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The legacy of the Hawaiian cultivator in windward valleys of Hawaii. (Volumes I and II)

Terry, Ronald Norman, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1988
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THE LEGACY OF THE HAWAIIAN CULTIVATOR
IN WINDWARD VALLEYS OF HAWAII
VOLUME I

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Geography and Anthropology

by

Ronald Norman Terry
B.A., The University of Hawaii at Hilo, 1980
May 1988
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ABSTRACT

The composition of a forest of relicts of cultivation in four uninhabited valleys in Kohala, Hawaii, is documented. A general hypothesis is made that arboreal distribution patterns are a function of both historical land use and ecological interaction since abandonment.

The physical and historical geography of the valleys was investigated. Climate varies little, but distinct geomorphic zones offer differing biological environments.

Prehistoric land use consisted of taro patches with intercropped banks. Talus slope gardens supported the Polynesian tree crops 'ohi'a 'ai (Eugenia malaccensis), kukui (Aleurites moluccana), 'ulu, (Artocarpus incisus), ti (Cordyline terminalis), and noni (Morinda citrifolia), important in today's flora. Gathering took place on slopes.

Western contact with Hawaii, initiated in 1778, brought new crops. Papaya (Carica papaya), mango (Mangifera indica), guava (Psidium guajava), and coffee (Coffea arabica) were important adoptions in Kohala. As land use changed, the region also suffered depopulation, losing half its numbers between 1830 and 1870. Chinese rice-growing forestalled complete abandonment, which finally occurred after 1920.

Current vegetation was assessed by creating 15 sampling units containing 554 quadrats. Inside quadrats,
the size-class and species of each tree was recorded, yielding measures of frequency, density, cover, importance, and richness. Four environmental conditions were also assessed. The resulting variables were mapped and inter-correlated.

Guava, kukui, noni, 'ohi'a 'ai, ti, hala (Pandanus odoratissimus), and coffee proved the most numerous species. Rarer species were often localized, illuminating historical land use.

The data were examined and reformatted into matrices suitable for cross-classification analysis. Consistent relationships included the association of guava with low-slope and 'ohi'a 'ai with high-slope. Richness showed association with high-slope and cliff proximity.

The mark of Hawaiian cultivators is apparent. Polynesian species accounted for 48.2% of the importance value. Size-class histograms revealed a stable structure for most species.

Certain Western exotics had spotty distributions or size-class structures that indicate impending extinction. Native species are rare except for hala. There are indications that they were probably scarce during prehistory as well.

This study exemplifies historical biogeography. It synthesizes methods of geography, ecology, and archaeology for the purpose of better interpreting cultural vegetation.
CHAPTER 1
INTRODUCTION

This thesis analyzes the arboreal vegetation of a set of abandoned valleys in Hawaii in relation to factors of historical land-use and the physical environment. Several specific questions of concern to a diverse group of researchers including biogeographers, anthropologists, forester, and ecologists studying Hawaii are addressed:

1. How do indigenous, Polynesian, and exotic trees interact when placed together and then neglected for decades by man?

2. Does the indigenous forest or any component of it revive?

3. Are abundance levels of certain species associated with any local environmental factors?

4. Did the former inhabitants leave a permanent legacy in the vegetation, or has their mark been erased?

5. What can we learn about them and their patterns of land-use from the vegetational relics they have left behind?

6. What will the future forests of the abandoned lowland valleys in Hawaii resemble?

The Study Area and the Character of Its Flora

A series of seven valleys incise the Kohala Mountains on the northwestern coast of the island of Hawaii, only one of which is still inhabited. Four of the remaining six
comprise the study area for this thesis (Fig. 1-1). The valleys have been abandoned for periods ranging from fifty to one hundred years, and the vegetation reflects the recent lack of human disturbance in its overgrown, wild appearance. However, the abundance of the relicts of cultivation belie the impression of a wilderness and make a description of the vegetation difficult. A valley is at once a forest and a garden, a seemingly wild community composed almost exclusively of cultivated trees.

A botanist might say that the vegetation of the valleys does not constitute a "natural forest", inasmuch as the flora is almost entirely devoid of a native element. The indigenous vegetation of Hawaii is the product of several million years of development and is overwhelmingly endemic in character. The current flora of the valleys originates from other sources.

When the first Polynesians arrived in Hawaii some 1500 years ago, they most likely encountered a stable system of complex and species-rich ecosystems. After a little over 1000 years they had transformed most of the lowlands into either agricultural areas -- which included wet and dry taro (*Colocasia esculenta)* fields, other monocrop patches, mixed gardens and fallow -- or semi-wild gathering areas (Kirch 1982). The numerical and geographical expansion of

*The binomial or Latin name for species in this thesis is given at the first mention of the species. Thereafter, a common name or genus name is used instead. The reader is referred to Appendix 1, a cross-listing of the various names of plants mentioned in this paper.
Fig. 1-1 The Hawaiian Islands and Kohala Valleys
the Hawaiian population over the heterogeneous terrain of the islands, the progressive changes in their agricultural techniques, and the rotation of different land-use zones had created a complex pattern of largely Polynesian exotic vegetation in the lowlands by 1778, the year of European contact.

Today, superimposed on the Polynesian patterns, are the contributions of post-1778 visitors from Asia, the Americas, Europe, Oceania, and Africa. Many species were introduced as crops or ornamentals and adopted by Hawaiians during the 1800's. Other plants escaped and became established as weeds. The mixture of plants from different sources has resulted in a flora that seems to the popular imagination curiously "Hawaiian" (e.g., Hargreaves and Hargreaves 1958, *Hawaii's Blossoms*, and Kuck and Tongg, 1958 *Hawaiian Flowers and Flowering Trees*), despite its non-indigenous affinities.

The Worldwide Prevalence of Human-modified Forests

Extensive human modification of a forest's flora is a phenomenon certainly not unique to Hawaii. Most of the trees that now characterize the lowland vegetation of Polynesian islands were introduced by the islanders (Merrill 1954). Barrau (1961) examined forests on dozens of Pacific island groups and pronounced the vegetation in most Polynesian forests "degraded" - meaning infiltrated by exotics but generally species-poor. Even on large and late-settled North Island in New Zealand the flora and
species patterns reflect the interference of the Maori (Cumberland 1963).

On continents, where many of the plants adopted by man are true natives of their region, the legacy of disturbance in a forest is often more subtle. The geographical pattern of a species may reflect human influence. The predominance of cultivars over naturally occurring varieties is another indication. In the Yucatan Peninsula of Mexico, the curious aggregation of trees vital to the Mayan civilization has long been noticed (Lundell 1937, Folan, Fletcher, and Kintz 1979). Similar species patterns, unexplainable in terms of natural forest ecology, have been noted in Nigeria (Jones 1956), Ceylon (Mangenot 1963), and northern Mexico (Alcorn 1981), and in many other regions (Anderson 1956). Indeed, wherever researchers closely examine the flora, they are likely to concede that a certain proportion of the species has been contributed by the action of man. Perhaps a majority of the earth’s temperate and tropical forest floras is in part a recent human artifact.

The ubiquity of human-disturbed forests is not the only reason for their importance. The novel flora of the forests is interesting in itself, but the new ecological relationships are even more intriguing and important. The structure and dynamics of such forests are poorly understood, and it is unknown if they are relatively stable or unstable in species composition. High species richness
values are often associated with disturbance, whether from human or natural agencies (Connell 1978). How these forests interact with the world's remaining native forests is another important question. Once such relationships are understood, we will be better equipped to decide how the exotic forests may be best managed for man's benefit.

Since man has helped create these forests, they are to some extent his artifact; they are "cultural" forests. And just as artifacts of stone or wood or metal have helped to ascertain the presence of certain human groups and to develop a history for such groups, perhaps the cultural forests may be used as similar indicators. The historical and cultural information latent in the disturbed forests, coupled with the potential understanding of their ecology, suggests a fertile arena of research, but one that has heretofore been little explored.

The Study of the Ecology of Disturbed Forests

Despite the acknowledgement by most ecologists of a significant anthropogenic component in the structure of most forests, actual ecological studies often overlook the human contribution. In Edgar Anderson's words, written three decades ago but still accurate today

...there has been a strong tendency to avoid such problems - to study the plants and plant associations of mountain tops and jungles rather than those of dooryard gardens, to think of plant and animal communities as they must have been in some blissfully innocent era before the advent of man. (1956:776)

Ecologists may reasonably justify their reluctance to
study human-modified biological communities. It is true that ecological processes are understood best in a long-standing community where genetic variation and interspecific interaction are finely balanced. In weedy vegetation, the species have not co-evolved and are thus not "tuned" to each other. Also, weedy assemblages are known to be, regrettably, the inevitable wave of the future, while undisturbed plant communities are disappearing at an exponential rate, and merit all the attention and more that has been given to them.

There are inherent difficulties, however, in concentrating on undisturbed vegetation. The geographer A.W. Kuchler outlined a scheme for classifying on a gross level the actual, as opposed to the ideal, vegetation of the earth (1969). The major units in his classification were natural and cultural. Cultural vegetation includes the following categories: semi-natural, potential semi-natural, and segetal (weeds). Under the heading of natural vegetation were two categories: potential natural vegetation, the presumed natural vegetation of an area, a hypothetical construct; and actual natural vegetation, an observable but, in Kuchler's terms, a "rare" vegetational type. Of all the plant communities on earth, it is the latter, possibly the most uncommon, to which the ecologist usually applies himself.

In order to study genuine natural plant communities one must travel to isolated locations, which is why many
vegetational studies focus on unpopulated regions of the less developed countries of the tropics, where, presumably, industrialized society has had the least effect. Even in remote locales the human factor continues to confound controlled research. The carefully guarded forest reserve of Barro Colorado Island in Panama offers one of the few truly ideal situations for investigating natural forest ecology (Croat 1978). Such reserves are uncommon, and though they are undoubtedly valuable arenas for scientific research, their very rarity is an indication that generalizations drawn from them cannot be validly applied to most of the earth's vegetation - the complex tangle of weeds that surrounds us.

**Cultural Forests as Keys to History and Prehistory**

Employing the supplemental evidence found in the flora of various forests to help unravel questions about the past is an old practice, but one which has had few systematic practitioners at the micro-scale. Anthropologists (Gilmore 1930, Robbins 1963, Yarnell 1965), geographers (Sauer 1957, Carter 1945, Cumberland 1941) and scientific popularizers (e.g., Thor Heyerdahl) are among those who have speculated about the movements of peoples, based on the plants that have been left behind in the forests. While some of these efforts are little more than a raid on the forest flora in order to bolster a pet theory (an abuse which inspired Elmer Drew Merrill to publish an entire volume of criticism in 1954), much conscientious research has been done. Most
of it has been rather general, and the instances of close scrutiny of the structure and history of a forest in order to extract the human component have been few but provocative. Two studies in Meso-America illustrate the potential. Alcorn (1981) developed an ethnobotany of the Huastec Indians of the Sierra Madre Oriental of Mexico that illuminated the process by which a set of land-use practices over time creates a culturally determined but semi-wild vegetational landscape. Folan, Fletcher, and Kintz (1979) examined the long-abandoned Mayan forest near Coba, a legacy of land-use of the type described by Alcorn, in order to extract evidence concerning the social relations among the previous inhabitants based on the current plant geography. The latent information in cultural forests concerning their present and past inhabitants has been recognized, but progress in research has been limited, perhaps because of the large inter-disciplinary gap that must be bridged to conduct such research.

**Historical Biogeography**

In an era of academic fragmentation it is lamentable to establish another gratuitous category of specialization. The term historical biogeography, however, is perhaps too apt to be avoided in this context. Even if it must partake of a makeshift methodology, it has a specific field of study and a genuine purpose to serve. The historical biogeographer is one who is willing, if inevitably
under-equipped, to address certain challenging problems that straddle many disciplines.

Topics of Synthetic Research

Many purposes may be served in a single study of a human-modified forest uniting the techniques of ecologists, anthropologists, and historical geographers.

Because of the importance of disturbed vegetation and the lack of understanding about it, there is a need to simply create a record of vegetation in particular regions. With such a record one may study the distribution of plants, focusing on such concepts as dominance, species richness, or community types, in relation to physical parameters such as soil, slope, drainage, sunlight, and elevation. If some record exists of the time and place of introduction, one may begin to understand to what extent a plant has become naturalized, and how it interacts with other species. Determining ecological relationships among plants, animals, micro-organisms, and their inorganic substrate is the first step to managing a forest, whether it be a putative wilderness or a collection of weedy trees. A natural extension of a study of different-aged patches in a disturbed forest is the projection of what the forest of the future will resemble. Information of this type is valuable to the forester, wildlife manager, and state and local planners who have been faced with relatively unstudied and therefore unpredictable conditions over an increasingly significant portion of the earth's surface.
Similarly, species distribution data may be studied in relation to human history. Understanding the facts of introduction, spread, and use of plants by people helps explain the present ecology of a region. Especially if environmental factors are controlled for, it is of interest to examine the correlation of the values of species dominance and richness, or the categories of vegetational assemblages, with different varieties of land-use.

In many cases, the modification of forests has occurred recently enough to be well documented. One may often clearly assess the nature and degree of human impact on vegetational systems. Such information contributes to an understanding of local vegetation as well as to the development of a theoretical approach to the effects of humanity on vegetation.

An especially valuable contribution of an eco-historical study of forests is the establishment of a reliable scheme for interpreting the patterns of prehistory from the structure and flora of present forests. Any such deductions must be arrived at cautiously so as to avoid the traps of circular reasoning and over-eager inference. Nevertheless, certain generalizations developed from a study of vegetation and known historical conditions may be applied with care to prehistoric situations, if historic and prehistoric conditions are known to be congruent, especially for the purpose of generating hypotheses to be tested by archaeological methods.
The Hawaiian Lowland Forests in a Worldwide Context

The development of a new flora in the Hawaiian lowlands is an example of the worldwide process of human disturbance of a natural ecosystem with partial replacement of its components by exotic elements. The transformation has been so widespread that the study of the native, undisturbed forest on the Hawaiian Islands must be limited to restricted montane zones on a few of the larger islands (e.g., Mueller-Dombois, Bridges, and Carson 1981), and even there a small exotic component intrudes. The forests below 750 m in the Hawaiian Islands, whether in valleys, plains, hills, or ridges, are composed overwhelmingly of exotic trees. The notion that the lowland forest comprises an assemblage worthwhile for study in its own right, and not simply as a threat to the native forests, has been expounded by several researchers, notably Wester (1977, 1983, with Juvik 1983). There is evidence that in many locations a fairly stable association composed of exotic trees has emerged.

The numerous exotic forest associations in Hawaii merit further study for a variety of reasons, including concerns of wildlife biologists, foresters, endangered species organizations, and increasingly, social scientists. The existence of a large body of inter-disciplinary information about the islands makes a synthetic type of study possible.

The actual flora of the exotic forests has been
competently treated by many authors, most thoroughly by Neal (1948, 1965)*. Concerning man's association with the distribution of exotics, there is a wealth of evidence, much of it anecdotal, in studies of botany, anthropology, and history in Hawaii (e.g., MacCaughey 1917, Handy 1940, Handy and Pukui 1972, Degener 1945. Kirch 1979, Kirch and Kelly 1975).

Students of Hawaii are fortunate in that the history of Western contact, land-use, demographics and migrations is well documented. It provides many sources from which to construct a historical geography of a specific place or region.

The abundance of botanical and historical information in Hawaii, coupled with the islands' accessibility and relative lack of conditions discouraging to research (e.g., unstable governments or infectious disease) makes Hawaiian valleys ideal laboratories for the investigation of man's legacy in the vegetation.

Methods and Organization of the Study

The organization of this thesis is to address the questions phrased initially by integrating information on the physical environment, the indigenous vegetation, and the history of land use for the valleys. These factors are the subjects of Chapters 2-5. Next, the special problems

*The new compendium of Hawaiian flora by the Department of Botany of the B.P. Bishop Museum (in preparation) will provide an updated, comprehensive, and systematic review of all species present in Hawaii, including locational data.
of assembling a valid abstract of the geography of trees in the valleys are discussed. Chapter 6 reviews the ecological approach to studying natural vegetation, and Chapter 7 critiques the application of this approach to cultural vegetation and outlines the alternative scheme for sampling and analysis used here.

Chapter 8 presents the distribution of certain species abundance parameters in the valleys by means of maps and descriptive statistics. In the following chapter, habitat preferences for each species and other data pertinent to the discussion of tree location are introduced. Hypotheses concerning the association between environmental variables and species abundance parameters are stated and tested in Chapter 10. The legacy of the Hawaiian farmer in the flora and vegetation of the valleys is discussed in Chapter 11 in the context of the findings of the preceding chapters. The next chapter addresses the composition of the future forest of the valleys. Chapter 13 presents a summary of this thesis and evaluates the practical and theoretical use of its conclusions to the disciplines of geography, history, botany, and anthropology.
CHAPTER 2
THE PHYSICAL ENVIRONMENT OF THE
WINDWARD VALLEYS OF KOHALA

The Geography of the Hawaiian Chain

The Hawaiian Chain comprises over 30 islands, most of
them reefs and atolls. Though insignificant in total area,
they trace a 1500 km arc across the central Pacific. The
main islands are eight in number: from east to west,
Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and
Niihau (Fig. 1-1). Lanai, Kahoolawe, and Niihau have less
than 400 square km each, do not exceed 1000 m in elevation,
and are situated in the lee of larger islands. The other
five are all large, high islands with distinct windward and
leeward regions.

Origin of the Islands

The accepted theory for the origin of the islands is
that a "hot spot" in the asthenosphere of the earth's crust
and mantle has been responsible for the emergence of the
volcanoes which have built the chain (MacDonald et al
1983:2). The islands progress in age from the southeast to
the northwest, reflecting the direction of the passage of
the Pacific plate over the hot spot. The northwesternmost
of the windward islands, Kauai, is apparently the remnant
of a volcano active five million years ago. Hawaii, the
southeasternmost island, is composed of what may be
considered six separate volcanoes: Ninole is almost buried;
Mauna Loa and Kilauea are still active; Hualalai is recently dormant; Mauna Kea is dormant and possibly extinct; and the Kohala Shield, the specific location of the study area, is extinct and highly eroded (MacDonald et al 1983:303).

Windward Valleys

The combination of old volcanic parent material and annual precipitation of over 1250 mm has led to similarities in geomorphology on the windward coasts of the five largest islands. The most dramatic and typical features of the windward coasts are the steep-sided valleys (Fig. 2-1). Oahu’s valleys are populated in places, although at a low density when compared with the rest of the island. On other islands most valleys are somewhat isolated, and are often without inhabitants. Lennox (1955) identified nine major valleys in the Hawaiian chain (Fig 2-2) with similar traits: 1500-3800 mm annual rainfall, an orientation facing the tradewinds, reduced sunlight, good alluvium, a plentiful supply of water, and flooding problems. As this study focuses on the Kohala valleys*, the formation and environment of windward valleys will be addressed in the context of their expression in the Kohala

*The name Kohala is applied in this thesis to the area including the four valleys under study. Kohala as an administrative unit does not include Waimanu Valley, which is instead part of Hamakua. Since the valleys are all part to the Kohala Mountain system, it is both convenient and accurate to refer to the surrounding area as simply Kohala.
Fig. 2-1

View of Kohala Valleys
Fig. 2-2. Nine Major Abandoned Hawaiian Valleys
valleys. With some variation, many of the details would also apply to valleys on the other islands.

Geomorphology of the Kohala Valleys

On the Kohala Shield, the form of the valleys has been controlled by several factors: stream dissection in differentially structured parent material, the action of waves, and the fluctuation of sea level during the Pleistocene. Together, they have created and maintained the basic valley shapes.

Geology

The Kohala Shield is composed of lava flows, intrusive features, and ash from an oval shield volcano active from one million to one hundred thousand years ago. The deposits have been divided into two series (Pololu and Hawi) based on age by Stearns and MacDonald (1946). The Pololu Series is a collection of basalt layers from one to fifteen meters thick, interfingering with ash layers that are rare but most numerous near the surface. The Hawi Series was deposited after a period of time sufficient to allow the formation of valleys up to ninety meters deep in the Pololu surface (MacDonald et al 1983:357).

Dissection by Streams

Because of non-homogeneity in the parent material, the classic radial drainage pattern often encountered on volcanoes is not predominant in the windward Kohala region.
Fault scarps running parallel to the coast seem to have determined the headwater positions of the major valleys. The advantage this conferred to the valleys in terms of the diversion of more than usual runoff allowed them to incise deeply into the basalt dome. As erosion progressed, the stream valleys cut into numerous dikes, where large quantities of groundwater were confined, adding to the flow of water (Waipio valley, e.g., captured 198 dikes; Waimanu 16, Honokane Nui 38, and Pololu only 1, according to Stearns and MacDonald 1946:175). The same fault scarps that helped position the heads of the valleys also diverted the later Hawi Series lava. The already prominent valleys continued to be dissected unimpeded by additional lava and have evolved into "master canyons" as deep as 750 m and as wide as one kilometer in places.

The streams between some of the major canyons run parallel and incise shallowly in the mountain, creating a landscape more typical of basalt domes. An unusual feature of these inter-valley streams is that they often enter the ocean as hanging waterfalls, demonstrating that waves have been much more effective in wearing down the land than have small streams.

Dissection and Slope Instability

The steepness of the valley slopes deserves explanation, because it uniquely characterizes the valley region of the islands, serves to isolate the valleys by
discouraging access by land, and engenders a set of vegetational environments.

Dissection in the early stages of stream development in Hawaii as elsewhere tends to form a V-shaped gulch, with downcutting more prevalent at first than lateral erosion. Eventually, as the stream approaches grade, widening of the valley occurs, and a fairly level cross-section is obtained. Steep walls are maintained throughout parallel slope retreat, a phenomenon Wentworth (1928, 1943) explained as a combination of stream erosion and chemical weathering. As a basalt dome ages, the mantle of rock on the slopes becomes badly chemically weathered, and develops into a veneer of rock, soil and plants termed taluvium. The stream action necessary to remove the taluvium is often inadequate except at the valley bottom because of the high substrate porosity and the consequently low runoff. Therefore, gravity becomes the primary agent of debris removal. Slopes are steepened by the removal of material below and the addition of material from above, and eventually they undergo mass movements such as rockfalls, slumps, and especially soil avalanches. The latter type of slope failure is prevalent in Hawaii and is effective in maintaining a parallel retreat of steep slopes (Scott and Street 1976). It involves a long, narrow mass of debris of even thickness sliding down to a lower position on the slope, usually induced by the added weight and decreased friction of the mass during heavy rainfall (Wentworth
Fig. 2-3
Talus Slope

Fig. 2-4
Papayas on
Taluvial/Colluvial
Slope
The taluvium is removed from the base of the slope by stream action, which begins the steepening process anew, the high slope angle being determined basically by the angle of repose of vegetated taluvium. Recent stream-table experimental research indicates that groundwater sapping may be the dominant force in maintaining and widening amphitheater-headed valleys in Hawaii (Kochel and Piper 1986). Colluvial deposits at the bottom of valley floors range from minimal to extensive, varying from valley to valley. In certain parts of the Kohala valleys, rockfalls are confined to a zone five to twenty meters from the base of the valley wall (Hubbard 1972:12). In other locations there is a gentler-sloped colluvial mass which extends up to one hundred meters from the base of the cliffs (Figs. 2-3 and 2-4).

