kamehameha butterfly, is found on Pipturus (preferred host), Urera, Neraudia, Touchardia and Bochmeria, all members of the Urticaceae or Nettle family. The Hawaiian lycaenid, V. Blackburni, feeds on Acacia koa (preferred host), Pipturus, Perrottetia, Dodonaea, Pithecellobium, Samanea, and Redyotis (Kadua).

OAHU: POAMOHO, AIEA HEIGHTS, MANOA CLIFF TRAILS

ODONATA. Anax, Megalagrion (Freycinetia), Nesogonia, Sympetrum.

ORTHOPTERA. Gryllidae: Leptogryllus, Paratrigonidium, Prognathogryllus. Tettigoniidae: Banza.

HEMIPTERA. Scutelleridae: Coleotichus (Acacia, Dodonaea). Pentatomidae: Oechalia (Metrosideros). Reduviidae: Nesidiolestes, Empicoris. Lygaeidae: Oceanides (many native plants), Glyptonysius, Neseis (many native plants), Nysius (many native and introduced plants), Pseudocymus (Eragrostis), Nesocymus (sedges, Carex, Cyperus, Eragrostis, Pipturus), Sephora, Metrargax (Freycinetia). Nabidae: Nabis (many plants). Anthocoridae: Lasiochilus (Straussia, Antidisma, Cibotium, Coprosma). Miridae: Kamehameha (Cyrtandra, Pipturus), Psallus (Acacia), Engytatus (many native plants), Nesidiorchestes, Pseudoclerada, Oronomiris. Cixiidae: Oliarus (Acacia, Broussaisia). Saldidae: Saldula.

HOMOPTERA. Psyllidae: Trioza (galls on Metrosideros, Pelea), Kuwayama (Metrosideros), Megatrioza, Hevaheva (Pelea). Cicadellidae: Nesophrosyne (Kadua, Bobea, Metrosideros, Cyrtandra, Wikstroemia, Pipturus, Touchardia, Myrsine, Eugenia), Balclutha (grasses). Cixiidae: Oliarus (many native plants), Iolania. Delphacidae: Leialoha (many native plants), Nesodryas (Freycinetia), Aloha (Dubautia, Euphorbia), Nesorestias (Cibotium, ferns, Elaphoglossum, Phegopteris), Dictyophorodelphax (Euphorbia), Nesosydne (many plants), Kelisia (grasses).

COLEOPTERA. Carabidae: Atelothrus (Freycinetia), Mecyclothorax, Mesothriscus, Metromenus (Pipturus), Nesocidium (Pipturus), Anchonymus, Baryneus (Acacia). Staphylinidae: Diestota, Lispinodes, Myllaena (Freycinetia), Oligota (Pipturus). Histeridae: Acritus, Nitidulidae: Eupetinus (Freycinetia, Metrosideros, Pipturus), Conicryctus (Pipturus), Nesopeplus, Nesopetinus (Freycinetia), Orthostolus (Freycinetia, Pipturus). Dermestidae: Labrocerus. Anobiidae: Holcobius, Microsternus, Xyletobius. Ciidae: Apterocis, Cis (Acacia, Coprosma, Myoporum, Smilax, Vaccinium, Pipturus, Dracaena, Freycinetia). Elateridae: Eopenthes (Acacia, Metrosideros, Scaevola), Anchastus (Clermontia). Eucnemidae: Dromaeolus (Rubus). Cerambycidae: Neoclytarlus (many native plants), Plagithymsus (many native plants). Aclycyderidae: Proterhinus (Acacia, Cibotium, Coprosma, Euphorbia, Metrosideros, Pelea, Pipturus, Cheirodendron), Heteramphus (Astelia, Straussia, Metrosideros, Elaphoglossum), Oodemas (many native plants), Rhyncogonus (Scaevola, Acacia, Bidens, Pelea, Sida, Freycinetia), Nesotoccus (Cheirodendron, Tetraplasandra).

DIPTERA. Tipulidae: Limonia (Cyrtandra), Gonomya. Psychodidae: Trichomyia, Psychoda. Chironmidae: Calospectra, Telmatogeton. Mycetophilidae: Orfelia. Sciaridae: Plastosciara, Sciara. Dolichopodidae: Emeroptera, Chrysotus, Syntormon, Eurygnaster. Pipunculidae: Pipunculus. Calliphoridae: Prosthetochaeta, Dryscritomyia. Anthomyiidae: Lispocephala. Drosophilidae: Drosophila, Tantalia, Titanochaeta, Idiomyia. Tephritidae: Tephritis (Dubautia). Ephydridae: Neoscatella. Asteiidae: Asteia.

HYMENOPTERA. Ichneumonidae: Atrometus, Enicospilus, Echthromorpha, Neolelaps, Toxeuma. Eupelmidae: Eupelmus. Mymaridae: Polynema. Bethylidae: Scleroderma, Sierola. Formicidae: Ponera. Vespidae: Odynerus. Sphecidae: Nesomimesa, Deinomimesa, Nesocrabro, Oreocrabro. Prosopidae: Nesoprosopis.

MAUI

INSECT GENERA CONTAINING NATIVE SPECIES

ORTHOPTERA. Tettigoniidae: Conocephaloides, Banza. Gryllidae: Paratrigonidium, Leptogryllus (Freycinetia, Cibotium).

ODONATA. Anax, Nesogonia, Megalagrion.

HEMIPTERA. Scutelleridae: Coleotichus (Acacia, Dodonaea). Pentatomidae: Oechalia. Lygaeidae: Oceanides (many native plants), Neseis (many native plants), Nysius (many native and introduced plants), Metrarga, Sephora (Coprosma, Gouldia, Scaevola, Straussia, Sadleria). Tingidae: Teleonemia scrupulosa (introduced for control on lantana, only tingid in Hawaii). Nabidae: Nabis (many native and introduced plants). Anthocoridae: Lilia (Acacia, Cyanea, Straussia), Lasiochilus (Antidesma, Cibotium, Coprosma). Miridae: Oronomiris (grasses), Psallus (Acacia, Euphorbia), Sulamita (Freycinetia, Zanthoxylum), Sarona (Metrosideros, Pelea), Orthotylus (many native plants). Saldidae: Saldula.

HOMOPTERA. Cicadellidae: Nesophrosyne (Coprosma, Sadleria), Balclutha (grasses). Cixiidae: Oliarus (Cibotium, Crytandra, Pipturus, Sadleria). Delphacidae: Leialoha (Metrosideros), Nesosydne (Cyrtandra, Argyroxiphium, Dubautia, Geranium, Coprosma, Pipturus, Gunnera, Astelia, Styphelia, Raillardia, Tetramo opium, Cyanea). Psyllidae: Trioza (galls on Metrosideros), Kuwayama (Metrosideros), Hevaheva (Pelea).

NEUROPTERA. Hemerobiidae: Nesomicromus. Chrysopidae: Anomolochrysa.

COLEOPTERA. Carabidae: Atelothrus, Disenochus, Mecyclothorax, Mesothriscus, Metromenus, Nesocidium, Baryneus, Anchonymus. Staphylinidae: Diestota, Lispinodes, Myllaena (Freycinetia), Oligota (Pipturus). Histeridae: Acritus. Nitidulidae: Eupetinus (Metrosideros, Freycinetia, Pipturus), Gonicryctus (Pipturus), Nesopeplus, Nesopetinus (Freycinetia), Orthostolus (Freycinetia, Pipturus). Dermestidae: Labrocerus. Anobiidae: Holcobius, Microstermus (Bidens), Xyletobius (many plants). Ciidae: Apterocis, Cis (Acacia, Coprosma, Myoporum, Smilax, Vaccinium, Pipturus, Coprosma, Freycinetia, Sadleria). Elateridae: Eopenthes (Metrosideros, Scaevola, Acacia), Anchastus (Clermontia). Eucnemidae: Dromaeolus (Rubus). Cerambycidae: Neoclytarlus (many native plants). Curculionidae: Dryophthorus (Metrosideros, Suttonia, Pipturus), Heteramphus (Straussia, Metrosideros, Elaphoglossum), Oodemas (many native plants), Rhynocogonus(Scaevola, Acacia, Freycinetia, Bidens, Pelea, Sida). Scolytidae: Xyleborus.

DIPTERA. Tipulidae: Limonia, Gonomyia. Chironomidae: Calospectra, Telmatogeton. Mycetophilidae: Orfelia. Sciaridae: Sciara. Dolichopodidae: Chrysotus, Campsicnemus, Eurynogaster. Pipunculidae: Pipunculus. Drosophilidae: Drosophila, Titanochaeta, Idiomyia. Anthomyiidae: Lispocephala. Ephydriadae: Neoscatella.

HYMENOPTERA. Ichneumonidae: Atremetus, Enicospilus. Eupelmidae: Eupelmus.

Mymaridae: Polynema. Bethylidae: Scleroderma (Sapindus, Straussia, Euphorbia), Sierola (Coprosma, Metrosideros, Pipturus, Dodonaea). Vespidae: Odynerus (Argyroxiphium, Freycinetia, Metrosideros). Sphecidae: Deinomimesa, Nesomimesa, Nesocrabro, Oreocrabro. Prosopidae: Nesoprosopis (Sophora, Raillardia, Broussaisia, Clermontia, Smilax).