The process of erosion results in a landscape of cliffs, talus slopes, and valley floors, each with its own maintenance processes. Cliffs are subject to mass movements of various scales which slowly peel away the taluvium while conserving a steep slope (Wentworth 1943, p. 63, estimated the rate of removal in the Koolau Mountains of Oahu as one foot per 400 years). Talus slopes are subject to avalanche from above, rapid chemical weathering, and removal of material below by streams and groundwater emerging from the walls. Valley floors are levelled by stream flooding, which deposits and removes alluvium. The potential for creating distinctive vegetational
environments in each zone is revealed by the differences in geomorphological processes.

Wave action

The contributions of waves to the form of the valley have been the creation of towering sea cliffs and the flattening of valley floors during their submergence due to sea level rise.

Sea cliffs are formed as waves progressively erode a sloping shoreline, creating notches at the landward edge of the terraces they cut. The notches undercut the slope and cause periodic collapse of overlying material. Rocks formed by the collapse become material for renewed attacks on the cliffs by the waves. In the Hawaiian Islands the sea has carved cliffs as high as 1100 m.

Sea cliffs isolate the Kohala valleys from each other and from the region of gulches and plains that lies to the northwest and southeast. The southeasternmost valley, Waipio, is fringed by a sea cliff of 250 m with a 67 degree slope. The northwest sea cliff barrier at Pololu Valley is less impressive but still formidable at 100 m and 45 degree slope. Most of the valleys are separated from each other by long coastlines of cliffs of between 150 and 250 m, but between Waimanu and the two valleys on either side of it are cliffs that average 300 m and reach as high as 400 m. Slopes on the coast between valleys usually exceed 45 degrees and often approach 75 degrees. The steepness and
height of the cliffs indicate that waves have caused the shoreline to recede more than a kilometer (MacDonald et al 1983:355).

Small land shelves, some inhabited into the 19th century, fringe some of the sea cliffs and permit human access to the valleys. The land shelves are discontinuous, however, and are in constant jeopardy from slope failures.

Sea level Fluctuation and Flat Valley Floors

Of the seven valleys in the Kohala Mountains, the largest three, Waipio, Waimanu, and Pololu, have extensive, level marshy floors. Stearns and MacDonald (1946:42) attribute the floors to "alluviation concurrent with submergence of the island." Dozens of ancient shorelines are evident on all islands, between +110 to -340 m, the results of both tectonic and eustatic processes. Though the chronology of the rise and fall of sea level is exceedingly complex, it is accepted that much of the fluctuation occurred during the late Pleistocene (MacDonald et al 1983:24). The Recent history of sea level change has been a slow rise, inducing a deposition of marine re-worked alluvium composed of stony silts and sands up to 100 m thick in some Kohala valleys (MacDonald et al 1983:24).

Tsunami

Among the most threatening of natural disasters on Hawaii, an island also subject to earthquakes, volcanic eruptions, and high surf, is a phenomenon to which the
valleys of Kohala are particularly prone: the seismic sea wave or tsunami. A rapidly sloping sea floor coupled with an embayed coastline tends to focus tsunami energy on a valley (Camfield 1980). The tsunami of 1946, which originated in the Aleutian Islands, caused destruction in all seven of the valleys, particularly in Waipio, at the time the only inhabited valley. In Pololu Valley the run-up was 17 m (MacDonald et al 1947), the maximum value recorded in Hawaii since systematic run-up measurements were initiated in the 1940's (University of Hawaii Dept. of Geography 1973:52). Although tsunami are infrequent, they are unpredictable, and before the establishment of the Pacific tsunami early-warning system in the 1950's, they arrived without any warning. Hawaiians never seemed to have eschewed beach settlement as a concession to the possibility of tsunami, but such waves are now considered hazardous impediments to valley exploitation.

The major geomorphological effect of tsunami has been to help level the seaward edges of the valley floors and to deposit marine salt, sands, gravels, and even boulders up to 500 m inland.

The Form of the Landscape: A Composite of Processes

The basic form of the valley region is depicted in Fig. 2-5, a rendering of the topography using the 250 foot (76 m) contours from USGS topographic maps.

The Kohala Mountains, which reach an elevation of
THE KOHALA VALLEYS

Fig. 2-5. Topography of Kohala Valleys
1603 m between the headwaters of Waimanu and Honokane Nui Valleys, are incised by seven valleys with floors that extend to almost sea level. The largest part of the region is composed of interfluves dissected by minor streams. Steep walls characterize both the east and west slopes of all valleys. Each valley is separated from the others or from the adjoining regions by high sea cliffs. The 200 foot (76 m) contour in all valleys extends at least one kilometer inland, creating a lowland area suitable for settlement and agriculture ranging from 15 ha and up to 1350 ha.

The steepness of the sea cliffs in addition to the rough windward sea conditions have combined to make access from the sea difficult. The escarpments make land access also difficult, and pose other problems in the form of landslides and reduced sunlight, especially near the cliffs and in the back of the valleys.

**Climate of the Kohala Valleys**

The island of Hawaii is situated near 20 degrees N latitude, inside the belt of tropical trade winds, where daylight varies from 13 hours 10 minutes in summer to 11 hours in winter. Hawaii is surrounded for thousands of miles by little but unbroken ocean. These factors help establish a warm and stable annual temperature regime with moisture-laden winds blowing year round.
Temperature

Temperature on the island of Hawaii shows little seasonal variation. A weather station at Niulii, one mile from Pololu Valley at sea level, has an average annual temperature of 23.2 degrees C, with a maximum of 24.5 degrees in August and a minimum of 21.9 degrees in February (Blumenstock 1978:285). Average diurnal variation ranges from about 4 to 6 degrees seasonally. Inside the valleys, temperature variation is a function of elevation, which induces a drop of 2.75 degrees C per 500 m of added altitude. Since the specific study area lies in the lower valleys at elevations of less than 100 m, elevationally-induced variation is minimal. Katabatic winds on the largest volcano of Hawaii have produced temperatures as high as 37 degrees C in lowland areas. These winds also occur in the larger valleys (Hubbard 1972:72), but the height from which they descend is not large enough to produce noticeable temperature rises.

Winds

The normal wind pattern for the valleys is northeasterly trades of seven to fifteen meters per second (MPS), strongest and most prevalent in the summer, when they dominate circulation 80 to 95% of the time (Blumenstock 1978:267). During winter the trades slacken and are occasionally replaced by southerly winds from kona storms. Strong easterly waves in the summer may also
temporarily replace trade winds. Though intense tropical storms and hurricanes are uncommon in the Hawaiian Islands, normal winds reach steady speeds of 13 MPS over the open ocean and gust higher during squalls.

The irregular topography of the valleys modifies the wind regime substantially. The seaward and eastern flanks of the valleys lie partially in the lee of the prevailing winds, while the ridges, particularly the western ones, experience higher speeds and gustier conditions. Wind speeds increase to the northeast as trade winds are around the Kohala mountains.

Precipitation

Rainfall is probably the most variable climatic element in the valleys (Fig. 2-6, after University of Hawaii Dept. of Geography 1973). Annual precipitation increases from near 1900 mm on the eastern and western margins of the valleys' shoreline to a maximum of over 2500 mm in the center. Rainfall also increases away from the shore toward the mountains, but remains below 3750 mm in the lower parts of the valleys. However, as the data were collected from only eight gauges in or near the valleys, there may be considerably more local variation than displayed on the map. The average annual rainfall for the three stations nearest the valleys ranges from a high of 3545 mm at Niulii, just to the west of Pololu Valley to a low of 1329 mm at Awini, between Pololu and Honokane Nui
THE KOHALA VALLEYS

RAINFALL

Isohyets in inches

Contour Interval is 250'

Fig. 2-6. Rainfall of Kohala Valleys
Microclimate and Weather Events

In any study of vegetation, local variation in soil chemistry and structure, water budgets, groundwater, wind regimes, atmospheric chemistry, and solar radiation are determinants perhaps as important as regional climate. However, few data on these factors exist for most places on earth, including the valleys of Kohala. In the absence of specific information, general principles of microclimate may be applied to the valleys to illuminate the major variations encountered within small areas. Severe weather events are better studied, and their effects on vegetation have been detailed for at least some parts of the islands.

As temperature is not a limiting factor in lowland vegetation in Kohala valleys, the most important microclimatic variation to consider involves soils, groundwater, wind, and the duration and timing of sunlight. Soils and groundwater are discussed in a later section.

Local Wind Variation

Trade winds direct the dominant flow of wind near and above the valley region. When they encounter massive cliffs and narrow gorges, the flow becomes turbulent. Wind streamlines are concentrated near cliffs, and updrafts are created in a flow that has usually already become somewhat turbulent by travelling over an aerodynamically "rough" sea. Lee sides of hills or cliffs experience standing
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Table 2-1
Rainfall for Three Windward Coastal Kohala Stations (in mm)
waves, while vortices or eddies occur over rough terrain surfaces. The convection induced by these disruptions of the wind streamlines upward and also by daytime heating of the surface tends to increase the turbulence of the flow. The net effect of all these actions is to increase gustiness and to distribute the force of the wind in all directions, though not equally (Sutton 1953).

The irregularity of windflow in the valleys has several implications in terms of vegetation. Microscopic salt particles are picked up over the ocean and deposited on the soil and vegetation, especially on the seaward slopes, but also extending hundreds of meters inland. Wind is funneled through gorges and may in some places travel in a direction opposite to the mean southwesterly flow. Although lee sides of cliffs and valley walls are somewhat sheltered from wind, turbulent counterflow enables them to receive rainfall even in a strong wind. Updrafts and downdrafts may induce local condensation and evaporation, causing variation in rainfall and especially in cloud-drip.

Solar Radiation

The character of solar radiation received by any small site in Kohala varies in three ways: duration, timing and intensity by wavelength.

The highly irregular topography of Kohala blocks many hours of sunlight from the valleys, which are oriented more-or-less perpendicular to the diurnal passage of the
sun. The effects are naturally most pronounced in steep, narrow valleys with nearly north-south alignments. This is especially important during the winter, when the path of the sun keeps it behind the higher inland walls of the valley, further reducing the already shortened daylength.

Windward areas in Hawaii tend to be cloudy (greater than 8/10 of the sky covered by clouds) 40 to 60% of the time, and clear (less than 3/10 covered) 15 to 20% of the time (Blumenstock 1978:273). Cloudiness increases in the Kohala valleys from the sea to the mountains, which are usually shrouded. The absorption spectrum of clouds tends to block out infrared radiation during the day and tends to help the land retain its heat at night. For this and other reasons, night temperatures seldom dip below 16 degrees C at sea level in Kohala.

Weather Events

The effects of storms on the climate of Hawaii are reflected only poorly in the average rainfall and wind patterns. Some storms cause intense ocean waves, rainfall, and winds, which may disrupt, or if frequent enough, set limits on the form of vegetation.

Storms are of four major types in Hawaii. Cold front passages, which occur one to six times each winter, bring spotty but locally heavy rainfall, and brisk to high winds. Kona storms are low pressure cells that bring moderate but steady wind and rain, and occur one to five times per
winter. Hurricanes and intense tropical storms in the Hawaiian Islands may be considered rare events; only six have caused significant damage to property, mainly through high waves, in the last eighty years. Upper level lows, the fourth storm type, occur several times each winter and carry light winds but often bring torrential rains and flash flooding (Blumenstock 1978:278).

Hawaii is popularly known for gentle showers, but it also experiences rainfall intensity as high as 150 mm in a half hour and up to 950 mm per day. The majority of Hawaiian rainfall stations have recorded 300 mm on at least one day during their history (Ibid.:276), usually the outcome of a major storm. Winds of over 18 MPS in Kohala are uncommon except during these storms. The Honolulu airport has reported sustained winds of 25 MPS with 35 MPS gusts during tropical storms and cold front passages (Ibid.:272), and it is likely that the valleys of Kohala experience similar conditions occasionally.

Jointly, Hawaiian storms are frequent enough to be of importance in vegetation damage. In and near streams, the soil foundation around trees may be eroded during heavy rainfall and the trees subsequently uprooted. On steep slopes intense rainfall triggers soil avalanches (Wentworth 1943), while flat and low-lying areas may be temporarily inundated.
Soil

The environment of Kohala has been outlined in detail except for the matter of soil, which is a necessary precursor to the discussion of vegetation. Soils are so widely associated with the plants that root in them that many systems of soil classification rely on vegetation types as their chief indicators and symbols (Chikishev 1965). Soil in some ways can be treated as a super-variable in the determination of vegetation, because soil type is correlated with so many other environmental variables. It must be remembered, however, that soil and vegetation are interactive, and the question of cause is a complex one.

The soils of the Kohala Valleys have been classified into Soil Series by the U.S. Soil Conservation Service (Fig. 2-7, after Sato et al 1973). Much of the region is covered with soil derived from the ash and cinder that blanketed the Kohala Shield (types rAr and NID). Other areas have pockets of ash interspersed with what is called Rough Broken Land - steep, virtually soil-less slopes (RB). Valley bottoms are covered with alluvium (MT, Tr) and near their mouths occasionally with marine deposits (BN).

The ash-based soil is a mucky, acidic, silty clay loam, varying in depth from 25 to 75 cm, overlain by a thick mat of decomposing organic material, and usually underlain by a sheet of pahoehoe lava. The soil is quite permeable above this sheet and its runoff time is slow.
Fig. 2-7. Soils of Kohala Valleys
The NID Series, found on the northwest fringe of the valley region, is better-developed, better-drained and deeper than the more widespread Amalu Series.

The surface of Honokane Iki Valley and the rearward portions of all the valleys are classified as Rough Broken Land. A map at a larger scale would probably distinguish a narrow alluvial strip of land bordering the streams. Rough Broken Land occupies most of the area outside the valleys themselves.

The alluvial soils of the larger valleys are classified as Mixed Alluvial or Tropaquepts. The latter type is a moderately deep, poorly-drained soil that forms in the larger valleys, especially near the seaward margins, and whose properties are determined by frequent flooding and a high water table. The surface is a mucky silty loam and the subsoil is a silty clay loam. Mixed Alluvial is a miscellaneous category, but is basically composed of stream alluvium from the ash soil of the slopes. Talus deposits near the valley walls are also included in this soil type. Flooding is common, and the surface is in many places littered with stones and boulders.

Significant beach deposits in the Kohala valleys are confined to an irregular dune ten to twenty meters high that all but blocks the mouth of Pololu Valley.

Groundwater

Underground water is important not only as the main
supply of streamwater, but also as a factor in normal water tables, periodic flooding, and the water supply of former inhabitants.

Most of the water that flows into the valleys goes through a complex process of submergence and re-emergence before it reaches the sea. Precipitation infiltrates the soil and is trapped by volcanic dikes, along which the water is conducted shoreward by the flow of gravity. When valleys incise into a water-bearing stratum, the water is released into streams, where it may flow subaerially to the sea, or submerge again in the streambed. Pololu Stream has many tributaries that flow above ground until within a kilometer of the shore. From there on, except during floods, water is conducted seaward through subterranean stringers of sand and cobbles (Hubbard 1972:8). In valleys better supplied with runoff, permanent streams that reach the sea do exist, but the high water table underlying the whole valley reflects the passage of a large quantity of groundwater.

Springs perched in tuff beds on the sides of valleys may contribute to a more mesic water regime in certain narrow strips of the talus slope. Flow from these springs may be large, as in Waimanu, where Keawewai Springs supplies an estimated 120 million liters per day to the main valley (Stearns and MacDonald 1946:232).

The high water table maintained by groundwater induces rapid flooding during intense precipitation episodes, from
the valley center to the foot of the talus slopes.

**Environmental Zonation of the Valleys**

The effects of the environmental factors discussed in this chapter are imposed jointly on the different locations of the valleys. To summarize the environmental aspect, the focus of explanation shifts here from topical to locational. The actual study area is divided into geomorphic zones, in which conditions are treated as elements that contribute to the individuality of the zone. The basic zones are the beaches, the valley floors, the streambeds, the stream terraces, the talus slopes, the side gulches, and the cliffs. This division is based primarily on the author's field work in the Kohala valleys, but is also congruent with windward Hawaiian geomorphic zones as defined by other investigators, chiefly in archaeology (Kirch and Kelly 1975; Tuggle 1975).

**Beaches**

The influence of the sea is prominent in a zone that extends to five meters in elevation, especially within twenty-five meters of the mean high tide line (Fig. 2-8). The substrate is composed of sand, cobbles, and boulders, well-worn from the intense wave action, which deposits boulders up to three meters above sea level during storms. Salt water and spray, high porosity, and intense sunlight make the shoreline a xeric area for vegetation. Sand dunes are uncommon except for the immense one in Pololu Valley.
Fig. 2-8
Pololu Beach

Fig. 2-9
Pololu Dune
(Fig. 2-9), but the vegetation characteristic of Hawaiian dunes is also present on the Kohala shoreline.

Valley Floors

Although every valley by definition has a bottom, a valley floor as defined here includes only the fairly level area of alluvial deposits, and is found only in the major valleys of Waimanu and Pololu. In the seaward part of both valleys are slightly brackish marshes composed of a variety of grasses (Fig. 2-10). Near the back of the valleys the marshes grade into a low forest. The high water table, frequent flooding, and level terrain of this zone maintain a mucky, fine-grained, acidic soil, strewn with larger particles on the surface, especially near the edges. Mid-day sunlight is relatively unobstructed on the valley floor, particularly in the center.

Streambeds

Crossing the floors of the larger valleys and the terraces of the smaller are streambeds, which are often multiple (Fig. 2-11). They are depressed from the level of the valley floors by up to three meters in Pololu and Waimanu, and from the stream terraces in the other valleys by as much as ten meters. Boulders, cobbles, and a small component of sand make up their beds. They are commonly treeless, although in places they are shaded by branches from the adjacent terraces. Because they lack tree cover, and travel mainly in the center of the valleys, they
Fig. 2-10. Pololu Marsh

Fig. 2-11. Honokane Nui Streambed
receive more sunlight than any other zone except the beaches. Weedy islands of soil are often present in the rocky bed. Streams range from permanent to ephemeral, and they actively shift their beds causing their banks to erode.

Stream Terraces

Stream terraces adjoin the streambed in the smaller valleys and in the lower reaches of the side gulches of the larger valleys. Level to mildly sloping, each has originated in one or more of several ways. A stream may create a floodplain at one level and then for various reasons begin to incise its bed, leaving a terrace from the stream deposits (Fig. 2-12). Side gulches produce alluvial fans that grade into terraces and may be grouped with them for convenience. Also, Hawaiian cultivators purposefully terraced sections of the talus slope and upper stream terraces (Fig. 2-13). The net effect of their actions has been to create a stairstep-type profile between the edge of the talus and the stream in many places.

Some terraces are relatively low and subject to occasional flooding from the streams, while others are completely out of the flood zone. Because terraces adjoin the cliff/talus zone, the time of direct sunlight there is often restricted to mid-day and either afternoon or morning, depending on whether the terrace is on the east or west side of the valley. The soil on the terraces is often
Fig. 2-12
Pololu Stream Bank

Fig. 2-13
Prehistoric Terrace
in Honokane Nui
deep, well-drained, and high in organic material, especially where cultivators have intentionally developed it. Near the cliff side there is danger from rock avalanches, but in general the terraces are the zone freest from the environmental problems of stream flooding, tsunami, and slope failure.

Talus Slopes

Between the terraces or the stream itself and the cliffs there is a zone of talus accumulation. It is formed of mixed debris including talus, soil avalanche deposits, soil slumps, and vegetation, and may extend from 5 to 200 m from the cliff's edge, depending on the degree of stream activity at the base. Despite its unstable nature, the talus zone usually supports a thick forest.

Although the talus zone is in general free from problems of flooding, it is crossed at intervals by intermittent streams from the narrow side-gulches or waterfalls of the cliffs. These streams carve small channels through the talus in places, creating alluvial fans as well, but more commonly the water sinks under the talus and flows as groundwater into the banks of the streams or under the valley floor.

Rock avalanches are the major environmental hazards of the talus zone, scarring, shearing, or even killing trees (Fig. 2-14), and posing a danger to people who venture too near the cliffs.
Fig. 2-14

Tree Scarred by Rockfalls
Sunlight is restricted in this zone to a period of slightly over half a day, being concentrated in the morning on the western slopes and in the afternoon on the eastern ones.

Side-gulches

Small tributary streams form steep, narrow, parallel gulches in the main valleys and commonly terminate within 100 m of the main valley wall in waterfalls (Fig. 2-15). Often active only during heavy rains, the gulches are covered along much of their length with particles of talus, which show few signs of stream abrasion. Subject to flooding and avalanches, this is a dangerous zone for man and tree alike. Sunlight is often blocked from these canyons except at mid-day, and weeks may pass in the humid gulches without the penetration of a ray of direct, unclouded sunlight.

Cliffs

The valley walls vary in steepness but are generally steep enough to merit the term "cliff". Vegetated except on recent soil avalanches, the cliffs are the source of the talus that accumulates below (Fig. 2-16). East-facing cliffs near the sea are subject to strong, salty winds but also augmented precipitation, and on the higher reaches, cloud-drip. Bare or grassy patches of the valley region are perhaps attributable to dessicating, salt-laden winds, but are possibly anthropogenic instead. Sunlight reaches
Fig. 2-15  
Side-gulch in Pololu  

Fig. 2-16  
Cliffs in Honokane Nui
the cliffs for slightly more than half a day during the morning for the western cliffs, and during the afternoon for the eastern ones. A thin soil mantle covers much of the cliffs, but vegetation may cling to virtually bare rock.

The Distribution of Geomorphic Zones

Inside a Typical Valley

A typical large valley contains each of the seven zones named and described above. Fig. 2-17 shows three cross-sections of a large valley: at the mouth, across the mid-section, and at the head, including a side-gulch.