HAWAII

INSECT GENERA CONTAINING NATIVE SPECIES

ORTHOPTERA. Tettigoniidae: Banza. Gryllidae: Paratrigonidium. (Freycinetia, Metrosideros, ferns), Leptogryllus (Freycinetia, Cibotium).

ODONATA. Nesogonia, Megalagrion.

HEMIPTERA. Scutelleridae: Coleotichus (Acacia, Dodonaea). Pentatomidae: Oechalia (Dodonaea, Myoporum). Coreidae: Ithamar (Euphorbia, Sida, Sophora, Styphelia). Lygaeidae: Oceanides (many native plants), Neseis (many native plants), Nysius (many native and introduced plants), Metrarga (Metrosideros). Tingidae: Teleonemia scrupulosa (introduced for control of lantana, only tingid in Hawaii). Reduviidae: Nesidiolestes. Nabidae: Nabis (many native and introduced plants). Anthocoridae: Lasiochilus (Straussia, Antidesma, Coprosma, Cheirodendron, Cibotium). Miridae: Psallus (Styphelia, Acacia, Euphorbia), Sulamita (Freycinetia, Zanthoxylum), Sarona (Metrosideros, Pelea), Pseudoclerada, Orthotylus (many native plants), Oronomiris (grasses). Saldidae: Saldula.

HOMOPTERA. Cicadellidae: Nesophrosyne (many native plants), Balclutha (grasses). Cixiidae: Oliarus (Metrosideros, Maba, Astelia, Dubautia, Cibotium, Nephrolepis), Iolania. Delphacidae: Leialoha (Metrosideros), Nesothoe (Euphorbia, Metrosideros, Osmanthus, Antidesma, Maba), Nesodryas (Pritchardia), Aloha (Ipomoea, Bidens, Campylotheca, Cheirodendron, Lipochaeta, Lythrum), Nesosydne (many native plants), Kelisia (Eragrostis, Sporobolus, Vincentia, Deschampsia. Psyllidae: Trioza (galls on Metrosideros),Kuwayama (Metrosideros), Hevaheva (Platydesma).

NEUROPTERA. Hemerobiidae: Nesomicromus, Pseudopsectra. Chrysopidae: Anamalochrysa. Myrmeleontidae: Eidoleon.

COLEOPTERA. Carabidae: Atelothrus, Meoyclothorax, Mesothriscus, Metromenus, Nesocidium, Anchonymus, Baryneus, Barypristus, Colpodiscus. Staphylinidae: Diestota, Lispinodes, Myllaena, Oligota. Histeridae: Acritus. Nitidulidae: Eupetinus, Gonioryctus, Nesopeplus, Nesopetinus, Orthostolus. Dermestidae: Labrocerus. Anobiidae: Holcobius, Microsternus (Bidens), Xyletobius (Bidens, Straussia, Euphorbia, Pelea, Clermontia, Pipturus, Broussaisia, Antidesma, Coprosma, Smilax, Urera). Cucujidae: Brontolaemus, Laemphoeus. Ciidae: Aptercocis, Cis. Elateridae: Eopenthes, Itodacnus. Cerambycidae: Neoclytarlus (many native plants), Plagithmysus (many native plants). Curculionidae: Acalles, Dryophthorus, Heteramphus, Oodemus, Rhynocogonus, Deinocossonus, Nesotocus. Scolytidae: Xyleborus.

DIPTERA. Tipulidae: *Limonia*. Psychodidae: *Trichomyia*, *Psychoda*. Chrionomidae: *Termatogeton*. Ceratopogonidae: *Dasyhelea*. Mycetophilidae: *Orfelia*. Sciaridae: *Sciara*. Dolichopodidae: *Chrysotus*, *Hydrophorus*, *Euryno-gaster*. Pipunculidae: *Pipunculus*. Calliphoridae: *Dyscritiomyia*, *Prosthetochaeta* Anthomyiidae: *Lispocephala*. Drosophilidae: *Drosophila*, *Titanochaeta*. Ephydridae: *Neoscatella*. Asteiidae: *Asteia*.

HYMENOPTERA. Ichneumonidae: *Atrometus*, *Eniscospilus*. Eupelmidae: *Eupelmus*. Myrmaridae: *Polynema*. Bethylidae: *Scleroderma*, *Sierola*. Vespidae: *Odynerus* (*Freycinetia*, *Metrosideros*). Sphecidae: *Deinomimesa*, *Nesomimesa*, *Nesocrabro*, *Oreocrabro*. Prosopidae: *Nesoprosopis* (*Sophora*, *Raillardia*, *Broussaisia*, *Clermontia*, *Smilax*).