The most areally extensive zones are the valley floors, which are wide at the mouth and narrow at the back, and the cliffs, which are equal in width along the length of the valleys. Beaches form a narrow zone that occupies minimal area, while streambeds are also narrow but run the entire length of each branch of every valley. Terraces are often intermittent in appearance along the length of a valley, between the west and the east sides. They are occasionally missing from a geomorphological sequence that includes cliffs, talus, and streambeds or valley floors. Side gulches are intermittent and often absent in small valleys. The talus zone is a nearly continuous strip that runs along the base of the cliffs, absent only in the less common situation of a cliff rising directly out of the valley floor.
TYPICAL VALLEY CROSS-SECTIONS

Fig. 2-17. Typical Valley Cross-sections
All geomorphic zones except the beach are present along the length of the valleys, but they differ internally in their characteristics from the front of the valley to the back. The valleys progressively narrow towards the back, and the walls eventually meet, eliminating valley floors. Slopes become steeper on the floors and terraces towards the rear, and elevations thus increase slightly. Steep walls flanking narrow canyons hinder the penetration of sunlight except at mid-day, and because cloudiness increases inland, what sunlight does reach the back of the valleys is often filtered through clouds. Rainfall also increases towards the back of the valleys, as does cloud-drip. Wind is often partially blocked from the valley interiors, especially in sinuous canyons, and wind speed is consequently lower. In general, the backs of the valleys are cloudier, rainier, narrower, steeper, and less windy than the fronts.
CHAPTER 3

THE NATURAL VEGETATION OF THE KOHALA VALLEYS

A treatment of the natural vegetation of the valleys must take into account the flora, or the constituent species, and the structure, or the physical and numerical arrangement of those species, as they would be encountered in the various zones of the valleys. Biogeography also emphasizes the differential location of species or vegetation types as a function of environmental factors.

The Development of a Hawaiian Flora

Soon after the first volcano in the Hawaiian chain emerged from the water some millions of years ago, a Hawaiian flora began to develop. Propagules, mostly in the form of seeds and spores, arrived via the winds, currents, and the wings and stomachs of birds, from sources in the Americas, other Pacific islands, and especially from the Indo-Malaysian region of Asia (Carlquist 1970:307).

The early plant colonists helped modify the volcanic rock and ejecta into soil, and created an increasingly complex biogeochemical environment for the later arrivals.

A large number of higher plant species has accumulated in Hawaii, even by tropical standards. St. John (1973) listed 2800 specific and infraspecific taxa native to Hawaii. A few botanists believe this figure far too small as it does not account for the perhaps thousands of species extinguished between Western contact in 1778 and today.
(Degener and Degener 1974). The majority of researchers, however, would agree that Wester's (1983:99) estimate of 1630 extant native species (not including some 270 extinctions) approximates the true number of Hawaiian species. Whatever the precise figure, the remarkable fact about the Hawaiian flora is that all but 66 species are endemic. Hawaii's endemism rate is thus over 95%, one of the highest in the world.

Several factors account for this. The Hawaiian Islands are isolated by at least 3800 km from the nearest potentially important source of plants. The introduction of most types of propagules appears to have been a relatively rare event. Carlquist (1970) estimated that the introduction of merely 255 species could easily account for the present number of species. After introduction, adaptive radiation appears to have been considerable, especially in those species whose arrival was a particularly unusual event, and in which re-introduction and genetic back-crossing were thus more unlikely. Species adapted to lowland conditions on the continents have radiated in Hawaii into large genera adapted to conditions ranging from coastal to alpine. Xeric colonists, well-suited for original colonization, have evolved mesic descendants that have colonized the extensive rainy windward uplands.

Another distinct characteristic of the Hawaiian flora is the trend towards a loss of competitiveness. There are
few poisons, thorns, or secondary compounds in native plants. Botanists account for this trend by noting the absence of herbivores in Hawaii. Only one mammal, a bat, was present in Hawaii before the arrival of the Polynesians, and there were few other plant predators, whether insect, mollusc, or bird, that might have encouraged defensive adaptation in plants.

The Flora of the Windward Valleys

The windward valleys offer favorable conditions for plant growth along with a diverse array of sub-environments. Although no scientific observer has ever seen Hawaiian forests in a pristine condition, the flora and structure of some zones has been inferred by analogy with certain little-disturbed modern forests (e.g., Mueller-Dombois, Bridges, and Carson 1981). In the valleys with which this study is concerned, the composition and structure of the pristine flora are largely a matter of conjecture. The modification of the valleys, first by Hawaiian settlement and horticulture (Kirch 1982), and later by the introduction of non-Polynesian exotics (Wester 1983), has been so complete that no windward valley in a relatively undisturbed condition exists to supply even an analogy.

Figure 3-1 depicts the modern vegetational zonation of the valley region (adapted from the Atlas of Hawaii, University of Hawaii, Department of Geography 1973). The
THE KOHALA VALLEYS

VEGETATION TYPES

GUAVA  OHIA  KOA  MIXED

Honokane Nui
Honokane Iki
Honokea
Honopue
Waimanu

Contour Interval is 250'

Fig. 3-1. Vegetation Types of Kohala Valleys
<table>
<thead>
<tr>
<th>Genus or Species</th>
<th>Abund.</th>
<th>Verified</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pandanus odoratissimus</td>
<td>V</td>
<td>Y</td>
<td>0-300</td>
</tr>
<tr>
<td>Pritchardia spp.</td>
<td>?</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Pipturus albidus</td>
<td>V</td>
<td>Y</td>
<td>0-1500</td>
</tr>
<tr>
<td>Santalum spp.</td>
<td>V</td>
<td>Y</td>
<td>500-2000</td>
</tr>
<tr>
<td>Charpentiera obovata</td>
<td>C</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Broussaisia arguta</td>
<td>V</td>
<td>N</td>
<td>300-1000</td>
</tr>
<tr>
<td>Pittosporum spp.</td>
<td>V</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Pelea spp.</td>
<td>V</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Antidesma spp.</td>
<td>V</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Caloxygen sandiwicense</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Urera spp.</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Touchardia latifolia</td>
<td>?</td>
<td>Y</td>
<td>0-750</td>
</tr>
<tr>
<td>Ilex anomala</td>
<td>V</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Perrotetia sandiwensis</td>
<td>V</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Elaeocarpus bifidus</td>
<td>U</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Xylosma hawaiense</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Metrosideros collina</td>
<td>V</td>
<td>Y</td>
<td>0-3500</td>
</tr>
<tr>
<td>Eugenia sandiwicensis</td>
<td>?</td>
<td>Y</td>
<td>300-1000</td>
</tr>
<tr>
<td>Cheirodendron trigynum</td>
<td>C</td>
<td>Y</td>
<td>600-1500</td>
</tr>
<tr>
<td>Vaccinium calycinum</td>
<td>V</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Gouldia coriacea</td>
<td>V</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Myrsine spp.</td>
<td>V</td>
<td>Y</td>
<td>600-1200</td>
</tr>
<tr>
<td>Cyrtandra spp.</td>
<td>U</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Coprosma spp.</td>
<td>V</td>
<td>Y</td>
<td>300-1200</td>
</tr>
<tr>
<td>Hedyotis spp.</td>
<td>V</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Psychotria spp.</td>
<td>V</td>
<td>Y</td>
<td>1000-1500</td>
</tr>
<tr>
<td>Clermontia spp.</td>
<td>U</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Lobelia spp.</td>
<td>U</td>
<td>Y</td>
<td>600-1000</td>
</tr>
<tr>
<td>Delissea spp.</td>
<td>U</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Cyanea spp.</td>
<td>U</td>
<td>Y</td>
<td>1000-1300</td>
</tr>
<tr>
<td>Scaevola spp.</td>
<td>V</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Dubautia plantaginea</td>
<td>?</td>
<td>Y</td>
<td>300-1200</td>
</tr>
<tr>
<td>Platysdesma cornuta</td>
<td>?</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Labordea spp.</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Myoporum sandicense</td>
<td>C</td>
<td>Y</td>
<td>600-2000</td>
</tr>
<tr>
<td>Canthium odoratum</td>
<td>?</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td>Nothocestrum longifolium</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Acacia koa</td>
<td>V</td>
<td>Y</td>
<td>500-3000</td>
</tr>
<tr>
<td>Alyxia olivaeformis</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
</tbody>
</table>

Abundance V=very common, C=common, U=uncommon. Estimates from Carlquist (1970), and pers. obs.
Verified Y=known to Hillebrand (1888) to have been collected or sighted in Kohala Mts, or sighted by author.

Table 3-1
Potential Constituents of Prehistoric Wet Kohala Lowland Forest
coastal region belongs to the "open guava forest with shrubs" zone, an exotic community, while inland (i.e., higher in elevation) areas are classified as "closed ohia-lehua rainforest." Though the division is necessarily a crude one, as it was designed to cover the entire state, the zones reflect the basic contrast between upland native forests and the confusing situation in the valleys and the lower portions of the intervening ridges.

Above the valleys, on the higher ridges and near the summit of the mountain, a relatively undisturbed native forest exists. This upland forest is dominated by ohia, lehua (Metrosideros collina), with a variety of subdominants depending on elevation, rainfall, and topography. Table 3-1 lists the tree species of the upland forest, their elevational ranges, and an estimate of their current abundance.

Along the shoreline a strand vegetation similar to that of today was undoubtedly present. It included vines and shrubs such as Ipomoea pes-caprae and Scaevola sericea, and possibly the monocot tree hala (Pandanus odoratissimus).

Inland from the shore, the flora is assumed to have included many of the upland forest trees. Those trees with ranges extending to sea level in Table 3-1 are the most likely constituents of the native lowland forest.
Local Variation

The state of paleobotanical evidence today does not allow us to reconstruct the zonation of trees and shrubs inside a particular hypothetical vegetation type of the past. Neither can we infer the change of flora and structure along minor gradients within the valley, such as a soil catena of a ridge, or across a section of a valley extending from the marsh over the talus slopes to the cliff. Pearsall and Trimble's (1983) work with opal phytoliths and Allen's (1983) analysis of archaeobotanical remains as part of the Mudlane-Waimea-Kawaihae corridor environmental project (Clark and Kirch 1983) represent initial efforts to apply paleobotanical reconstruction techniques to small areas and environmental gradients. As the authors stress, however, the techniques are still undergoing modification. No such study has yet been conducted in any valley in the Hawaiian Islands. At present, one must be satisfied with a list of the most probable floral components, with no attempt to arrange the species into structural units within the various zones of the valleys.

The Ribbon Forest

The particular area chosen for analysis in this study consists of the talus slopes, side gulches, stream terraces, and cliffward margins of the valley floor (defined in the previous chapter). Restricting the study
to only some parts of the valleys is based on both environmental and historical considerations.

Cliffs have probably undergone little economic use in either historic or pre-historic times. They also pose problems in sampling vegetation because of their steepness. Valley floors, on the other hand, constituted the principal arena of cultivation of taro, and later, rice. However, since the abandonment of agriculture in the valleys, the floors have reverted either to marsh or to a monotonous woodland of guava (*Psidium guajava*), maintained by periodic flooding and a high water table, and thus exhibit little of interest to a cultural biogeographer.

The remainder of the zones, together with the cliffward flanks of the valley floors, consists of an area that for all its diversity may be thought of as a unit. I call this area the "ribbon forest" because it winds up and down the valley margins (Fig. 3-2) like a recurving ribbon and is for the most part densely covered with forest. It was the principal site of Hawaiian settlement and non-taro horticulture, particularly in historic times, as the chapter on the history of the valleys reveals. It is in the ribbon forest that the most direct correspondence between the past patterns of land-use and the present distribution of trees is displayed.
Fig. 3-2. Typical Ribbon Forest
CHAPTER 4
PREHISTORY OF THE VALLEYS

Hawaiian prehistory began at least 1500 years ago and did not end until 1778, the year of Hawaii's "discovery" by Captain James Cook. During that period, Polynesian voyagers colonized and settled all of the major islands, expanding in population from probably less than 200 to at least 200,000. In the words of Patrick Kirch,

Neither the contact period Hawaiian culture or its environment can be adequately comprehended except as the product of some 1400 years of interaction (1982:2).

This statement acknowledges the dynamic and adaptive characteristics of Hawaiian culture, which included a set of behaviors that ingeniously exploited the diverse habitats of the islands and encouraged a high level of productivity, as well as the unintentional environmental change this behavior fostered. Unfortunately, most of our knowledge of culture and environment in prehistoric Hawaii is derived from second-hand accounts or indirect inferences, and the reality of Hawaiian prehistory seems hidden from us. This chapter renders a portrait of the prehistoric Kohala valleys, employing archaeological and ethnographic evidence from Kohala and analogous locations in Hawaii. The major focus is the elucidation of the settlement and agricultural patterns responsible for the current vegetation landscape. Before discussing prehistoric land use, sources of information are described
along with the advantages and limitations of their use.

Sources

Sources on the prehistory of Kohala are of four types: local archaeology, archaeology in other Hawaiian locations (particularly windward valleys), local ethnographic and historic accounts, and historic and ethnographic accounts from other locations in Hawaii.

Local Archaeology

Tuggle (1976) supervised an intensive archaeological survey of the valleys of Pololu and Honokane Nui. Teams of workers also excavated in selected sites. The specific purpose of the Kohala survey was to search for evidence on how Hawaiians expanded into unoccupied territory. Although the survey was probably thorough, many of the published maps are difficult to interpret, and this author was unable to examine the original field maps. The published work (Ibid, and Tuggle and Tomonari-Tuggle 1980) has been of some use in constructing a general prehistory of the surveyed valleys and also in providing detailed information on several individual sites.

Waimanu Valley remains relatively unexplored by archaeologists. A report by the federal Office of Coastal Zone Management (1976:4) stated that archaeological remains in Waimanu were "in poor condition...nearly destroyed by the 1946 tsunami, and...of marginal value." Though this evaluation may be accurate regarding beach sites, it is
inapplicable to most of the valley, which escaped significant tsunami damage and retains abundant archaeological remains (pers. obs. 1983-1985). A cursory archaeological survey during the 1920’s revealed a number of sites, including two possible heiau or temples (Hudson 1931). However, no intensive survey has yet been undertaken, and Waimanu along with most of East Hawaii "remains an archaeological void" (Kirch 1985:154). A prehistoric geography of this valley is presently impossible to construct.

Archaeological Studies Elsewhere in Hawaii

Although the discipline of Hawaiian archaeology is relatively young, dating from the survey work of Kenneth Emory (1921, 1928) for the B. P. Bishop Museum in Honolulu, it has developed rapidly. A recent summary of Hawaiian archaeology by Kirch (1985) lists hundreds of archaeological publications in the bibliography. Particularly pertinent to the analysis of land-use in the Kohala valleys are the multi-disciplinary projects conducted in Halawa Valley on Molokai (Kirch and Kelly 1975), Anahulu Valley on Oahu (Kirch 1979), Makaha Valley on Oahu (Green 1969, 1970), and the Waimea area on Hawaii (Clark and Kirch 1983). In each of these studies, archaeological remains were considered in light of the historical geography and the ecological context of settlement and land-use. A partial picture of how
Polynesians progressively exploited windward valleys has begun to emerge, along with an appreciation of spatial and temporal variation of features and activities.

The best archaeological work in Hawaiian windward valleys has been conducted outside the Kohala region, and it is tempting to apply the conclusions of this body of work to Kohala. The various valleys in Hawaii are analogous but not really homologous. Differences in culture, time period, and local adaptations distinguish valley occupations on different islands. However, the cautious use of analogy is both necessary and justified in this study. Certain common patterns of settlement have been demonstrated in all investigated valleys during late prehistory. Some of these widespread practices can tentatively be assumed to have been operative in the Kohala region as well, especially when there is corroborative evidence. The archaeological literature concerning Hawaiian valleys has been examined in this thesis in order to determine which cultural elements windward valleys tended to share.

**Early Ethnographic and Historic Accounts of the Kohala Valleys**

Although the grandeur of the Kohala valleys elicited comments from early explorers (Beaglehole 1967: 502, 1153, Vancouver 1798:111), there is no recorded account of a sojourn in any of the valleys until the visit of William
Ellis in 1823 (Ellis 1969). The English missionary, late of the Society Islands, was a keen and relatively objective observer who was concluding a seven-week tour of the island of Hawaii by foot and canoe in the company of natives. While his accounts of Kohala are detailed and trustworthy, it is likely that conditions had changed markedly in the valleys in the years between Western contact and his arrival. Aside from the journal of Ellis there are no early accounts from this region. American missionary reports for this area span a later time period (A.B.C.F.M., 1838-1863) and shed little light on indigenous patterns of culture.

Ethnography and Accounts of the Early Historical Period in Hawaii

There are several histories and ethnographies written in the 19th century by literate and somewhat Westernized Hawaiians (Malo 1951, I'i 1959, Kamakau 1964). These provide useful insight into the social structure and material culture of contact-era Hawaii. Most of the accounts dealing with prehistoric Hawaii have been written by Westerners, usually without direct contact with unmodified Hawaiian groups. Early visitors recorded their observations, speculations, and reports of prehistory. Among the most famous and well-cited of these works are the journals of Captain Cook and his officers for the period of 1778-1779 (Beaglehole ed. 1967, Munford 1963, Rickman
1967), and those of Vancouver (1798) for 1792-1794, and Menzies (1920) for 1792. Other commentary on the early historic period is provided by de Freycinet (1978) for 1819, and the Rev. William Ellis (1969) for 1823. Modern scholars have synthesized primary accounts, often adding a perspective gained in working with contemporary Hawaiians living in a "traditional" manner. Works by ethnographers such as Brigham (1908), Fornander (1918, 1919), Handy (1940), and Handy and Pukui (1972) are often used as sources of information on traditional Hawaiian culture. Chinen (1958, 1961) studied land division in early historic Hawaii. Sahlins (1958) has compared some broad aspects of Hawaiian culture with other Polynesian societies.

The Use of Historic Materials to Infer Prehistoric Conditions

The collective body of Hawaiian history and ethnography is rich and detailed, and invaluable to the study of prehistory. However, there are dangers in unquestioningly applying these accounts to prehistoric conditions, especially those made long after 1778. The use of early historic materials to help reconstruct prehistoric cultural patterns was termed the Direct Historical Approach by Julian Steward (1942), and it is a long-standing practice in archaeology. The approach has come under criticism because it may rely on faulty analogies and stifle independent and unbiased archaeological inquiry (Binford 1968). Kirch has pointed out that in Hawaii,
cultural patterns have changed rapidly, and to assume stasis in the period of historical contact is just as unwise as assuming an unchanging Hawaiian culture before contact with the West (1985). Contrary to the assertion by the geographer Jones (1938:194) that "In 1853, except for the growth of small seaports, the mode of life and the use of land had changed little from Polynesian patterns," anthropologists and historians now believe that Hawaii changed significantly between 1778 and 1830. The decline in population from between 200,000 and 300,000 in 1778 to near 135,000 in 1823 (Schmitt 1968) is but one example. Reconstruction of prehistoric patterns from historic accounts, cautions Cordy (1981), is best accomplished with sources from earlier than 1820, before indigenous cultural patterns began to disintegrate. Even before that year, the rate of change was accelerating.

After Cook made contact with Hawaii in 1778, activity in the Pacific did not suddenly begin to focus on the islands. The next major exploration of Hawaii occurred with Vancouver's voyages beginning in 1792. Nevertheless, American trading vessels landed dozens of times during the 1780's, and some captains, such as Portlock, Dixon, and Meares, returned several times (Alexander 1890:38). Ship's captains came to Hawaii in the late 18th century mainly for water, salt, firewood, hogs, vegetables, and recreation (Kuykendall 1957:21). The potential for the introduction of disease as well as new ideas early in the contact period
is obvious. Until 1796, foreigners were few but influential, a "fashionable commodity" (Kuykendall 1957:22). Not only the visitors themselves but also what they left behind were significant. The introduction of goats and cattle by Vancouver in 1792 signalled the novel and unexpected effects foreigners would soon have on Hawaiian land and people.

During the early 19th century, many visitors began to report a society in flux. The Russian naval officer Urey Lisiansky, comparing the Hawaii of his first visit in 1804 with that of his second ten years later, said that provisions were now more expensive and that many natives had shipped with American whalers (1968:125, 128). Another Russian, V.M. Golovnin, confirmed the botanical invasion in 1818:

Many Europeans apply themselves to agriculture and produce everything they can possibly grow in this climate and this type of soil. For this reason no captain of an American ship ever comes here without bringing seeds or sprouts of some yet unknown plant (1979:216).

In 1819 de Freycinet reported that many villages were in ruin or on their way to it, because of disease, overwork, and debauchery (1928:65). By the time of the arrival of the American missionaries and Ellis, upon whom so much of our understanding of early historic Hawaii rests, Hawaii was obviously a changed land. The kapu (tabu) system had been virtually overthrown the year before (Kuykendall 1957:61). Patterns of demography, settlement,
diet, social structure, and economy had been altered, especially in the port towns of Honolulu, Hilo, and Lahaina.

Hawaiian culture did not merely reproduce itself in the early years of European contact and the Kingdom. In the course of reproducing that contact in its own image, it changed radically and decisively (Sahlins 1981:33).

Rapid change during the early 19th century does not invalidate contemporary ethnographic accounts, but it makes them suspect as prehistoric sources. Observations of cultural patterns during early history were based on a changed culture; accounts of earlier ways elicited from natives rely on their memories and veracity for credibility. Few early visitors were both inclined and able to produce objective observations. The prejudice of early observers produced a great many portraits of a people either benighted and primitive or blissful and ingenious.

The scientific ethnographers of the 20th century were by no means unaware of the displacement of their sources from the time period they attempted to study. Nevertheless, they often synthesized descriptions from accounts of various ages without explicit reference to their sources, and it is now difficult to evaluate the applicability of their ethnographies to pre-contact cultural patterns. Sahlins has critically reviewed the assumptions of scholars concerning the early historic period (1981). Several authors have recently reconsidered the relationships between social groups and land tenure in
light of new archaeological and historical evidence and attitudes (Cordy 1980, Linnekin 1983). These analyses have revealed the uncertainty of long-held assumptions about Hawaiian society and have generated a critical spirit in dealing with secondary sources.

Secondary and temporally-displaced accounts have supplemented archaeological and contact-era information for the reconstruction of prehistoric land-use patterns in Hawaii in this thesis. It must be understood that much of what is described has not been validated. As far as possible, sources before 1830 have been consulted.

Knowledge of the nature of agricultural and settlement systems in Kohala is scarcer and less reliable as one goes back in time. This condition is not as disadvantageous in this study as it is in work focusing only on the prehistoric past. Current plant patterns are a function of environment and the history of interference, with the most recent conditions of management generally weighing more importantly in the analysis. Exceptions to this rule include such drastic actions as water supply removal, severe soil erosion, and exotic plant introduction. Most environmental modification by Hawaiians seems to have been less severe, except in the case of plant introductions. Fortunately, the history of plant introduction is fairly well-established. For the purposes of this thesis, confounding late prehistoric and early historic conditions is not a critical error. The land-use patterns of the
early 19th century are known, and even if they were preceded by systems only imperfectly understood, it is the latter patterns that have been the most influential in creating the vegetational landscape that exists today.

**Hawaiian Prehistory: Colonization and Early Settlement of the Hawaiian Islands**

The most recent synthesis of archaeological evidence indicates that human occupation of the Hawaiian Islands dates from at least 500 A.D. The islands were settled by canoe-voyaging East Polynesians most likely from the Marquesas Islands. Early populations were of course not numerous, but they soon began to flourish. Their success had less to do with the hospitable island environment than with the Polynesians' adaptable culture and the panoply of imported food plants, especially taro. The geography of the first settlements in Hawaii is still unclear. Early radiocarbon dates have been established for excavations in dry and rugged Ka'ū, as well as from windward locations on several islands. Hawaiians appear to have subsisted from the beginning on a mix of marine and agricultural resources (Kirch 1985:66-68).

After an initial colonization period, the population began to grow rapidly, and settlements were soon founded in coastal locations throughout the islands. There is firm evidence that by the 1200's settlements were thriving in windward, leeward, and a few inland locations. The
sequence of environmental exploitation in Hawaii has received much attention since the 1960's. Pearson (1969) hypothesized that early economic activity was limited mainly to marine exploitation, followed by a swidden period and attendant deforestation. Finally, advances in hydraulic technology enabled Hawaiians to build elaborate terraces in windward valleys for taro agriculture. However, the idea that Hawaiians from the beginning exploited certain windward valleys for agriculture is supported by hydration-rind dating (Cordy 1981). Also, swidden agriculture at the leeward site of Lapkahi in Kohala seems to have been initiated somewhat late in prehistory, after 1300 A.D., perhaps in response to increasing pressure to produce, due to population expansion and the redistributive social system, according to Tuggle and Griffin (1973:64). It appears that the sequence of agriculture types and habitation areas was variable, depending on a number of local conditions including environment, social stratification, and population. A definite trend toward intensification of agriculture is prominent in the archaeological record. In any case, the fertile and well-watered windward valleys have been the focus of Hawaiian agriculture and settlement since shortly after colonization (Kirch 1985:31).

Polynesian Plant Introduction

Polynesians transported to Hawaii on their voyaging
canoes some of their most valued food plants, animals, and also some stowaways. Coconuts and pigs were introduced along with rats, lizards and several weeds (Kirch 1984). Among the trees and shrubs that flourish in the windward valleys today are many Polynesian introductions. The dates of introduction and naturalization of these trees are not yet ascertained with precision, but it is likely that most or all of these trees were established in Hawaii nearly a millenium ago. Whether certain trees are indigenous or exotic, however, is still a matter of controversy.

Trees considered by almost all botanists and anthropologists to be Polynesian include ohi‘a ai (Syzygium jambos), ki or ti (Cordyline terminalis), kamani (Calophyllum inophyllum), coconut (Cocos nucifera), ulu (Artocarpus incisus), kou (Cordia subcordata), milo (Thespesia populnea), and bananas (Musa spp.). There is some disagreement about several others.

The kukui (Aleurites moluccana), a widespread tree that covers acres of well-drained valley slopes, was judged by Hillebrand in his monumental Flora of the Hawaiian Islands (1888) to be exotic. Bryan (1915), St. John (1973), and Carlquist (1970) expressed agreement. However, Degener (1930) considered the kukui indigenous, and Neal (1965) inclined towards this view as well.

The noni (Morinda citrifolia) was considered a Polynesian introduction by St. John (1973), Wester (1983), and Krauss (1974), but its origin was deemed questionable
by Neal (1965). Degener (1930) and MacCaughey (1918) claimed indigenous status for the noni.

Proponents for a native origin for the hala (*Pandanus odoratissimus*) include St. John (1973), Neal (1965), and Degener (1930). Krauss (1974) expressed doubt about this.

The hau (*Hibiscus tiliaceus*) was considered by St. John (1973) to be native, but Hillebrand (1888), Handy (1940), and Krauss (1974) listed the hau as a Polynesian introduction.

Because one of the objectives of this thesis is to identify and evaluate the status of the "Polynesian" forest, it was desirable to assign these disputed plants a place of origin if possible. Based on the opinion of the majority of botanists and the most recent conclusions, for the purposes of this work the hala is considered native and the noni, kukui, and hau are considered introductions.

In any event, Polynesians exploited all of these trees throughout most or all of prehistory. Without the introduction of food plants, especially taro, yams (*Dioscorea* spp.), and sweet potatoes (*Ipomoea batatas*), human life would have been difficult to sustain. Aside from marine resources, the starch and leaves of certain ferns and trees, the fruit of the ohelo (*Vaccinium reticulatum*), and a berry (*Rubus* spp.) are the principal edible plant products native to the islands.

Whether all of these plants were available to Hawaiians in the first few centuries of habitation is not
yet known. It has long been held by some archaeologists and ethnologists that Hawaii was colonized on several occasions, most recently during the 1400's by Society Islanders (Emerson 1893, Emory 1968). Current opinion of this idea acknowledges the occurrence of wider contacts and two-way voyages, but de-emphasizes their importance and frequency (Kirch 1985:66). In any case these contacts seem to have ceased in late prehistory, and all of the plants mentioned above were part of the repertoire of the Hawaiian cultivator.

**Land Use Patterns**

**And Change in Windward Valleys**

The early patterns of settlement and land-use in windward valleys have been the subject of investigation on several islands. A clear picture of the location and characteristics of early settlement sites is difficult to discern, because many sites are still undiscovered or were intermittently or continuously occupied. Interpretation of charcoal layers, soil alteration, and site location patterns does seem to indicate that intensification and expansion of agriculture took place in many windward valleys (Pearson 1969, Kirch and Kelly 1975, Tuggle and Tomonari-Tuggle 1980). In Halawa Valley on Molokai, Riley (1975) interpreted stratigraphic soil sequences and found a shift from swidden agriculture to pondfield taro over a 1200 year span of occupation. Wet-taro cultivation was an
extremely productive, labor-intensive activity requiring
ejudicious management of water resources. The tendency in
many windward valleys was for the agricultural system to
culminate in wet-taro field systems. Such agricultural
landscapes were reported in the early historical period
throughout the windward valleys of the islands. In Waipio,
the large, populous well-watered valley several miles to
the southeast of Waimanu, extensive fields of taro were
reported by many early visitors (Bingham 1847, Ellis 1969).

Land-use and the Organization of Space in Windward Valleys

There are many obstacles to gaining a comprehensive
view of land-use in prehistoric Hawaiian valleys. Not only
is the physical evidence meager and uncertain, the cultural
context has also largely disappeared. A location on the
surface of the earth becomes a place as it is created and
inhabited by people who share certain understandings, and
thus a place inherently possesses ethnocentric and
egocentric attributes (Tuan 1971). Some of the cultural
context that can bring meaning to the jungle-covered piles
of stone is available through ethnographies, but much of
the logic in the spatial patterns is unclear. In the
absence of a clear cultural context, it is tempting to
invoke strictly ecological explanations for patterns of
residences, agriculture, and trade. It is important to
bear in mind that in Hawaii, as elsewhere

The human organization of space...involves more
than environmental or ecological
considerations....Architecture and spatial arrangement of architectural components are used by all cultures to represent and maintain distinctions between categories of people and categories of activity (Kirch 1985:247).

Some of the framework for distinguishing the ecological and social rationale for spatial arrangements in prehistoric windward Hawaii has been established by archaeologists and ethnographers. Detailed interpretations of specific places must still be regarded as tentative.

Social Structure in Hawaii

The landscape of Hawaiian windward valleys during late prehistory was undoubtedly affected by the highly stratified and redistributive nature of the social structure. In fact, the development of intricate hydraulic networks is probably best understood in terms of the social structure and the demands on production it imposed.

Hawaii was characterized by a complex structural hierarchy that exhibited three major status levels. The class of chiefs, the ali'i, was empowered with stewardship of the land in the name of the moi, or king, and it was itself internally stratified. The ali'i oversaw agricultural production, and had the power to punish those who disobeyed them. They were distinguished by many insignia of rank, and their relationships with common people were restricted by a system of rules and prohibitions, kapu. For example, the buildings, clothing, and even the shadows of ali'i were considered sacred. If a
commoner profaned them with his presence or even his gaze, he was subject to a punishment as severe as death. The chiefly class rarely engaged in subsistence economic activity.

Under the ali‘i were the maka‘ainana, or common people, who farmed, fished, and practiced certain specialized crafts such as canoe-making. They were bound to the ali‘i not only by the strictures of kapu but also by tribute. Surplus agricultural and crafts production circulated upwards and was redistributed, often in a ceremonial manner. A small class of people apparently used for sacrifice was the kauwa, whose members inherited their status. Although political upheaval was common, it mainly affected the upper social ranks, and common people were usually safe from dispossession of tenancy if not from the vagaries of war (Malo 1951, Sahlins 1958, Kamakau 1964, Handy 1965, Handy and Pukui 1972).

The elaboration of the system of social stratification in Hawaii, with its attendant increase in production capacity, redistribution mechanisms, and population, has been the subject of intense research by archaeologists. The phenomenon appears to have been current throughout the Hawaiian Islands, and to have been well-advanced by the 16th century (Cordy 1974, Earle 1978, Tuggle and Tomonari-Tuggle 1980).

The stratified arrangement of society can be associated with certain patterns of land use.
Socio-political control of land rested in the hands of the ali'ī. The ali'ī nui or paramount chief usually controlled an entire island. Under him were stewards (konohiki) of wedge-shaped districts (ahupua'a) that typically extended from the center of the island to the sea, encompassing the full range of environmental zones, from montane rainforests to coastal flats. The common people of Hawaii were mostly taro farmers, tied to the ahupua'a by their birth, and by their obligations as tenants and subjects to produce tribute for the chiefs. They were free to relocate in search of better conditions, and occasionally they would overthrow an oppressive chief and invite another to take his place. However, for the most part, they seem to have remained inside one ahupua'a as "people of the land," the literal translation of maka'ainana.

A second effect of social stratification on land-use was the ability of the chiefs to mobilize labor for roads, common structures, and hydraulic works. Massive stone temples that still remain on the landscape serve as reminders of the scale of planning and labor possible in labor mobilization projects. Organized, large-scale labor probably allowed the improvement and occupation of marginal habitation areas.

If it is generally accepted that society was stratified in Hawaii and that this arrangement encouraged orderly agricultural exploitation, the actual production units are a little less easy to define. The term 'ohana,
roughly equivalent to relatives by blood, marriage, or adoption, has often been identified as the fundamental social unit. Handy and Pukui interpreted the *ohana as a lineage segment associated with an ahupua'a, or an 'ili, a smaller unit usually within an ahupua'a. In Ka'u, a physically diverse district on the island of Hawaii, different households in the same *ohana might reside in separate environmental zones, such as the dry seacoast and the wet uplands. One household would specialize in fishing and the other in upland taro, and they would maintain an intimate and complementary trading relationship. Clark and Kirch (1983:14) have termed this system the ili-'ohana model of land-use, and contrast it with the shifting-residence pattern uncovered in Lapakahi in leeward Kohala on the basis of archaeological work by Rosendahl (1972). In Lapakahi, households of the same *ohana would shift all or part of their members from one resource zone to another, depending on seasonal activities.

In contrast to these models, which despite their differences depict the *ohana as an entity with definite territorial aspects, stands the interpretation of Linnekin (1983). Based on her research in the native testimony of the Great Mahele (land division) of the mid-19th century and that of Sahlins (1971), she concluded that the local community was composed not of descent groups but of "overlapping bilateral kindred" (Ibid: 173). The *ohana, she concluded, was a term that was relative to the
individual in question, a term more akin to the Western concept of "relatives". Land-use and tenancy are in the hands of households in this model, and not lineage groups. It is not clear from Linnekin's research whether this arrangement was true of prehistory as well or simply of the disintegrating social patterns of the post-contact era. Archaeologists interpreting data from investigations in Lapakahi and Anaehoomalu in leeward Hawaii have recently confirmed that prehistoric boundaries tended to conform to divisions between households, or clusters of households, rather than the large social groups conceived by Handy and Pukui (Cordy and Kaschko 1980). They argued that local residence groups, which are clusters of houses with a few common buildings such as a men's house or a religious structure, composed the units that were identified with the *ili or its prehistoric equivalent.

How specific social units influenced residence and agricultural patterns in the windward valleys of Kohala is not known. Archaeological work there has not determined how individual households were related to each other and to the land.

The names of the ahupua'a in Kohala at the time of contact were recorded early in the historic period and survive on U.S.G.S topographical maps. Surveying during the mid-19th century involved the precise determination of many of the ahupua'a boundaries in Hawaii, but not in the Kohala valleys. However, physical features such as ridges
and streams probably served to divide these ahupua’a as they do elsewhere in highly dissected terrain in Hawaii. The specific study area encompasses three ahupua’a: Pololu, Honokane (including Honokane Nui and Iki), and Waimanu. The locations and boundaries of ’ili inside these units are not known. The relative locations of certain ’ili of the mid-19th century can be ascertained by examining the transcripts of oral testimony of natives before the land commissions of the time (Office of the Board of Commissioners to Quiet Land Titles, Terr. of Hawaii: 1929). These ’ili are discussed in the next chapter.

As emphasized previously, an accurate assessment of how social groups were associated with the land in the Kohala valleys awaits further archaeological work. However, it is probably safe to assume that a number of households had tenancy over portions of valleys for long periods of time. Intermittent warfare was probably accompanied by redistribution of land and authority, which mainly affected the upper levels of society. Trade among households might have existed, enabled by surplus production, environmental variability and the consequent heterogeneity of crop and gathering areas, and some degree of specialization in certain crafts, both in a geographical and sociological sense. External trade may have been more significant. Ellis commented on the presence in Hilo, at an outdoor market on the banks of the Wailuku River, of valley residents offering taro products and pandanus mats
The economy of the Kohala valleys was probably fairly homogeneous, and despite their isolation, there was undoubtedly trade with nearby areas for fish, salt, and perhaps other products difficult to acquire locally.

**Housing**

Many ethnographic sources recount the large number of buildings that comprised one household, and this seems to be confirmed by analysis of archaeological remains. Handy and Pukui referred to the *kauhale*, or group of houses that made up a dwelling. A collection including the *hale noa* (sleeping house), the *hale pe'a* (where women retired during menstruation), the *halau* (canoe shed), and a cooking shed were said to make up the typical household arrangement of a chief. Many more outbuildings constructed for farming, *kapa* (bark-cloth) making, canoe construction, and other purposes were also common (1972:9-14). Nevertheless, a single shanty is said to have often sufficed for a commoner (Kirch 1985:251).

Houses were generally constructed on a framework of wooden posts upon which sills and rafters were lashed, overlain with a thatch of grass, sugar cane, or other plant material (Brigham 1908:78). Some walls were also made partially of stone, and houses were usually constructed on a low terrace of smooth rocks, filled with earth (Ladd 1983, Rosendahl 1975). These platforms could support an
entire cluster of buildings, or each structure could have an individual platform associated with it. Other less common houses included caves and the protected area beneath a thicket of hau trees (Handy and Pukui 1972:14).

The pattern of archaeological remains in Polulu, Honokane Nui, and Honokane Iki valleys reveals a mixture of individual structures and clusters of small structures often difficult to distinguish (Tuggle 1980). Ellis spent a night apiece in the valleys of Honokane Nui and Waimanu in August of 1823. Although he appears to have lodged with members of the chiefly class, he repeatedly referred to his hosts' homes as houses, not as compounds or clusters, but he did not describe them further (1969:372, 374, 379).

The Distribution of Houses Within the Valleys

Towns in the Western sense were absent in prehistoric Hawaii. Even densely populated Waipio Valley was not a center of political, religious, or commercial activity (Handy and Pukui 1972:1). European visitors in the early 19th century often called collections of houses hamlets or villages, but this was probably an ethnocentric appraisal. Archaeological studies reveal a dispersed pattern of settlement that varied with the type of environment.

Concerning most Hawaiians, Brigham's statement that "the old Hawaiian was a shore dweller...his chosen home was near the sea" (1908:82) was valid, excepting the inhabitants of a few inland sites such as Waimea on Hawaii
Island. In the V-shaped windward valleys, the opportunities and advantages of living near the sea are obvious. There is more flat land and more total area, and there are fewer rockfalls and less shade throughout the day. The Kohala valleys appear to have possessed a settlement pattern similar to that of the better surveyed Halawa Valley. In Halawa, taro agriculture helped determine the location of houses. Taro fields occupied the flatter and marshier sections of the valleys, while houses were scattered on the beach, lower ridges, and taluvial slopes (Rosendahl 1975:75).

An extensive archaeological survey of Halawa Valley found no sites further than an hour's walk from the sea (Kirch 1975:177). The interior of Halawa appears to have been settled relatively late in the prehistory of the valley, although it had been exploited for centuries (Ibid:177).

Early historic settlement in Kohala certainly reflects a similar pattern. The missionary Hiram Bingham visited Waipio Valley in 1830 and remarked on "the quiet hamlets near the cliff" (1847:379), a description echoed by a later visitor, John Shedden Davis (Joesting annot. 1970:209). Published maps of archaeological features in Pololu Valley seem to indicate that prehistoric settlement also was concentrated near the valley walls and on the beach (Tuggle 1974). The inland portions of Pololu and Waimanu appear to have been cultivated, but archaeological remains nearer the
sea are much denser (Handy 1940:123, Tuggle 1980, pers. obs.). Although the exact location of all settlements in the valleys is unknown, there is no reason to believe that the pattern there deviated from what seems to have been normal for other windward valleys in Hawaii.

Population

The number of inhabitants in the valleys of Kohala at any time during prehistory is not known with any precision. Archaeologists have not published population estimates for these valleys, even for those areas in which archaeological surveys are relatively complete. This is probably in recognition of the problem of ascertaining the exact nature of certain features and the contemporaneity of habitation of spatially adjacent structures (Hommon 1969:41, Kirch 1985:35).

Ellis furnished estimates of the population or number of houses gained during his two-day stay in Kohala in 1823. On the morning of his departure from Waimanu Valley, he gave a sermon, for which "about 200 collected, and were addressed from John vi 40" (1969:375). Presumably some natives were unable to attend the reverend. Concerning Honokane Nui, where he spent the following night, he spoke of 50 houses, which might represent some 250 people, based on the figure of 5 persons per household which he deemed typical in Waipio (Ibid:364, 379). The late date of his estimates relative to Cook's contact suggests that
prehistoric figures were probably greater, by some unknown amount.

Taro Agriculture

Taro was the mainstay of the Hawaiian diet, and its cultivation demanded a great deal of labor and ingenuity. Two major farming strategies, utilizing different mixes of cultivars, were practiced: dryland and pondfield. Taro was also encouraged to grow wild in narrow stream gorges. All of these methods were practiced in the Kohala valleys (Handy 1940:7, 123, Tuggle and Tomonari-Tuggle 1980:40).

Pondfield taro agriculture as described by E. S. C. Handy in The Hawaiian Planter (1940) consisted of a complex sequence of steps including land preparation, water-level maintenance, and attention to crops. Stone-lined ditches for irrigation and drainage were first constructed. Individual fields (which in modern times ranged in size from 0.05 to 0.6 hectares in Waipio according to Dashiell 1972:28) were separated by earthen causeways or stone terraces. The bases of terraces were pounded to prevent seepage. The wide banks between terraces served not only to contain fields but also as garden area for bananas, sugar cane, and other crops.

To plant, the field was cleared of weeds, and then small taro shoots were placed in the ground. The water was maintained at a low level until the plants rooted. After this initial period, water was allowed to flow onto the
fields continually at a depth of several inches. When somewhat more than a year had elapsed and the taro was deemed nearly mature, the flow of the water was stopped and the depth increased. The corms would enlarge during this period, and finally they were harvested and the cormels gathered for seed-stock for the next crop.

Maintenance of ditches, dams, terraces, and culverts was critical to a productive harvest. Control and administration of irrigation projects and water rights rested in the hands of the konohiki, a member of the chiefly class who supervised activity in an ahupua'a (Chinen 1958:3). The word for water in Hawaiian is wai, and the importance of water to Hawaiians is stressed in the words for wealth (waiwai), and law (kanawai). Labor on water projects was communal, and water was granted in acknowledgement of and in proportion to the amount of labor contributed by a household (Handy 1940:34-36).

Dryland cultivation was practiced in areas unsuitable for irrigation, and it demanded more labor for weeding but much less complex hydraulic networks. Swidden agriculture, or slash and burn, seems to have been common on slopes and in inland areas, especially in areas without extensive level land for taro fields. The significance of swidden agriculture in the Hawaiian economic system has not been assessed, but it appears to have been most common in earlier prehistory and on the margins of cultivation later.

The varying suitability of the Kohala valleys for taro
were probably a major influence in the differential timing and intensity of their settlement. Waimanu is reported to have been "second only to Waipio as a wet-taro valley" among all the valleys in the Hawaiian Islands (Handy 1940:123). While it has not yet been confirmed by archaeologists, Waimanu was probably settled soon after Waipio, perhaps a thousand years ago. Pololu Valley, burdened with an ephemeral water supply that occasionally grew to a flood, first possessed significant settlement in the 16th century, according to Tuggle and Tomonari-Tuggle (1980). Only by then, they hypothesized, was the social infrastructure able to mobilize the sort of labor required to terrace, irrigate, and protect Pololu from floods. Settlement in well-watered Honokane Nui soon followed. Honokane Iki is a narrow, shady valley, that was never terraced according to Handy (1940:122). Tuggle and Tomonari-Tuggle's hypothesis of an intensification of agriculture from swidden to dry-field to irrigated is borne out by the sequence of soil types they found in some locations of the valleys, although all farming types were probably practiced simultaneously, and many areas were unsuitable for irrigation. The scale of irrigation in the valleys of Pololu and Honokane Nui was in any case much smaller than that of Waimanu. Pololu apparently relied on dryland taro for most of its production.

Taro was significant in the Kohala valleys for many reasons. Its impact on the landscape was the use of most
of the marshy floor of Waimanu for pondfield agriculture, the terracing of the steep parts of Waimanu and the valleys of Pololu and Honokane Nui for dryland and limited pondfield agriculture. Taro cultivation was also instrumental in encouraging the exploitation of areas on the margin of the valleys, particularly in early times, for swidden agriculture.

Other Agricultural Areas

Because of the intensive nature of Hawaiian agriculture, one might label their system of cultivation as horticulture. This is perhaps most appropriate of the gardens cultivated by Hawaiians on their taro banks, near houses, and in outlying patches. Archaeological evidence is scanty concerning Hawaiian gardens, but voyagers to Hawaii before 1800 remarked extensively upon them (Menzies 1920:23, Portlock 1968:191, Vancouver 1798:165). Archibald Menzies, a botanist aboard the H.M.S. Discovery with Vancouver, described a "plantation" in Waikiki in 1792...

...nearly level and very extensive, and laid out with great neatness into little fields planted with taro, yams, sweet potatoes, and the cloth plant. These, in many cases, were divided by little banks on which grew the sugar cane or Draecena [Cordyline terminalis] without the aid of much cultivation, and the whole was watered in a most ingenious manner by dividing the stream into little aqueducts (1920:23).

Visitors to Waipio between 1823 and 1847 commented on the gardens of bananas, sugar cane, breadfruit, and other crops visible on the hillsides above the taro fields (Bingham
1847:329, Ellis 1969:356, Joesting 1970:209). Because the sources of information on such gardens are quite displaced in time from prehistory, most of their observations are discussed in the chapter on history, but some general comments are apt.

Both Brigham (1908) and Handy (1940) described the dooryard and outlying gardens of prehistoric Hawaiians. Patches of trees valued for shade, firewood, fruit, and building grew alongside gardens of sweet potatoes, yams, ki, arrowroot, bananas, and sugarcane. Taro banks were said to be planted with similar crop mixtures. There is archaeological confirmation that terraces in Halawa Valley served, among other purposes, as stable surfaces for tree crops (Riley in Kirch and Kelly 1975:112). It is probable that the emphasis on horticulture and mixed cropping so noticeable during the early historic period had its basis in prehistoric Hawaiian agricultural practices.

The mixture of crops has much to recommend itself as an agricultural strategy. Different crops may require labor and come to fruition at different times, optimizing the seasonal use of time. Handy and Pukui (1972:23-25) discussed the variation of activity with the seasons customary among Hawaiians of the 19th century in Ka'ū. Although the environment of Ka'ū differs somewhat from that of windward Kohala, the timing is likely to have been similar. In February and March, taro was planted, followed by sweet potatoes and gourds. Later, bark cloth and fiber
trees would be harvested and processed, and bananas and wild ferns collected as sources of food until other crops would be ready. By June, sweet potatoes would yield their tubers, and in July, gourds were harvested. On the calm summer sea Hawaiians would fish, and the weather of late summer was optimal for drying fish. November through March is a somewhat rainy time in both Ka‘u and Kohala, and indoor activities such as weaving, spinning, and net-making were common.

Another advantage of mixed gardens was the prospect that one crop would succeed if another failed. Also, crops that required shade could be provided a proper environment under trees useful for other reasons. Common shade trees were the kou and hau, and the kamani and kukui which provided edible and other useful products. Coconuts, breadfruit, and mountain apples provided fruit, while wauke (Broussonetia papyrifera) and olona (Touchardia latifolia), which were grown mostly in monocrop patches in the lower forests as well as mixed in gardens, provided sources of fiber and cloth.

Gathering Areas

The acquisition of fiber, timber, bark, medicinal and ceremonial plants, special stones, bird’s feathers, and other commodities required Hawaiians to exploit wild zones outside their fields and gardens. The opportunity for gathering may have come about during the course of visits
for trade or social reasons to other locations, or strictly as an end in itself.

Brigham’s research on Hawaiian houses revealed the extent of one aspect of gathering. Most of the timber customarily used in house-construction was obtained in the forest zone of the mountains. The best houses were constructed of naio (Myoporum sandwicense), uhi‘uhi (Caesalpinia kauaiensis), kaula (Alphitonia ponderosa), mamane (Sophora chrysophylla), and koa (Acacia koa), all of which are distinctly upland species. ’Ohi’a (Metrosideros collina) or lama (Diospyros spp.) were less acceptable but more accessible, although they too rarely grow near shore (1908:77-84).

Many of the plants used for medicine, dye, and ceremony in Hawaii were available only in the forests above the fields. Examples of such forest plants are kolea (Suttonia spp.), useful for dye (Neal 1965:664), and ’ekaha (Asplenium nidus) a bird’s nest fern, used in a canoe building ceremony (Krauss 1974).

When Hawaiians stayed overnight in the forest to gather plants, they would build temporary huts of banana, ti, grass, or ferns. The remnants of their staging areas are still vaguely evident in the vegetation (MacEldowney 1979:27, Handy 1940:196). The vegetation on the forested ridges, particularly below 750 meters in elevation, consists mostly of Western-introduced weed trees such as guava (Psidium guajava), lantana (Lantana spp.), and
Christmas berry (Schinus terbinthifolius), interspersed with hala, ohia lehua, and several native shrubs. However, the ridges also abound in localized clumps of the relics of cultivation, which probably indicate former temporary habitations or resource areas from the prehistoric and historic era. Both the localized clumps of cultivated plants and the general weedy nature of the vegetation may be in part attributed to repeated exploitation this zone for gathering, and later, for limited agriculture. The native species prized by prehistoric Hawaiians are infrequent in the lower elevations. Above 750 m the forest becomes increasingly indigenous, reflecting the reduced degree of interference experienced by montane forests in Hawaii, particularly during historic times. Although the forest zone in which prehistoric Hawaiians did most of their gathering lies outside of the specific study site of this paper, it is important to understand that the resource base in prehistoric Hawaii was not limited to the fields and gardens of the valley floors and talus slopes.

**Exploitation of Marine Resources**

If the mainstay of the Hawaiian diet was taro, fish was a close second. Hawaiians exploited a wide variety of marine resources, including seaweed, reef fish and invertebrates, and pelagic fish. They also practiced aquaculture in taro ponds and in special tidally-influenced enclosures. This thesis concentrates on the vegetational
relics of Hawaiian land-use, and thus marine resource exploitation is of only indirect importance. In ancient Hawaii, certain households possibly practiced fishing nearly to the exclusion of farming, but it is unclear if such specialized households existed in the Kohala valleys. It is more likely that most valley households pursued fishing to some degree, as was common in most coastal locations in Hawaii. The coastal waters of Kohala are rough and turbid due to their windward aspect and the heavy influx of stream sediment. This limits reef development and nearshore fishing, and also inhibits offshore ventures, especially during prolonged periods of high surf in the winter. Even if the Kohala valleys were not ideal fishing locations, shellfish and tackle remains discovered during archaeological excavation testify to local marine resource use. Fishing activities involved land use most directly in the acquisition of materials for tackle. Canoes, lines, nets, floats, and other gear were derived from terrestrial resources, and required either gathered or cultivated materials. Prehistoric Hawaiian canoes were constructed of whole logs from a variety of trees, including *koa*, coral tree (*Erythrina sandwicensis*), and *ulu*, although *koa*, found only in the mountains, was preferred. The *hau* tree served as a source of wood for floats and outriggers, and many other trees also served various purposes. Much fiber for lines, nets, and lashing was needed. The coconut, *hau*, and especially the *olona* were important sources of fiber.
A Summary of Prehistoric Land-Use in Kohala

The windward valleys of Kohala may be divided into two groups in terms of settlement and agriculture. Waimanu Valley, a smaller version of the greatest valley in the isles, Waipio, was probably settled early, and it certainly had a landscape dominated by pondfield taro agriculture. The other valleys relied on dry fields and scattered irrigated terraces for their taro production, because of unsuitable conditions in either topography (Honokane Iki and Honokane Nui) or water supply (Pololu). The latter group was apparently settled rather late in prehistory, after 1500 A.D., when some combination of population pressure and social conditions encouraged the exploitation of these somewhat marginal agricultural environments.

The settlement pattern in all valleys was dispersed, with houses concentrated on the beaches and near the cliffs. In narrow Honokane Nui and Honokane Iki, this was unavoidable. In Waimanu, the marshy floor was probably occupied by taro fields rather than houses, although houses were probably not entirely absent. In Pololu Valley, dryfield agriculture did not preclude settlement in the valley center, and probably the center as well as the margins were occupied, although flooding may have discouraged central settlement.

The social contribution to settlement patterns is more problematic to assess. Given the small size and isolated
nature of the valleys, it is reasonable to assume that little economic specialization occurred (in the sense described by Handy and Pukui, 1972, for Ka‘u). Most households in the valleys probably participated to some degree in farming and fishing. This statement is difficult to validate without better archaeological evidence. Trade with other regions undoubtedly occurred, but to what extent and in what ways this influenced land-use remains unclear.

Prehistoric inhabitants of the valleys were supplied with the full range of crops introduced by their Polynesian ancestors. Although taro fields and terraces dominated the landscape, intercropping was also common on the taro banks and gardens near the houses and in outlying areas, where sugar cane, yams, sweet potatoes, bananas and other plants grew. Tree crops such as coconut and ulu were also cultivated, alongside other trees native and exotic used for fiber, cloth, medicine, ceremony, or timber. The taluvial slopes were particularly common sites for gardens and patches of trees. Also, certain specialty crops such as olona were grown and processed in the forest zone. Gathering in the forest rounded out the Hawaiian exploitation of the Kohala valleys. Marine resource use also made demands on the products of tree crops such as olona, hau, coconut, and wild forest plants.

All of these land-use practices had an affect on the soil, topography, and vegetative cover of the various zones of the valleys, depending on the intensity and duration of
use. Given the dense concentration of stone house and field remains and the reportedly intensive agricultural practices of the Kohala valleys, it is safe to say that the entire valley bottom, including the floor, taluvial slopes, stream beds, and side-gulches, experienced modification. Most of these areas in all four valleys were probably cultivated, in one manner or another, at some time in prehistory.
CHAPTER 5
THE HISTORICAL PERIOD

Introduction

One of the remarkable aspects of Hawaii is the rapidity with which its geology, biology, and even culture have changed. The adaptable Hawaiian people entered an era of accelerated transformation after the visit of Captain James Cook in 1778. Many records exist pertaining to this relatively modern period owing to the nature of the early explorers and travelers, many of whom were naval officers and missionaries of precise and systematic habits. But despite the abundance of meticulous reports on early Hawaii, we still lack much of the sense of how, when, and where change came about. Perhaps this is because the feudal, stratified society with an elaborate stone-age technology evolved so quickly into a polyglot and forward-thinking kingdom at a strategic nexus of Pacific trade routes. The abundance of documentary sources and the magnitude of change are still providing a great challenge to cultural historians (Sahlins 1981), and they offer many opportunities for the study of land-use as well. Although the general progression of land-use in Hawaii in the last two centuries is well understood, adequate documentation concerning specific places are rare. For this reason, a study of history in Kohala must oscillate between a focus on the general and the specific in order to gain the
clearest portrait of land-use. The advantage of this approach is that it provides a general context in which to interpret the specific historical events in Kohala. The disadvantage is the risk of applying generalizations to a situation that is unique.

The organization of this chapter is to unfold a general summary of Hawaiian history by periods, which have been delimited by the author on the basis of salient social, economic, or political occurrences affecting land-use. The major events and trends of the period are first discussed, and then their specific effects on land-use in Kohala are explored. Settlement patterns, population distribution, agricultural changes, plant introduction, and environmental change form the principal topics of interest.

The Early Post-Contact Period: 1778-1800

Two significant trends developed after Cook’s visit to Hawaii in 1778: the gradual political unification of the Hawaiian Islands into a Kingdom under a native chieftain, and the increasing prominence of foreigners, with their trade, diseases, and examples. Kamehameha I was born on the island of Hawaii, and according to local tradition spent much of his youth in the valleys of Kohala (C.K. Sproat, pers. comm. 1985). He began his conquest of the islands in 1782 and emerged as supreme ruler of all Hawaii by 1803. During this time of almost constant warfare among
rival chiefs, the aid of foreigners was vital to all contestants. Kamehameha shrewdly exploited the services of two English sailors captured in 1790 on different islands, Isaac Davis and John Young (Kuykendall 1957:35).

Between the visits of Cook in 1778 and Vancouver in 1790, at least six captains were refreshing their supplies and crew in the islands (Alexander 1890:38). After 1790, Hawaii became a regular port-of-call in the American trade with China, which often included a stop for furs in the Pacific Northwest. Hawaii grew from simply a convenient source of provisions in the mid-Pacific to a market for American goods, a haven for deserting sailors, and a source of crewmen for merchant and whaling ships. By 1809, there were over sixty foreigners living on the island of Oahu alone (Kuykendall 1957:8).

Estimates of the native population vary from 100,000 to 400,000, the most commonly accepted range being from 200,000 to 250,000, based on Schmitt’s work with a variety of sources (1971).

Effects on the Hawaiian People and Environment

A number of unfortunate occurrences, especially the introduction of European diseases that turned more virulent among the isolated Hawaiian population, soon began to reduce the numbers of Hawaiians. One demographic scholar estimated the annual rate of decline during the period from 1778 to 1823 at 1.8%. He attributed this to low fertility
associated with venereal disease, abortion, and miscarriage, as well as poor sanitation, disease, alcohol, and disrupted social conditions (Schmitt 1973:16).

In the same period, new crops and animals were being introduced, which added to the Hawaiian subsistence base, provided articles for trade, and began to alter the vegetational landscape. Captain Cook brought one male and two female goats to Niihau in 1778, and other ship's captains, including Vancouver, periodically added to that stock during the 18th century (Marques 1905:51). Vancouver recorded in his journal for March 4, 1792, that he had presented "some vine, and orange plants, some almonds, and an assortment of garden seeds" to a chief named Tianna (Vancouver 1798:173). We are fortunate to know something about the introduction of at least a few species new to Hawaii, but the great majority have gone unchronicled (Wester 1978:2).

It is certain that a number of new crops were introduced quite early in Hawaiian history, but the rate at which they were incorporated in Hawaiian agriculture can only be surmised from later accounts.

Social and Cultural Change

The beginning of social change can be detected in accounts from this period. Not only did Hawaiians adopt some of the crops, ornaments, and technology of the haole, but they also began to integrate European outlooks into
their Hawaiian view of life. Some of the new ways undoubtedly destroyed the old and set the stage for a new Hawaiian culture. Other apparent changes constituted merely the reproduction of Hawaiian culture substituting European symbols (Sahlins 1981:29). Certainly new agricultural patterns, which tended to incorporate exotic crops in the Hawaiian farming scheme, follow most closely the latter pattern. A more important alteration may have been the replacement of the traditional ceremonial context for the exchange of goods by a commercial setting. As Hawaiians began to understand the benefits and obligations of the Western concept of trade, they became shrewd traders, and began to produce some goods with the sole object of gaining advantage through trade. Agriculture remained basically subsistence in character in the early historic period, but the commercial component grew rapidly.

The Kohala Valleys

The phenomenon of cultural change in Hawaii did not proceed with equal speed or along equivalent pathways in all areas of the islands. Honolulu, on Oahu, Lahaina, on Maui, and Hilo, on the Big Island, had the most contact with foreign people and ways. The windward valleys of Hawaii Island were bounded by formidable cliffs and seas, offered poor access to interior sources of supplies, and thus underwent little direct contact with Europeans. This author has been unable to uncover a single eyewitness
account, or even a mention of a shore visit, by a European before 1823 in the Kohala valleys. Viewed from aboard a passing ship, the physical beauty of the valley landscape elicited frequent comment. The earliest reference to the valleys themselves comes in an entry for Dec. 7, 1778, in the journal of David Samwell, surgeon aboard the Discovery.

At this place are two Vallies where we saw many houses, the most easterly of the two is called Oi-e-pe-o [Waipio], the other Oi-manoo [Waimanu]; between them is a high bluff covered with shrubbery on which several waterfalls, the most beautiful I ever saw, which falling down from a considerable height almost perpendicular between the verdure, have a very pleasing and grand effect (Beaglehole, ed., Vol. 2 1967:1153).

Ship's captains visiting in the 1780's occasionally anchored off the flatter portions of North Kohala to board supplies (Alexander 1889:39). Captain Vancouver sailed by the Kohala valleys several times, including a pass in 1793, when he remarked

...the coast is composed of a cluster of remarkably high steep rugged and romantic cliffs, discharging from their naked summits many rapid cataracts into the ocean....an enchanting, cultivated, and populous country (1798, Vol. 2:111).

The early post-contact period in Kohala does not seem to have been a time of wholesale social change due to contact with foreigners; however, some indirect effects, such as venereal disease, depopulation, and increasing contact with foreign goods, may have been widespread.

The Calm Before the Storm: 1800-1819

The start of the 19th century saw the end of war among
Hawaiian chiefs and the beginning of the hegemony of the Kamehameha dynasty, which was to last a hundred years. Kamehameha I had united all of the islands under his rule except Kauai, which was forced to pay tribute and slowly lost all vestiges of independence. During the first two decades of the 1800's, the traditional Hawaiian religion, social system, and land tenure arrangements were maintained, while adjustments were made to the demands of the increasing foreign population.

New Crops and New Farming Styles

Hawaiian subsistence farming began to give way in many places to commercial agriculture, which supplied sailing vessels engaged in the Orient trade, and the small but growing whaling industry. The cheap and plentiful provisions of early years grew relatively scarce as the market for Hawaiian produce increased and the full value of supplies began to be demanded by Hawaiians (Lisiansky 1968:125). Royal monopolies were imposed on certain items such as pork and sandalwood, and a large supply of naval stores, guns and ammunition, liquor, and cloth was thus collected for use and distribution by the crown (Kuykendall 1957:84, de Freycinet 1978:87). The development of the sandalwood trade was particularly lucrative for the chiefs, who exacted a heavy toll on their tribute subjects. This burden increased as supplies began to dwindle (Kuykendall 1957:84). Sandalwood had flourished at elevations above
300 m on all the major islands, but the tree was progressively eliminated in the early 1800's from the lower to the higher elevations.

The fact that new crops had become established in Hawaii by 1819 is certified in several traveler's accounts. De Freycinet compiled a list of crops seen during his voyage around the islands in 1819, including garlic, celery, chicory, cabbage, shallots, cucumbers, beans, gooseberries, lettuce, corn, melons, peaches, parsley, pears, red pepper, apples, tomatoes, pumpkin, radishes, and grapes - each one exotic! (de Freycinet 1978:50-51).

V. M. Golovnin noted in 1818 the reason for such a profusion of exotics.

Many Europeans apply themselves to agriculture and produce everything they can possibly grow in this climate and this type of soil. For this reason no captain of an American ship ever comes here now without bringing seeds or sprouts of some yet unknown plant (1979:216).

Environmental Effects

Meanwhile, the population of wild goats had begun to increase enormously, and several other grazing animals had also become feral or developed extensive unfenced ranges (Marques 1906:51). Lisiansky noted the havoc created in the plantations and valleys in 1804 by the descendants of Vancouver's cattle (1968:189). By 1815, the further multiplication of cattle fostered by the fledgling tallow industry constituted a menace on most islands (Hall 1904:17).
Kohala

Although direct evidence is lacking, the benefits and misfortunes associated with new crops and animals were undoubtedly experienced in the valleys of Kohala. T. Stell Newman inferred, from the archaeological record of Lapakahi, a few miles to the south of the valleys,

rapid changes in the terrestrial ecosystem owing to the American and European introduction of exotics such as mesquite, cactus, lantana, and herbivores (in Pearson, ed., 1969:8)

However great the changes that had already occurred, the immediate future would make them seem paltry by comparison.

The Missionary Period: 1819-1850

Ralph Kuykendall called the year 1819 a watershed in Hawaiian history for several reasons. Kamehemea I died, and deprived Hawaii of a ruler strong and adaptable, and yet committed to the traditions of his people. Shortly after his death, the strict kapu forbidding men and women to eat together was ceremonially broken by the new king and several ali'i women, initializing a rapid breakdown of similar strictures and symbolizing a new epoch of uncertain social relations among Hawaiians. Whaling ships had also begun to visit Hawaii in large numbers. The Yankee trader then descended upon the islands, promoting items as diverse as scissors and billiard tables to the foreign population and the wealthy chiefs. In 1820 came the missionaries.
The Missionary Impact

The American Board of Commissioners of Foreign Missions, a New England-based group of Presbyterians and Congregationalists, established their first mission in Hawaii in 1820. They enlisted over the course of more than thirty years thirteen companies of young ministers, doctors, teachers, tradesmen, and their wives (Anderson 1870). In the words of Kuykendall

[They] came out of Puritan New England, from that stratum of society which had been most thoroughly permeated by evangelical influences. They had the strengths and the weaknesses of the evangelical Protestant, in character, conduct, and theology (1957:101).

The missionaries were successful in converting natives to Christianity, and perhaps more importantly, in converting the oral Hawaiian language to a written form. The schools they founded helped allow the majority of Hawaiians to achieve literacy by 1850. They instructed Hawaiians in many trades, including printing, blacksmithing, carpentry, sewing, and similar Western activities assuming importance in 19th century Hawaii. They were much less successful at improving Hawaiian agriculture, a failure usually attributed to their utter lack of experience with tropical farming conditions. Credit must also be given to the Hawaiian farmers themselves, who had developed ingenious systems in little need of alteration. The missionaries' earnest attempts to inculcate in Hawaiians the Western notion of sanitation seem today tragically ironic in light
of by the diseases to which they, along with fellow haole, submitted the natives. Occupying a prominent role in the early history of Hawaii, they are often given the credit and blame for the course of Hawaiian history after their arrival. The missionary legacy is important to this thesis largely because they left records of the progress of social and demographic conditions, and also left progeny who began to shape Hawaii into a commercial, Western-style kingdom.

Censuses and Population Decline

Missionaries conducted the first censuses in Hawaii in the 1830's, and their efforts yielded "generally accurate" results according to Schmitt (1973:6). In 1832, 130,313 people were counted in all the Islands, including 45,792 on Hawaii. The second missionary census, conducted in 1835-1836, counted only 108,579 in all, with 39,364 on the Big Island of Hawaii(Ibid:15). This loss occurred despite the addition of foreigners. Schmitt calculated the annual rate of native population for this period (based on these data and refined by calculations using local figures) at 3.6%, the highest rate during Hawaiian history (Ibid:15). Disease and social conditions conducive to decline were at their peak during this time. Ellis observed shortly after the coming of the missionaries that "the great body of people....are generally averse to our remedies" (1969:335). Apparently the healing traditions of the Hawaiians were unable to cope with the new diseases; Western medicine would have little more success in the decades to come.
Epidemics often carried away great portions of the population in a matter of months or even weeks. Henry Lyman, son of a missionary stationed in Hilo, recalled that one-tenth of Hilo's native population succumbed to an epidemic of measles in 1850 (1906:168). According to the first official government census, conducted during that same year, the population of the islands had dropped to 84,165, of whom 25,684 resided on the Big Island.

The Synthesis of Foreign and Hawaiian Ways

At the same time as the numbers of the Hawaiians were declining, missionaries began to establish themselves, and they and other foreigners began to bring about changes in the laws and foreign relations of Hawaii. During the 1830's, Western-style penal and civil codes were promulgated by the crown (with advice from the foreign community), along with liquor laws, a declaration of legal protection for the property of foreigners, and a compulsory education act (Kuykendall 1957:136-147). Schoolhouses improved from crude thatch huts to enclosed structure of coral, lava, or adobe, by 1840 (Ibid:110).

The period from 1820 to 1850 was a time of great alteration in the traditional Hawaiian life-style. Particularly noteworthy were the addition of new items to the material culture, and the confusing redefinition in social relations that ensued the demise of the kapu system. Despite increasing Westernization in the Hawaiian
government and changing social and material conditions, much of rural Hawaii was only peripherally affected by foreign ways. An anthropologist reviewing agricultural practices in this period has said

The overall character of both the region and the predominant Hawaiian approach to land use remained recognizable throughout the early historic period, even though specific features of these patterns were undergoing substantial change (MacEldowney 1983:211).

The observations of both Ellis (1969) and C. S. Stewart (1833, 1970), a missionary who first came to Hawaii in 1823, indicate that the inhabitants of the island of Hawaii were much less sophisticated and affected by European ways than residents of Lahaina or Honolulu.

Substantial changes in material culture occurring throughout the islands included the increasing use of imported cotton cloth instead of the traditional kapa of bark, the substitution of iron for wood or stone in implements, and the widespread consumption of alcohol (Bates 1854:147, Kuykendall 1957:174).

Exports, Imports, and Agriculture

The expansion of trade during this period encouraged the production of traditional and introduced crops, the consumption of exotic goods, and increasing contact with foreigners. The average annual number of whaling ships visiting Hawaii rose steadily from 104 during 1824-1827 to 419 during 1843-1854 (Kuykendall 1957:307). Each ship bought large amounts of pork, fowl, beef, vegetables, and
wood. Hawaii continued to be a provisioning point in the increasing trade between North America and the Orient. In addition, the "California connection" became more important after 1830, with Hawaii supplying great amounts of food and hides to California, especially during and immediately after the Gold Rush of 1848-1850. The Rev. Henry Cheever traveled in Maui in 1849 and noted a booming export trade in sugar, coffee, hides, tallow, sweet and Irish potatoes, pumpkins, oranges, coconuts, onions, fowls, and melons (1851:314). The potato boom ended abruptly in 1851 (Kuykendall 1957:321), when ex-gold miners began to supply the local market with produce from the fertile soil of California, but the strong economic ties between Hawaii and California persisted and grew.

The many travelers accounts from this period illuminate the expanding agricultural repertoire of the foreign and native gardeners and farmers. Although many of the newer crops were undoubtedly confined to mission areas or commercially-oriented farms, many also were likely adopted even in isolated family farmsteads, as the astonishing legacy of vegetational richness in long-abandoned plots reveals today.

A Spanish immigrant of the late 18th century, Don Francisco de Paula Marin, is credited with the introduction to Hawaii of dozens of choice garden fruits and vegetables, including the tamarind, fig, guava, mango, and pineapple (Golovnin 1979 and Stewart 1970 are among contemporary
accounts that lend credence to popular belief). For reasons of commerce, and perhaps vanity, Don Marin was often reluctant to disperse many of his most exotic specimens. Stewart commented that in 1823 Marin had "perseveringly denied the seed, and every means of propagation, to others" (1970:159). Notwithstanding Marin's monopolistic aims, these fruits began to flourish in other gardens by the 1830's. Tropical fruits were by no means common, however. A son of the missionaries recalled that "guavas were choice garden fruits in the thirties, not becoming wild until some twenty years later" (Bishop 1916:39). Henry Lyman, also born to missionary parents, remembered in 1906 that as a child in the 1840's, "fruit of any kind was a rarity," although on occasion his family would obtain guavas, pineapples, watermelon, and papayas (Lyman 1906:60). The dearth of fresh fruit in Hilo began to be remedied, as the missionaries

improved every opportunity to procure seeds from foreign lands, and in this way after I had finally left home [in the 1850's], Hilo became well supplied with a variety of tropical fruit (Ibid:59).

Frances Allyn Olmsted, fresh from Yale and travelling for health reasons aboard a whaling ship from 1839 to 1841, described the valleys on Oahu as being "in a high state of cultivation," producing abundant melons, figs, grapes, and pineapples, as well as native crops (Olmsted 1969:191).

How many of these new food supplies were seen outside of haole gardens and were actually adopted by Hawaiians in
this period is still unknown. The accounts by well-traveled missionaries such as Ellis (1969), Bingham (1947), and Stewart (1833, 1970), and the botanist Bloxam (1925) remark principally upon the "plantations" of native crops, such as taro, breadfruit, wauke, and sugar cane, although potatoes and melons also drew mention. A letter from "Alien" in The Friend (a missionary newspaper) of April 15, 1846 commented, "In travelling over the fertile districts of this group of islands, one is surprised to find few, or no, fruit-bearing trees." It can be assumed that the more distant a location was from a mission station, the less likely it was to have had a great variety of exotic crops, at least before the middle part of the 19th century.

The groundwork for monocrop commercial agriculture, so characteristic of Hawaii in later years, was being laid during the early missionary period. John Wilkinson, an English agriculturalist, traveled with Lord Byron (George Anson) in 1825 to Hawaii, and started a coffee and sugar plantation in Honolulu for Governor Boki (Thrum 1876:46). The first permanent sugar plantation was begun by Ladd and Company on Kauai in 1835, and by 1838, missionaries were grinding cane for natives on shares (Kuykendall 1957:175, 180). Despite these early developments, the importance of plantation agriculture lay in the future.

European beasts and fowl were rapidly adopted in Hawaii, and many had become feral by 1840. The first horse
had come to Hawaii with Richard J. Cleveland on the *Lelia Byrd* in 1803 (Apple 1965:83), but despite continuing imports they were quite scarce and valuable before 1840 (Kuykendall 1957:93). The development of trails suitable for horses became a government priority, and this was implemented by means of road taxes and forced penal labor (Ibid:48). Missionary families kept Polynesian chickens and also imported turkeys, ducks, and chickens from America. They were, to judge from their remembrances, better supplied with fowl, pork, and beef than with vegetable products in the early days (Lyman 1906:59-60, Bishop 1916:16, Lyons n.d.:11). As mentioned earlier, goats became feral in the early 1800’s. Cattle soon followed them into the plains and mountains, and were "ravaging" native plantations by 1804 (Lisiansky 1968:135). Tallow and hide exports increased greatly after 1834. An 1846 estimate of wild cattle put their numbers at over 25,000, in comparison with 10,000 tame (Kuykendall 1957:317-318).

Increasing Environmental Degradation

Environmental change resulted from the introduction of new crops, weeds, animals, and farming techniques. Overgrazing led to erosion in many locations and desertification in semi-arid grasslands. Native bird populations, having adjusted to the stresses imposed on them by prehistoric Hawaiians, were again under siege, and
many species became extinct (Carlquist 1970:178). Over 25,000 ha of native forest on Maui alone were cut solely to supply the firewood demands of whalers (Korte 1961:3). Just as native Hawaiians suffered from introduced diseases, native and Polynesian forests became exposed to new pathogens. A fungus struck the *kukui* in the 1800's and caused major damage (Nelson 1967:6). As the social system was rearranging itself, many natives began to ignore some of the traditional environmental *kapu* that had helped to regulate the exploitation of natural resources. Cheever reported a tale of an old and formerly sacred grove of *kou* (*Cordia subcordata*, a native tree) being felled to produce bowls for the king (1851:69). The story may be apocryphal, but countless more violations went unrecorded.

The Establishment of Western-style Land Tenure

One of the developments of early 19th century Hawaii that affected the Kohala valleys most directly was the success of foreigners in seeking fee simple land titles. The nature of the traditional rights of tenants in Hawaii is still a matter of debate, although it is generally accepted that the king fundamentally owned all land and allocated it through a hierarchical system to native farmers and residents. Foreigners in the 19th century argued that such an arrangement was antiquated, unfair, and contrary to the best interests of land improvement, commerce, and the coffers of the crown. The push for "land
reform" gained legal results in 1839, when a declaration of rights granted foreigners some measure of protection, but the law failed to quell the clamor (Chinen 1958:6). By this time, genuine leaseholders were difficult to distinguish from squatters, and a crisis was in the making. Finally, in 1845, legislation was passed that set up a Board of Commissioners to Quiet Land Titles, chartered originally for two years but actually active until 1855 (Kuykendall 1957:279). The first task was to divide Hawaii into crown (government) lands, the king's personal lands, and the lands of the nobility. This process, known as the Great Mahele, was accomplished by 1850. Foreigners could then legally buy land or certify title to land already held. Native tenants could also validate claims on their small parcels (kuleana), which lay within the larger divisions belonging to the crown, the king, and the ali'i. Tenants were granted the right to gain fee simple title to all improved land they occupied, free of commutation. But first they were required to have their land surveyed, and to provide proof of occupation and intensive use at hearings before the Board. Despite the sincere efforts of many parties, most natives failed to gain title to their land. The difficult and time-consuming process of legitimizing a claim discouraged some natives (Lydgate 1915:104). Others were skeptical of the ultimate goal of the process:
Many [natives] thought it to be a ruse to tempt them to build better houses, plant trees, and make such improvements in cultivation as should enrich the chiefs, hereditary owners of the soil (Coan 1882:124).

Some relied, as they had always done, on the guidance of their chiefs in the future as well as the present. Natives were in some cases tricked or bullied into not registering their claims by chiefs or unscrupulous foreigners harboring designs on their kuleana (Lydgate 1915:104). Many claims were awarded but reduced in area by the Board, because of the shortsighted exclusion of fallow land, or in some cases, outlying garden patches, from the claims process. In the end, only 9337 kuleana were awarded, comprising only 12,145 ha of the 10,000,000 ha divided during the Great Mahele (Kuykendall 1957:295). Most of this land was to vanish from native hands during the next 50 years.

Isolated Kohala

The Kohala valleys received occasional visits from 1820 to 1850, and several eyewitness written accounts survive today. The journal of Rev. William Ellis provides great insight into conditions around the island in the early missionary period. When Ellis arrived in Waimanu on August 19, 1823, the chief of the valley was engaged in directing the loading of sandalwood, collected from high in the mountains, aboard the governor's sloop. Youths were surfing on the beach, which elicited a lengthy, admiring
paean to the Hawaiian joie de vivre in Ellis' memoir (1969:368). The juxtaposition of the traditional and the novel are perfectly reflected in the narrative, and the commonality of Waimanu's experience with that of the more visited island ports is illustrated. Ellis likened Waimanu to Waipio, in which

the bottom of the valley was one continued
garden, cultivated with taro, bananas, and sugar
cane, and other productions of the islands, all
growing luxuriantly (Ibid:356).

He commented that Waimanu was "not so spacious or cultivated" as Waipio (Ibid:368). As discussed in the previous chapter, the population of Waimanu, judging by the numbers of those who attended a sermon on the beach, must have exceeded 200.

Ellis proceeded by canoe from Waimanu towards Honokane Iki, and he remarked on the people he spied walking about the cultivated land shelves and ravines that lay between valleys, and the goats they were said to raise for passing ships. In Honokane Nui, Ellis reported, he was received kindly, and was provided with, among other items, two exotic foodstuffs, a duck and some goat's milk. He stated that the valley contained 50 houses. Following his formula, this translates to roughly 250 people (Ibid:379). After a brief stay, he journeyed overland to Pololu, upon which he did not comment, and on to the village of Hala'ula on the North Kohala Plain.

In the 1820's, as earlier, most foreign witnesses to
the splendor of the Kohala valleys viewed the area only from the sea. The botanist Andrew Bloxam sailed by the valleys in 1825 aboard H.M.S. Blonde and commented upon the landscape

Lofty and abrupt dark-colored cliffs...intersected by numerous ravines so accurately and regularly cut as to appear a work of human art...two valleys of extraordinary depth and romantic features (Bloxam 1925:50).

A mission station was not set up in Kohala until 1837 (Anderson 1870:370). Although the ministers considered the far-flung valleys a part of their parishes, there was apparently little contact, and when churches were established in the valleys, services were conducted by natives. Artemas Bishop's journey to Pololu preceded the establishment of the mission by over a decade, and he recorded in his journal for Dec. 17, 1825, that he found it "a deep valley under cultivation" (in Damon 1827). The mission reports for the valleys (Polulu, Honokane Nui, and Honokane Iki; Waimanu was served by a different station) from the period from 1838 to 1872 recorded fifty-eight conversions and twenty-five baptisms, and for 1839 to 1882, twenty-five deaths and nine emigrations (Tuggle 1976:65). Disasters in the general Kohala region also generated sympathetic comments in the reports. The end of a famine lasting approximately a year was noted in 1839 (American Board of Commissioners of Foreign Missions [ABCFM] 1839:1). An epidemic of unspecified origin "prostrated the population for three weeks" during 1845 (ABCFM 1845:5),
while the dual "plagues" of smallpox and Mormonism infested Kohala several years later (ABCFM 1853:3). Both Hiram Bingham (1847:379-382) and Sereno Bishop (1916:25) traveled to Waipio during the 1830's, and reported a thriving native population there, but neither apparently made the extra journey to Waimanu.

The missionary census of 1836 counted the inhabitants in some civil subdivisions, and the figures for the valleys of Kohala have been preserved (Table 5-1). The total population for the valleys of Pololu, Honokane Nui, and Awini (an upland area nestled among the valleys) stood at 181. Tuggle estimated that the prehistoric population never exceeded twice this figure (1976:12).

<table>
<thead>
<tr>
<th></th>
<th>Pololu</th>
<th>Honokane</th>
<th>Awini</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>36</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Women</td>
<td>27</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Children</td>
<td>21</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>84</td>
<td>66</td>
<td>31</td>
</tr>
</tbody>
</table>

All Valleys Combined: 181

Table 5-1
Population of Kohala Valleys, 1836 Missionary Census

The records of the Land Commission provide a partial assessment of valley settlement and population in the late 1840's. Partial, because prior and later census figures reveal populations higher than those implied by the number of claims registered with the Land Commission. The Office of the Commissioner of Public Lands for the Territory of Hawaii compiled an index of awards in 1929, the relevant portions of which are summarized in Table 5-2. In Waimanu,
a total of seventeen small kuleana were awarded, in addition to the enclosing 'ili granted to the ali'i V. Kamamalu. It is interesting to note the lack of a second

<table>
<thead>
<tr>
<th>Valley</th>
<th>Awardee</th>
<th>Number</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waimanu</td>
<td>Auwae, M.</td>
<td>7268</td>
<td>3.85</td>
</tr>
<tr>
<td></td>
<td>Kepaa</td>
<td>7115</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>Kaili</td>
<td>7107</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Ikoa</td>
<td>7275</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Kamehaiku</td>
<td>7108</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Kawelo</td>
<td>7133</td>
<td>6.14</td>
</tr>
<tr>
<td></td>
<td>Nakanelua</td>
<td>7257</td>
<td>1.87</td>
</tr>
<tr>
<td>Kamamalu, V.</td>
<td>Pahau</td>
<td>10608</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td>Kamule</td>
<td>7110</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>Kaawanui</td>
<td>7105</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>Makuaaukai, Z.</td>
<td>7246</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Kamehaiku</td>
<td>7108</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>Kapahowai</td>
<td>8368</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>Namaielua</td>
<td>7108-B</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>Keakuku</td>
<td>7111</td>
<td>7.70</td>
</tr>
<tr>
<td></td>
<td>Namaielua</td>
<td>7108-B</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Pahau</td>
<td>10608</td>
<td>0.90</td>
</tr>
<tr>
<td>Polulu</td>
<td>Nuuanu</td>
<td>10442</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>Opualualu</td>
<td>10581</td>
<td>2.55</td>
</tr>
<tr>
<td></td>
<td>Nuuanu</td>
<td>10442</td>
<td>0.36</td>
</tr>
<tr>
<td>Honokane</td>
<td>Apaapakau</td>
<td>8030</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Hulu</td>
<td>8614-B</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>Kaipuhole</td>
<td>8695</td>
<td>12.00</td>
</tr>
<tr>
<td></td>
<td>Kamamalu, V.</td>
<td>7713</td>
<td>Ahupuaa</td>
</tr>
<tr>
<td></td>
<td>Kaneohiohi</td>
<td>8897</td>
<td>0.53</td>
</tr>
</tbody>
</table>

| Table 5-2 | Kuleana Awarded by Land Commission in the Kohala Valleys |

name for most awardees, a practice that would not become prevalent among the common people until the last half of the 19th century. In Pololu, only three kuleana were awarded, and in the ahupua’a of Honokane, there were four. If the number of kuleana are multiplied by five, as Ellis
did with houses in Waipio in order to derive a rough population estimate, the population projection for Pololu is fifteen, for Honokane twenty, and for Waimanu, eighty-five. Even assuming that some kuleana accommodated two or three households, the small size of the projected population indicates that in the valleys, as has been documented elsewhere in Hawaii (Coulter 1931), far fewer kuleana were registered than were inhabited.

The tax maps in use by the State of Hawaii today preserve the location of most of the Land Commission Awards (Fig. 5-1). Because of the low number of kuleana that were actually claimed and subsequently mapped, the meaning of the pattern on the map is unclear. Waimanu and Honokane Nui display somewhat dispersed distributions of kuleana, but in Pololu they are concentrated on the beach. Whether or not this is an accurate but reduced reflection of the actual distribution is unknown.

Part of the Indices consists of the native testimony concerning the kuleana they claimed, and some of it has been translated from Hawaiian into English. A typical claim is that of Mika Auwae of Ahuakolea in Waimanu Valley. On Feb. 1, 1848, he testified before the Board that his kuleana consisted of two taro patches in Ahuakolea, one at Makole, and a fish enclosure at Kaapeape. He called his claim Punaanapa, and supplied the names of bordering claims (Office of the Commissioner of Public Lands, Territory of Hawaii, Vol. 8, 1929:284). This author has been unable to
Land Commission Awards in Northern Valleys
Land Commission Awards in Waimanu
discover a map that provides of either the 'ili or kuleana of any of the valleys circa 1850, although their general locations can be approximated by examining the location of the awarded kuleana and later maps. Further research in the untranslated testimony might clarify the vague geography of land holdings in the Kohala valleys and elsewhere. However, it is evident from the multitude of named parcels bordering the claimed kuleana that settlement was considerably more dense than the registered claims imply. It is likely that the population of the valleys had declined considerably since 1778, but the paucity of registered kuleana in the valley probably overstates the magnitude of the decline.

The Rise of Sugar: 1850–1892

Sugar production in Hawaii began at least as early as 1825, and a permanent mill was established by 1835 (Kuykendall 1957:175). During the next twenty years, sugar production steadily rose until 131,800 kg were exported in 1855. By 1860 this figure would more than quadruple, and by 1875, more than 11 million kg were leaving the island each year (Kuykendall 1953:141). An increasing California sugar market due to improving refining capabilities and transport connections made this possible. The development on the islands of capital, sugar factors, irrigation, plantation-style management, and cheap imported labor also were responsible. The reciprocity agreement reached in
1876 with the United States, which waived the tariff on Hawaiian sugar, ensured even more impressive gains for the next twenty-five years, after which Hawaii was annexed to the United States. The economics of sugar became so vital to the state, especially to the foreign and second-generation haole, that politics began to be dominated by the considerations of the sugar industry (Daws 1968). The progression from reciprocity to revolution to annexation can be considered a march towards a better political climate for plantation sugar production.

The Diverse Effects of Plantation Sugar Cultivation

Hawaiian commoners were affected directly and indirectly by the sugar business. The overwhelming majority of kuleana on windward coasts were lost to the sugar plantations that came to surround them (Hobbs 1935:75). Hawaiians were recruited for labor on the plantations, and when they were scarce or declined to work, the planters looked to foreign sources of labor.

Contract labor began in 1852 with the importation of 293 male Chinese (Char 1975:60). Plantation owners successively tapped the workers of Portugal, other European nations, Puerto Rico, Japan, and the Philippines to man their labor-intensive enterprises.

Sugar stimulated the economy of the islands in many ways. Ports such as Hilo and Honolulu became important transportation nodes, linked to plantations by narrow-gauge
railroads. These cities also functioned as service and financial centers. Plantations and associated businesses and trades drew Hawaiians in droves from the countryside. Hawaiians, who had always engaged in some degree of intermarriage with the small haole population, began to intermarry with the much more numerous foreign laborers. This produced the cultural and racial melange that is celebrated in Hawaii today, but it also tended to cut short the perpetuation of the customary relationship of the Hawaiian to the land.

Population Decline and Further Cultural Change

The population of the islands continued to decline until the 1870's, when the surge of foreign laborers caused it to rebound (Table 5-3). The general rise in population was not paralleled by an increase in the number of Hawaiians. Epidemics such as the outbreaks of measles in

<table>
<thead>
<tr>
<th>Year</th>
<th>Kohala</th>
<th>Hamakua</th>
<th>Hawaii I.</th>
<th>All Islands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1853</td>
<td>na.</td>
<td>3395</td>
<td>24,450</td>
<td>73,138</td>
</tr>
<tr>
<td>1860</td>
<td>2632</td>
<td>2230</td>
<td>21,481</td>
<td>69,800</td>
</tr>
<tr>
<td>1866</td>
<td>2345</td>
<td>2050</td>
<td>19,808</td>
<td>62,959</td>
</tr>
<tr>
<td>1872</td>
<td>2086</td>
<td>1516</td>
<td>16,001</td>
<td>56,897</td>
</tr>
<tr>
<td>1878</td>
<td>3299</td>
<td>1805</td>
<td>17,034</td>
<td>57,985</td>
</tr>
<tr>
<td>1884</td>
<td>4481</td>
<td>3908</td>
<td>24,991</td>
<td>80,578</td>
</tr>
<tr>
<td>1890</td>
<td>4303</td>
<td>5002</td>
<td>26,754</td>
<td>89,990</td>
</tr>
<tr>
<td>1896</td>
<td>4125</td>
<td>5680</td>
<td>33,285</td>
<td>109,020</td>
</tr>
</tbody>
</table>


Table 5-3
Population of Kohala and Hamakua Districts, Island of Hawaii, and Hawaiian Islands, 1853-1896
1848 and smallpox in 1853 joined with endemic conditions of high infant mortality, poor sanitation, and what can only be called demoralization, to cause the native population to decline (Coulter 1931:5).

In 1853, the population was 97% Hawaiian (Ibid:3). While the total population nearly tripled between 1876 and 1900, the Hawaiian population, even including part-Hawaiians, fell from approximately 50,000 to 40,000 (Table 5-4). Among other groups, there were over 61,000 Japanese in 1900, outnumbering Hawaiians, who by then constituted less than 25% of the population.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hawaiian</th>
<th>Haole</th>
<th>Part-Hawaiian</th>
<th>Japanese</th>
</tr>
</thead>
<tbody>
<tr>
<td>1876</td>
<td>46,500</td>
<td>3050</td>
<td>3000</td>
<td>0</td>
</tr>
<tr>
<td>1900</td>
<td>30,000</td>
<td>9000</td>
<td>10,000</td>
<td>61,000</td>
</tr>
<tr>
<td></td>
<td>Chinese</td>
<td>Portuguese</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1876</td>
<td>2500</td>
<td>450</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1900</td>
<td>26,000</td>
<td>18,000</td>
<td></td>
<td>61,000</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1876</td>
<td>55,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900</td>
<td>154,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 5-4

<table>
<thead>
<tr>
<th>Ethnic Composition of Hawaiian Islands Population, 1876-1900</th>
</tr>
</thead>
</table>

In some ways, the Hawaiian people had continued to perpetuate their traditional lifestyle well into the 19th century (Jones 1938, Coulter 1931). And yet changes in Hawaiian customs and social relations were the subject of
much comment by travelers in the 1850's. G.W. Bates, a self-styled critic of the islands who attributed his memoirs to "A haole" (1854), provided anecdotes that illustrate the contradictions. On O'ahu, he said,

The natives usually follow their own inclination in regards to habits [fashion], or they tenaciously cling to the customs of their progenitors (Bates 1854:76).

He commented again on the semi-civilized costume of polyglot natives vending miscellaneous items at the port in Kauai'i (Ibid:59). He was told that fifteen years previous, natives had still been fashioning kapa cloth from the bark of wauke trees. "Now, however, they are well-clothed with imported cloths, silks, etc." (Ibid:147). In the windward valley of Halawa on Moloka'i, he observed that young scholars could read English perfectly well but were unable to speak it fluently. He further observed that they slept on sheets of kapa in Halawa (Ibid:263, 279).

The peripatetic Bates visited Waipio Valley as well, where he was "much impressed with the primitive character of the inhabitants" in the "Eden of the Hawaiian Islands" (Ibid:383).

The idea expressed by Elizabeth Handy that after the eating kapu were broken

the old order was null and void...[and] it would be decades before a new order, based on New England Congregationalist and French Roman Catholic mores was really comprehended (in Handy and Pukui 1972:232)

is apt here. European commodities, beliefs, and symbols
were being incorporated in a traditional world that was simultaneously losing its core, its basis in reality. Samuel Kamakau in the 1860's found an audience in the native readers of a Honolulu Hawaiian-language newspaper for his articles detailing the ways of Ka Po'e Kahiku -- the people of old.

The changes that had accumulated by 1860 accelerated after that date with the imposition of a new economic order, hordes of immigrants, and the removal of much of the declining Hawaiian population to towns and cities. Grass houses were observed to be common outside the larger towns in the 1860's (Brigham 1908:1), but by 1884 they were disappearing.

The Hawaiian grass house is rapidly becoming a thing of the past, even in the out districts. Natives now find it cheaper to build of wood and emulate the style of modest cottage architecture of their foreign brothers (Anon. 1884:5).

By 1878, Hawaiians were largely a landless group (Hobbs 1935:71), and soon even the Hawaiian tongue was to become uncommon except in the most isolated districts, the rocky shores of leeward Kona and certain windward valleys of Hawaii, Maui, Molokai, and Kauai.

Coffee and Rice

The last half of the 19th century also saw the rise of large-scale farming of two crops that were to affect all parts of the islands, especially the windward valleys: rice and coffee. T.G. Thrum, who chronicled the rice boom in
1877, soon after it had begun, credited H. Holstein of the Hawaiian Agricultural Society with the introduction of rice in 1860 (1877:46). Actually, Henry Cheever had noted during a tour of the island a family of Chinese raising rice in 1850 (Cheever 1851:124). But Holstein's breeding and proselytizing efforts apparently created a rice-growing craze after 1861. As Holstein was reported to have said in 1861, "Everybody and his wife...are into rice" (Thrum 1877:46). In 1862, the total production of rice was 50,000 kg, but by 1875, it had risen to 685,000 kg. (Ibid:48). Early rice production was intended primarily for export to California. By 1899, near the peak of Hawaiian rice, a large local market of Asian laborers had developed, and out of the 15,000,000 kg harvested in Hawaii in that year, less than 455,000 kg were exported (Kuykendall 1968:48).

Speculators and agriculturalists of all nationalities began to plant rice, but Chinese plantation workers, discouraged with the drudgery and low pay of cane labor, came to dominate the rice business. They utilized abandoned or active taro patches, marshes, and swamps (Glick 1980:46). Windward valleys were in special demand because of their pre-existing water supply and terraces. Chinese were so predominant in some valleys that the life and landscape began to resemble rural China more than Hawaii.

The center of valley life was the store, a one or two story frame building with 5 or 6 rooms. Adjoining the store there was generally an inn or
hotel where visitors stayed. Also there were generally a few Chinese farm homes from which the lessees of farms went out to work them (Char 1975:99).

Permanent change on the landscape, however, was made unlikely because of the temporary nature of the enterprise, what Clarence Glick (1980) has called the sojourner outlook. Farmers tended to lease rather than buy land, to construct cheap buildings, and to abandon farming once they had made enough money to move into town and set up a business. Nevertheless, the impact on Hawaiian land-use and vegetation was substantial. Chinese men married Hawaiian women, and their children, who often possessed an outlook quite distinct from their maternal ancestors, inherited the land. In addition, exotic plants were introduced and cultivated extensively on the Chinese rice plantations. As early as the 1850's, Chinese fruit trees were arriving in the islands. A contract-labor ship captain named Cass was said to have imported on one trip in 1852 pomelo (Citrus paradisi), wong pee (Michelia champaca), longan (Euphorbia longan), mandarin orange (Citrus nobilis var. deliciosa), kumquat (Fortunella japonica), and lichee (Litchee chinensis) (Char 1975:60). Rice farmers usually tended a garden which supplied most of their food wants aside from fish and rice (Ibid:2). Included in these gardens were mango, lemon, several varieties of banana, orange, and the native hau, which was used for cordage (MacCaughey 1916A:713). Bananas
constituted a second cash crop for many Chinese rice farmers, and by 1915, 280,000 bunches a year were being produced in Hawaii, mostly by Chinese (Glick 1980:61).

Although rice in Hawaii died out by the early 20th century, Coulter and Chun observed in 1937 that

Clumps of introduced trees -- Chinese orange, mango, and lichee -- remain to mark the sites of former Chinese rice farms in Hawaii (p. 62).

Unlike rice, the Hawaiian coffee industry survives today, even if limited to a small area on the Kona coast of the island of Hawaii. Coffee culture in Hawaii probably began in Don Marin's gardens in 1817, but he seems to have had little success (Thrum 1876:46). John Wilkinson's efforts on Governor Boki's plantation in Manoa produced better results, and soon missionaries on Hawaii Island were growing small patches as well (Ibid:47). Kaua'i had 400 ha in 1845, much of which was destroyed in 1851 by a blight, which presaged setbacks to come (Ibid:47). Exports of coffee showed a steady rise from 110 kg in 1845 to over 90,000 kg in 1850 (Ibid:50). Coffee remained a minor crop in terms of export, but supplied completely the large local market. The methods of culture outside of the principal farms in Kaua'i or Kona were not intensive.

Coffee cultivated in all other localities of the islands was left very much to chance, with little care or attention. Localities of shade and shelter found favorable were planted with either seed or young plants and then left to themselves until it was time to gather the fruit. These localities were generally small valleys or ravines, where may be found the coffee fields of the Hawaiian Islands today (Ibid:48).
Whitney (1875:14) also reported that "most [coffee] now gathered grows wild in the woods." Coffee appears to have been cultivated in a variety of settings, including large-scale monocrop plantations, small mixed farms, and kitchen gardens.

The 19th century saw several other crop crazes that were of limited duration. Silk flourished for a while, mainly on Kaua‘i, before falling victim to disease. Cotton, peanut, orange, and grape production were all essayed but with little consequence. A gathering enterprise involving a native plant, the tree-fern (Cibotium spp.) lasted longer and became damaging to both the environment and the health of the populace. The soft, fibrous material that grows nestled in the fern’s trunk amid the emerging fiddleheads was called pulu by the Hawaiians. They had employed it in various capacities during prehistory, including as an embalming material (Degener 1930:29). The use of pulu for stuffing mattresses and pillows became common in the 19th century, and an export trade developed in the 1850’s. Pulu was gathered in the mountains, transported to Hilo, then shipped to Honolulu, and finally conveyed to San Francisco. In 1851, 1125 kg were exported; between 1860 and 1879, an average of 172,000 kg a year left the islands, after which the industry began to die out (Kuykendall 1953:79). Kohala was one of the centers of pulu activity.
An Adventive Flora Develops

Agronomists, government officials, and tour-guide writers praised the increasing import and establishment of new crops, particularly fruit trees and ornamentals, in the Hawaiian islands during the late 19th century (Whitney 1877, Baker 1877, Hill 1883, Anon. 1892, Wells 1906). The litany of new species included the Chinese fruits, a variety of trees from Southeast Asia and Australia, a few species from the New World not already common, and some European plants which flourished only at higher altitudes in the islands. Although many of the new species were uncommon (and remain so today), some were rapidly adopted by farmers and gardeners. Today such trees as royal palms (Roystonia regia) and African tulip trees (Spathodea campanulata) grace the streets of even the smallest hamlets throughout the islands. Tracing the chronology of the introduction and dispersal of these exotics is difficult. In the words of a geographer speaking of the adventive flora of the islands,

> It is rare to discover the precise facts of the introduction and spread of a species, and we must be content to learn the earliest record of its presence. In the case of many of the crops and ornamentals this date may not correspond with the first incidence [of] escape from cultivation (Wester 1978:2).

This thesis will not attempt to document the arrival and/or escape of any of the hundreds of exotic species that constitute the adventive and exotic flora of Hawaii. It is of interest to the study of the exotic flora of the
valleys, however, to note the abundance of exotic trees now associated with Hawaii already present in Hawaii by the late 19th century.

Several exotic plants became wild in the 19th century, including mesquite (*Prosopis pallida*), lantana, and prickly pear (*Opuntia* spp.). Hillebrand prepared for his posthumously published *Flora of the Hawaiian Islands* (1886) an introduction written circa 1870 that identified the Pride of India (*Melia azedarach*), the tamarind (*Tamarindus indica*), and several species of *Acacia* and *Eucalyptus* as trees established on the islands. The most notable naturalized tree in windward environments was the guava. The "choice garden fruit" of Sereno Bishop's youth in the 1830's (1916:39) became "universal" in windward Hamakua by the 1870's (Bird 1890:89). The guava was joined in the wild at some time during the 20th century by other fruit trees, including several species of *Syzygium*, but no exotic tree today approaches the numbers of guava.

The Kohala Valleys in the Late 19th Century

Several valuable sources of demographic information about Kohala in the late 1800's exist. Censuses were conducted during 1878 and 1890 in Hawaii. Some of the schedules from the valleys have been preserved in the archives of the State of Hawaii. The Real Property Tax Records of the Kingdom of Hawaii, also only partially extant, are housed in these archives as well. In addition,
visitors to the valleys or to nearby Waipio have also left some records of their journeys.

The populations of the Kohala and Hamakua districts were rising in the second half of the 19th century due to the influx of plantation laborers (Table 5-3, prev.). Although the record of population in the valleys in the 19th century can only be derived by putting together diverse and not completely compatible sources, the population was clearly diminishing until the advent of rice-growing in the 1880's (Table 5-5). The population of Honokane, an administrative unit which subsumed Honokane

<table>
<thead>
<tr>
<th>Source</th>
<th>Waimanu</th>
<th>Honokane</th>
<th>Pololu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1823 Ellis</td>
<td>200#</td>
<td>250# **</td>
<td>84</td>
</tr>
<tr>
<td>1836 Missionary Cens.</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1850 Coulter est.</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1863 Real Property *</td>
<td>(53)</td>
<td>(24)</td>
<td>(27)</td>
</tr>
<tr>
<td>1868 Real Property *</td>
<td>(49)</td>
<td>(20)</td>
<td>(22)</td>
</tr>
<tr>
<td>1873 Real Property *</td>
<td>(31)</td>
<td>(16)</td>
<td>(15)</td>
</tr>
<tr>
<td>1873 Bird</td>
<td>117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1878 Real Property *</td>
<td>(28)</td>
<td>(17)</td>
<td>(23)</td>
</tr>
<tr>
<td>1878 Census</td>
<td>85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1883 Real Property *</td>
<td>(37H/8C)</td>
<td>(20H)</td>
<td>(23H/24C)</td>
</tr>
<tr>
<td>1886 Real Property *</td>
<td>(28H/99C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1890 Census</td>
<td>55***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Approximate figure.
* Property owners only.
** Honokane Nui only.
*** Chinese apparently excluded.
H= Hawaiians, C= Chinese.

Table 5-5
Population Figures for Kohala Valleys, 1823-1890; Censuses and Estimates

Nui and Iki in most statistical reports of the time, appears to have remained fairly level throughout the
1800's, dropping only slightly. Waimanu's population had dropped by half in the fifty years following Ellis' visit in 1823, and continued to decline until some ten years later when Chinese began to immigrate and to grow rice. The census of 1890 apparently neglected to enumerate Chinese, who may have been considered temporary inhabitants. Pololu Valley showed a progression similar to that of Waimanu, and Chinese came to outnumber Hawaiians by 1890. Despite the influx of Chinese, population levels were well below the figures reported in the early missionary period.

As the number and character of the inhabitants of the valleys changed, so did the nature of land-use and settlement. The introduction of rice culture, accompanied by the restructuring of old taro terraces and the planting of Chinese gardens, is the most obvious example. More subtle shifts, involving a new economy and changing orientation to the outside world, were beginning to be evident. A review of travelers' accounts from the period provides illustration of the change.

Henry Lyman, a Hawaiian-born son of missionary parents in Hilo, accompanied a government surveyor engaged in the surveying of land during the Great Mahele in the summer of 1851. Their work took them to Waipio and the more remote valleys to the northwest. His recollections stress the isolated beauty of the further valleys,
...reached only by ancient foot paths that went straight up and down their precipitous walls. When, as at Waimanu, these bluffs were sixteen hundred feet high, no little effort was needed; in fact, the natives preferred the canoe path by sea, though this was only practicable in seasons of calm (Lyman 1906:216).

During two weeks of arduous surveying, he passed nights in the natives' houses and came to appreciate their unique situation.

We found the inhabitants of these remote glens living in great simplicity and comfort. Food was abundant; the thatched huts were clean and commodious. They had their tiny school houses....When the sun went down, and the restless ocean moaned along the boulder-strewn beach, while lingering sea-breezes made mournful music among the rustling fronds of the cocoanut trees, it seemed as if nothing could tempt one to tarry in such an abode. But when the dawn of day awoke everything to life, when the young men and maidens came forth from their huts by the shore, rejoicing in light and air, with sunshine on their cliffs, with rainbows in the waterfalls, and delicious zephyrs softly stealing from the highlands that overlooked the sea -- it was impossible to deny the charm of savage life beside the mighty ocean (p. 217).

The lyrical memories of an old man paint an idyllic picture which nevertheless acknowledges the utter isolation of the setting. But whether a consciousness of estrangement from rapidly Westernizing Hawaii afflicted the inhabitants is unknown. Lyman's more experienced comrade, Curtis Lyons, seems to have quickly become inured to the beauty. His complaints remind us that the valleys were neither idyllic nor out of touch. In Waipio Valley some two years later, he wrote in his journal, "Those stingy Waipio folks don't bring us any food" (Lyons n.d.:25). On Sept. 6, 1853, he
commented on the litigious nature of a dissatisfied client who had hired a lawyer to seek redress (Ibid:107).

John Shedden Davis, a Scotsman travelling aboard the schooner Emily Bourne in 1852, is the likely author of the ship's log for that period (Joesting annot., 1970). Comments on an excursion made into Waipio Valley confirm the idea of a beach-and-margins settlement pattern also noted by Bingham (1847:379) and Ellis (1969:356) previously.

Along the base and edges of the steep hillsides are the huts, clumps of coconuts, banana, coffee, and sugar cane, Mammu trees [annot.: Mammee?], and as you proceed onwards, the valley becomes firm grazing ground with a herd of cattle (p. 209). Much of this depiction probably applies to Waimanu Valley as well.

Of the other end of the valley region there is less news for this period. Mission station reports, probably written by Rev. Elias Bond, continued to comment on conditions in Kohala in general, some of which surely extended to the more distant valleys of the parish. Bond indicates that Mormonism seems to have diminished by 1857 (ABCFM 1857:1), only to be replaced by a more vague malaise, depopulation. The report for 1858 stated

As a people and as a church we are sensibly diminishing in number. The stream which ever sets toward our great Hawaiian slough -- Honolulu -- appears to have deepened and enlarged itself within the year past (p. 1).

The next year, a craze for gathering pulu captured the
energies of much of the native population of Kohala and elsewhere. Rev. Bond termed it a "curse", and claimed that natives would

pull up the entire family, leaving lands unplanted, houses desolate, schools unattended...and go away for months and live in a most heathenish and abandoned style (p. 1).

The missionary lamented the fact that natives would fail to save money and often, furthermore, ruin their health in the pursuit of pulu.

By the 1870's the valley populations had declined considerably and seemed on the verge of abandonment. An intrepid female traveler, Isabella Bird, visited the Hamakua coast on horseback in 1873, including Waipio. She commented on the garden-like atmosphere of the valley, with its coffee trees in bloom, and its papayas, oranges, figs, and castor beans interspersed among the taro patches. She also reported hearing that the stream in Waimanu served as the principal road at the time (1890:98-99). Henry Whitney, a promoter of tourism and guidebook author, briefly described Waipio Valley for the sake of prospective visitors. He noted that while Waimanu was more inaccessible than Waipio, "guides can always be found to conduct the tourist to both places" (1875:68, 98). The prevailing quality of the valley region in the late 1800's, isolation, can be summed up with a quote from Robert Louis Stevenson, who spent five months in Hawaii during 1889:

...there are coves which even the daring boatmen of Hamakua dread to enter; and men live isolated
in their hamlets or communicate by giddy foot paths in the cliffs (Stevenson 1973:7).

Of course, this impression of remoteness is one conveyed by American and British writers, and how natives felt about being "isolated" in the valleys is unknown. Population information provides another clue.

For a combination of reasons, chiefly high mortality and emigration by the young, the valleys were depopulating. Had it not been for the boom in rice, which lingered for forty years in Pololu and Waimanu Valleys, they may have been all but abandoned by the 20th century. A sense of isolation and the promise of wider opportunity in other parts of the islands undoubtedly contributed to the decline.

Coulter and Chun examined rice production figures for the Kingdom and Territory of Hawaii, and concluded that at one time, 3050 ha of rice were under cultivation in the islands. The most extensive plantation was at Mokuleia, O'ahu, with 299 ha. Waipio valley had 81, Waimanu 34, and Pololu 29 ha during their peak production years (1937:21).

It is apparent from archaeological survey (Tuggle 1976) and contemporary description (Lothian 1983, Dove 1896) that in only the center of both valleys was rice grown, with settlement immediately adjacent. A description of rice cultivation by Chinese in Pololu as remembered by descendants of the principals is summarized in Lothian (1983). Goo Chin Akina arrived in Kohala around 1870 and
married a Hawaiian woman who owned land in both Pololu and Waipio. Akina proceeded to plant rice, hire a number of Chinese workers in both valleys, and settle in Pololu. The rice grown in Pololu was milled outside the valley near a sugar mill, but cultivation and threshing of the rice required several large structures and some machinery. Since there was no boat landing in Pololu, the equipment was unloaded at Honokane Iki and laboriously rafted over to Pololu.

The relationship between Chinese farmers and Hawaiian landlords was said to be more cordial than that which obtained between haole and Hawaiian. Chinese laborers would accompany their Hawaiian neighbors on canoe trips or fishing parties on Sundays (Coulter and Chun 1937:43). Judging from the degree of mixing and intermarriage reported in the valleys, one assumes that such friendliness was common in Kohala as well.

The Honokane area did not grow rice, and yet its population remained stable. The history of Honokane Iki in the 19th century is unclear. It was always combined with the larger valleys adjacent in statistical reports, and no data pertaining to it alone survive. W.K. Sproat, a part-Hawaiian who was born in Pololu and lived and worked for many years in the Honokane area, believes that by 1900 Honokane Iki was already abandoned, although it had been inhabited up to a few years previous (pers. comm. 1985). Honokane Nui itself then probably accounted for most of the
twenty Hawaiian property owners listed in the Real Property records of 1883 (a few inhabitants may have been scattered in the uplands).

In the next period, the valleys were to be abandoned. In Waimanu and Pololu, the process was to be gradual, but settlement in Honokane Nui would abruptly terminate.

**Hawaii Is Joined to America: 1896-1930**

For over a hundred years, foreign residents in Hawaii had lived under a succession of Hawaiian kings. The foreigners and their descendants had always enjoyed great influence through cabinet appointments and other positions of power. Nevertheless, they were vexed by the difficulty of achieving their ends under a ruler who, in the opinion of many, over-zealously guarded native rights, spent government funds irresponsibly, and behaved in other ways unpredictably. Discontent among the haole, who by virtue of owning the sugar cane plantations controlled most of the economy and supervised most of the workers of the Kingdom, became intense by the 1880's. A constitutional monarchy was forced upon the willful, brilliant, somewhat dissipated King David Kalakaua in 1887, and for a time this uneasy compromise forestalled drastic change. The death of the King in 1891 initiated a crisis.

The situation was exacerbated by the accession to the throne of Kalakaua's sister Liliuokalani, who cherished absolutist notions of the monarchy along with traditional
Hawaiian ideals. An almost bloodless revolution in 1893 established the Republic of Hawaii, whose founders after a short delay achieved their goal of annexation to the United States in 1898. The new state of affairs was profitable for the sugar planters, who had been deprived of the benefits of reciprocity by the McKinley Act, which had removed all tariffs while authorizing a bounty on domestic sugar (Daws 1968:243-289).

However salutary annexation was for sugar planters, the effect of the defeat of the monarchy on the Hawaiian people was devastating. They had in the previous twenty years lost their land, their majority status, and their kingdom. They came to be more and more strangers in their own land, except in the rural districts and smaller islands.

During the 20th century, sugar continued to profit and expand, the U.S. military increased its operations and personnel on the islands, and the tourist trade began to expand. These three activities have continued during the late 20th century to remain the principal basis of the Hawaiian economy (Schmitt 1977:165; University of Hawaii, Department of Geography 1973:165). The character of Hawaiian agriculture evolved from diversified subsistence to monocrop plantation, with sugar and pineapple exports accounting for 41% of total state income in 1939 (Schmitt 1977:164). Coffee exports had all but ceased by 1910, although the local market was still supplied by domestic
production. During that year, there was some production of rubber, tobacco, and pineapple, but such obvious export crops as guava, papaya, and mango were not being raised commercially (Anon. 1909). Despite the lack of large-scale diversified agriculture, farmers were producing for local consumption an astounding variety of fruits and vegetables, which made the markets of Hawaii a fascinating stop for tourists (Farquhar 1900:55).

Rice began to decline about 1910. A peak of 3816 ha were under cultivation in the islands in 1909, but by 1919 that figure was 2349 ha and by 1935 only 457 ha (Coulter and Chun 1937:53). One explanation for the decline in rice was the fact that Chinese growers failed to account for the tastes of local Japanese, who disdained the long, hard, non-glutinous Chinese variety (Krauss 1912:129). However, the main culprit in the demise of rice was the growth of a more competitive rice industry in California.

Hawaii was transformed from a rural to an urban state beginning in the early 1900's. In the 1910 census, 69.3% of the population was classified rural, which figure fell to 46.3% by 1930 and to 16.5% by 1970 (Schmitt 1977:8). The corollary to the growth of urbanism in Hawaii was the abandonment of villages in outlying areas. The depopulation of the Na Pali coast on Kauai, the windward valleys of Oahu, Halawa valley on Molokai, the Hana district of Maui, and North Kona and the Kohala valleys on
Hawaii Island all accelerated during this period. Most of these areas remain without population today.

It was in the most isolated places that traditional Hawaiian lifestyles were being preserved. For example, grass houses were common in rural areas in the 1860's according to a contemporary ethnologist, William T. Brigham (1908:1). By the start of the 20th century, these structures had all but disappeared.

The only complete Hawaiian village I have ever seen was in the valley of Kalalau on the island of Kauai. Remote and difficult of access, it remained uncontaminated by foreign fashions until a few years ago when the attractions of city life drew its remaining inhabitants to Honolulu, and its frail houses fast perished (p. 72-73).

The popular image of Hawaii, of natives living in grass shacks and farming little taro patches beside the sea, clothed in kapa and speaking Hawaiian, rapidly became a fiction during the 20th century.

The vegetational landscape of the abandoned windward valleys began to take shape in this period. Most of the species now prominent in the valleys were introduced and wild (or at least stably self-replacing) by the 1920's. MacCaughey surveyed in 1917 the vegetation of the back of Manoa Valley, Oahu, a moist leeward location. He found the valley's floor to be covered mainly by economic species. His description of the elevational differences in the vegetation of Manoa Valley in 1916 is equally true of Kohala today:
This condition is in striking contrast with that of the rain forest, only a few miles distant, where the vegetation is almost wholly endemic or indigenous (1917:571).

He found mesquite, cactus apple, guava, lantana, ohia ai, Solanum sodemeum, and noni, a mixture which reflects slightly drier conditions than prevail in true windward valleys. In another survey dealing with the forests of the islands as a whole, MacCaughey noted the abundance of guava, kukui, and ohia 'ai in the lower forest zone (1916A). Guava formed "chaparral thickets," which were exploited by Asians for charcoal (Ibid 704). Other observations during the several previous decades had also stressed the ubiquity of guava (Bird 1890:88, Farquahar 1900:53).

It appears that the lower elevations of all islands were overrun with exotics by 1900.

The naturalized forest occupies the lower valleys and plains, the number of indigenous plants in these localities at present being insignificant. This flora is rapidly encroaching on the native forest, especially where conditions are changed by fire or grazing (Forbes 1911:323).

Even the forests above 600 m elevation were being threatened. Sandalwood trees taller than 12 m were seldom seen, a legacy of exploitation a century before. The forester William Hall (1904) bemoaned the toll that grazing, fire, wild pigs, insects, and exotic species had taken on the Hawaiian forest by 1900. On Mauna Kea alone, at least 10,000 cattle still wandered, grazing the choice seedlings of many indigenous trees (p. 17). The
increasingly influential professional foresters attempted to mitigate soil damage by importing seedlings native to six continents and vigorously replanting the slopes. The U.S. Forest Service Records for the period from 1908 to 1960 indicate that over 10,000,000 individuals of some 80 genera and 300 species were planted (Nelson 1965). The personal records of one of the most indefatigable foresters, L.W. Bryan, reveal that he and his helpers were often engaged in reforestation work in the montane forest above the valleys of Kohala during the 1920's and 1930's (Bryan n.d.).

Kohala Abandoned

The course of events in the Kohala valleys reflect the general trends of the isolated regions in all the islands. Since a fair record of events in this period survives today, each valley may be discussed individually.

Archaeological evidence indicates that Pololu Valley was abandoned progressively from the interior to the sea during the 19th century (Tuggle and Tomonari-Tuggle 1980:306). By 1900, according to Tuggle (1976:24), there were five or six part-Hawaiians living in the valley, mostly on the dune, and approximately twenty Chinese laborers in the center of the valley. A crude map made for the Office of the Commissioner of Public Lands (Gov. Reg. 53, not reproduced) depicted two houses on the lower east side of the valley, two near the dune, and four on the west
side of the valley, the most inland being approximately 1000 m from the shore.

The U.S. Census of Population in 1910 enumerated fifty people: eighteen men, eight women, and thirty-four children. Their backgrounds and personal characteristics provide an interesting portrait of social change in the valley region (Table 5-6, compiled from information in the National Archives 1910 Census Microfilm Publication: Schedule T624, Roll 1752). Hawaiians or part-Hawaiians made up thirty-four of the inhabitants. There were also nine Chinese, six Japanese, and one haole. All of the Chinese in the valley were reported engaged in the production of rice, and most were bachelors, or in any case, did not have wives residing in the valley. The one Chinese head of household with a family had married a Hawaiian woman, as did the immigrant from Mexico, Hosa Raymond (probably Jose Ramon). None of the three households with Hawaiian heads were farmers, all being employed in road work or odd jobs outside the valley. For some reason, perhaps a lack of available land, a low market price for taro, or more attractive intervening opportunities, Hawaiians in Pololu declined to farm. However, some of these families had large and diverse gardens, according to a contemporary observer (W.K. Sproat pers. comm. 1985), The head of the Japanese family was employed maintaining the large irrigation project that captured the water above Honokane Nui and Pololu Valleys.
<table>
<thead>
<tr>
<th>Head of Household</th>
<th>Number</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hosa Raymond</td>
<td>7</td>
<td>A Mexican-born farmer. Wife Hawaiian, born Pololu Valley. 4 children, 1 grandchild.</td>
</tr>
<tr>
<td>N/A</td>
<td>8</td>
<td>7 Chinese rice laborers and 1 Hawaiian boarder</td>
</tr>
<tr>
<td>Lo Pung Yo</td>
<td>3</td>
<td>Chinese rice farmer with Hawaiian wife and daughter</td>
</tr>
<tr>
<td>Daniel Pupuka</td>
<td>15</td>
<td>Hawaiian roadworker, Hawaiian wife. 2 adult children, 11 others: children, relatives, friends. Some worked on roads.</td>
</tr>
<tr>
<td>Moses Kahipa</td>
<td>2</td>
<td>Hawaiian roadworker and wife.</td>
</tr>
<tr>
<td>Kahai Mersberg</td>
<td>8</td>
<td>Part-Hawaiians, odd jobs.</td>
</tr>
<tr>
<td>N/A</td>
<td>1</td>
<td>Chinese rice laborer</td>
</tr>
<tr>
<td>Tokutaro Kawamoro</td>
<td>6</td>
<td>Kohala Ditch employee, wife and 4 children</td>
</tr>
</tbody>
</table>

Source: Schedules from U.S. Bureau of Census 1910 Census for Territory of Hawaii

Table 5-6
Pololu Households of 1910 Census

Forty years previous all of the occupants of the valley had been Hawaiian, and all had been farmers.

One of the children of Hosa Raymond was W.K. Sproat's mother. She left the valley to receive an education and later returned to teach school. By 1900, enrollment was declining considerably, according to the recollections of her son (W.K. Sproat pers. comm. 1985). But from the census schedules it is evident that in 1910 there were still twenty-four children in the valley.

The United States Geological Survey mapped the valleys...
in the years 1911-1913, and the Waipio Topographic Quadrangle of 1916, at a scale of 1:62,500, was the result. On this map six structures appear in Pololu Valley, including a school (Fig. 5-2).

In 1916, much of the water supply of Pololu Valley was diverted to the cane fields to the west (Hubbard 1972:2). By 1920, W.K. Sproat remembers, only three settlements remained. One was the Raymond place, the home of his grandmother, midway up the west side of the valley. Another Hawaiian lived across the valley behind the sand dune, and several Chinese still occupied the center of the valley and farmed a few acres of rice. A photograph of the valley taken in 1925 (Fig. 5-3, misidentified in the State of Hawaii archives as Honokane Valley), showing one structure on the dunes, three on the west side of the valley, and a complex of structures in the center of the valley, confirms the description of Sproat.

Rice cultivation ended in 1925 (Tuggle 1976:12), and soon thereafter the valley was abandoned except for part-time residents of the Raymond place.

Honokane Nui

The narrowness of Honokane Nui Valley belies the size of its drainage area in the Kohala Mts. The potential of its watershed, along with those of Pololu Valley and several other minor streams, to irrigate the drier sugar cane fields of Kohala was recognized by the owners of large
Fig. 5-2

1913 Structures in Northern Valleys
Fig. 5-3

Pololu Valley in 1925
plantations in Kohala in the late 19th century. The Kohala Ditch Company was formed to survey the area and engineer a suitable water transport system. The Kohala Ditch consists of dozens of miles of tunnels, culverts, and bridges required to span the incredibly dissected terrain of the higher slopes. It was begun in 1904 and completed two years later. The boon to the plantations was the death knell to agriculture and settlement in Honokane Nui. In 1906, the flow of water into the valley was reduced to a trickle except during times of flood, and habitation ceased. The residents were compensated for their water rights, and many were relocated to the island of Lanai. The end of a community that had probably begun in the 1600’s (Tuggle and Tomonari-Tuggle 1980), and even in 1900 had a number of farmers, a church and a school, ended abruptly in 1906. This was not entirely the end of settlement in Honokane. The Kohala Ditch required maintenance, and several cabins were constructed on the upper slopes above the valley for temporary and permanent residents. A Japanese pig-farmer came to occupy some land seaward of this after 1905, and during the 1920’s two Japanese bootleggers had a shack and a still hidden on a ridge (W.K. Sproat pers. comm. 1985). Farming in the valley itself, however, was never resurrected.

Honokane Iki

Honokane Iki, which was abandoned before the 20th
century began, received new inhabitants as a result of the opening of the Kohala Ditch. The father of W.K. Sproat, who today lives directly above Pololu Valley, worked for the Kohala Ditch Company. He obtained a lease on the valley from the plantation company that owned it, built a house, and began to raise pigs sometime after 1910. In the 1920's W.K. Sproat rebuilt the house and moved in with his family. During over ten years of residence, the family planted banyan and breadfruit trees and other exotics, many of which have persisted. They also allowed free run of the valley to their donkeys, who promptly eliminated every clump of bananas in the valley. The Sproats left the valley in the 1930's, but their structure remained and was used for family outings and Kohala Ditch Company business into the 1980's.

Waimanu

The record of the abandonment of Waimanu Valley is enhanced by an excellent map at a 1:2400 scale done by Charles Dove, surveyor, for the Commissioner of Public Lands of the Territory of Hawaii in 1896 (Fig. 5-4 reproduces a portion of the map, Gov. Reg. 2385, located in the State Survey Office of the Hawaii Department of Land and Natural Resources in Honolulu). This map preserved many of the names of parcels in Waimanu, some of which are identical to those mentioned in the native testimony before the Kingdom's Board of Commissioners to Quiet Land Titles
Fig. 5-4. Dove Map of Waimanu, 1896
in the 1850's. Unfortunately, after this date systematic evidence becomes sketchier, as no census records specific to Waimanu appear to have survived.

The primary purpose of the map was to survey private and public holdings, but Dove also sketched in taro patches, structures, rice fields, and notes on the local vegetation cover. It appears that eleven structures existed near the beach, including a school and a Catholic church. No structures were evident on the east side of the valley, nor were there many private lots. However, the entire length of the east side exhibited the remains of taro patches. A number of taro patches, but no structures, occupied the lower west side of the valley. Presumably these patches were the property of the inhabitants of the beach area, as was common practice in Hawaii. Perhaps Chinese rice farmers also tended taro. Rice apparently occupied the entire central portion of the valley. In the upper west side of the valley five structures were depicted. Active taro patches were located upvalley from these structures, as deep as 2000 m inland. Past this point, only remains of taro patches existed, covered with scattered guava, 'ohi'a (probably 'ohi'a 'ai, Eugenia malaccensis), and kukui. This inland area was used for pasture.

The Dove map shows Waimanu in transition, just as the census schedules do for Pololu. The situations in these two valleys are quite parallel. Settlement and agriculture
were retreating from the rear of the valley towards the front, where rice had come to replace taro as the principal crop in the valley. The relatively abundant taro patches mapped by Dove correspond to the earlier stage of the land-use progression in Pololu from taro to taro/rice to abandonment. Just as in Pololu, housing in Waimanu was concentrated on the margins of the valley, as indeed was the pattern in Halawa Valley in late prehistory (Rosendahl 1975:75) and in Waipio valley in the 1840's (Bingham 1847:379, Joesting 1970:208).

Contemporary eyewitness accounts from Waimanu confirm the trends made manifest in Dove's map. A description of the valley for a short article in Thrum's Hawaiian Annual For 1901 mentions an abundance of rice:

...the floor of the valley was filled by a map-like arrangement of rice fields, as symmetrical and fascinating as a chessboard or a plot of town lots in a real estate office (Anon. 1900:147).

The bridge that used to cross the main stream was gone, along with the cleared trail to the head of the valley (p. 143).

A few years later, a popular article concerning more accessible Waipio discussed the isolation of Waimanu:

In this region the life of the Hawaiian is primitive in the extreme, and the sound of tapa (kapa) beating is still heard in the land (Sheridan 1912:425).

Whether the residents of Waimanu still engaged in the manufacture of kapa or whether the romance of the idea led
the author's pen astray is undeterminable; in Henry Kinney's tourist guide of the following year the assertion is repeated:

...rice is under cultivation though the industry is dying out owing to transportation difficulties. It is the only place in the islands where the making of tapa cloth is still carried on... (1913:34).

Places like Waimanu had become symbolic of a bygone land and culture, and their characteristics were perhaps exaggerated and cherished in the popular literature. It is likely that in the decade between the visit of the author of the Thrum's piece and the later article, although Waimanu had lost population and agricultural area, it had retained some of its traditional lifestyle. The USGS Waipio map, for which reconnaissance was done in 1911-1913, mapped Waimanu as well as the northern valleys. Three structures were depicted on the beach, one several hundred meters inland on the west margin of the valley, and two behind the rice fields (Fig. 5-5).

Between 1913 and 1920 the process of abandonment accelerated. A former resident of Waipio, Rose Chock, recalled to journalist Helen Baldwin in an article entitled "Trip to Waimanu Over 60 Years Ago" that "no one lived there now all the time" (Hawaii Tribune-Herald, 5/30/76, "Orchid Isle" section, p. 3). Old buildings were ramshackle but serviceable for travelers, and the cattle appeared sickly. The precise year of her visit was unstated, but the title implies that it must have occurred
Fig. 5-5

1913 Structures in Waimanu
before 1916. This timetable is contradicted by the recollections of Robert Kahele, Joe Kala, and David Makaoi, former residents of Waimanu who were interviewed by Vivien Lee and Yukie Yoshinaga as part of a college oral history project in the 1970's concerning Waipio Valley (University of Hawaii Ethnic Studies Oral History Project 1978).

Kahele said he was born in Waimanu in 1917, and had stayed there till he was four. Rice, he recollected, did not end until 1928 (p. 520). Kala was a child when his family left the valley in 1920, at which time "a lot of people still resided there" (p. 58). Makaoi recalled that in the twenties, one Hawaiian family still occupied Waimanu (p. 865). An aerial photograph of Waimanu in the archives of the State of Hawaii (dated approximately 1920, Fig. 5-6) clearly shows four frame structures on the beach, four along the west valley wall, and what are possibly remains of others. The fields appear overgrown, although it is possible that some of them were simply between crops.

In 1931, an archaeologist who visited Waimanu said it was uninhabited, and noted that "with the decline of the local population, dense guava has overrun the valley" (Hudson 1931 n.p.). Probably, the valley was abandoned fitfully with residents returning part of the time to fish, tend their gardens, and repair their former houses.

Modern Hawaii: 1930-1987

In the 40 years from 1940 to 1980, the Hawaiian
Fig. 5-6

Waimanu Valley Circa 1920
population grew from 423,000 to 965,000. Current population is estimated at 1,054,000 (US Bureau of the Census 1986:20-22). The gross economic production of the state has risen accordingly, based on construction, tourism, other services, military expenditures, and agriculture.

Isolated windward valleys lost whatever straggling inhabitants that might have remained in 1930. A geographer (Lennox 1955) has commented on the parallels among these valleys scattered on five islands. All face the trade winds, have 1500-3000 mm annual rainfall, are narrow and therefore suffer from reduced sunlight, have good alluvial soils, are subject to flash floods and tsunami. The pattern of land ownership is often a mosaic of small parcels embedded in large state-owned tracts.

Isolation is one of the most dominant factors inhibiting the establishment of a rural population and the use of the lands for the production of crops requiring market outlets (p. 18).

Distance to market represents one of the many obstacles to resettlement of the valleys, but isolation in a more general sense -- from other people, from the world of the future, and from the world of the past -- probably explains best why the valleys were abandoned at all.

In Kohala, all the valleys were virtually deserted by 1935. In 1976, an environmental writer for the Honolulu Star-Bulletin spoke to two former residents of Waimanu who had returned one day during the late 1930's to tend to
their property. They noted that the taro fields and fishponds were still intact, and a few abandoned houses still stood, but they remembered no permanent inhabitants (5/7/76:A-21). The subject of Waimanu in the 1940's elicited memories from the oral history project respondents of an old Filipino man residing part-time in the valley and tending cattle, and also of hunters paddling canoes in to shoot pigs (University of Hawaii Ethnic Studies Program 1978:471, 475). The tsunami of 1946 penetrated to an elevation of more than 13 m in Waimanu and destroyed the last standing houses (Nelson Chun pers. comm. 1985).

The tsunami caused much damage in Pololu and the Honokane valleys as well. The wave in Honokane Nui was high but not precisely recorded. The crude structures on the beach there were destroyed, but because of the lack of economic activity monetary damage was insignificant. In Pololu, a devastating 17 m run-up was measured. Clyde K. Sproat recalled the tsunami wrecking the front gate of the Raymond place, some 1000 m inland. Every structure was swept from the lower valley floor and even from the high dune at the mouth. A vivid testimony to the force of the tsunami is the military landing craft that today rests mired in the mud 500 m from shore (Fig. 5-7). Until the tsunami, this craft had lain offshore for several years where it had been accidentally sunk in training exercises during World War II. The rice and taro fields were destroyed by the tsunami, and the archaeological
Fig. 5-7

Landing Craft in Mud, Pololu
interpretation of the valley made a challenge by the reworking action of the waves.

Pololu Valley, with its ready access to the main road, was even more likely than Waimanu to have experienced a fitful sort of abandonment. Tuggle (1975:25) reported that shortly after the tsunami the last descendants of Mary Kainoa Raymond finally left the valley. Hubbard (1972:2), who interviewed W.K. Sproat concerning the matter, had determined that the last permanent inhabitants had moved out during the 1920's after the demise of rice.

The Sproat family had occupied Honokane Iki until 1935, when Sproat decided that his children were spending too much time away to attend school (W.K. Sproat pers. comm. 1985). Their house remained a communication center for Kohala Ditch employees, who would report stream stages by telephone, which, remarkably, had been installed in these valleys without roads, electricity, or permanent inhabitants. The tsunami of 1946 floated the house in Honokane Iki off its foundation and destroyed several outbuildings seaward of the main structure, which was itself repaired soon after.

In the aftermath of the tsunami, guava came to overrun the margins of the old rice-fields in Waimanu and Pololu, and a marsh composed of grasses and sedges regained dominance in the low centers of both valleys. Cattle and pigs have been pastured in Pololu Valley ever since, and the felling of trees to encourage the growth of forage has
caused the lower valley to become a jungle of trunks, limbs, vines, and weedy trees. The animals also wander extensively in the higher portions of the lower valley. Wild pigs also inhabit Waimanu and attract hunters on a regular basis. Campers have been a frequent sight in Waimanu since the 1970's, averaging several a night, although many weeks pass without visitors during the winter rains.

The fate of Waimanu began to attract the attention of state planners in the 1970's. The State of Hawaii owns 1490 ha in the valley, while a major landowner, the Bishop Estate, owns 36 ha. The Department of Hawaiian Home Lands owns 81 ha, and 23 ha, the remnants of the kuleana of the 1850's, are in private hands. The Hawaiian Homes Agency has declared that Waimanu is unsuitable to the goal of settlement because of its inaccessibility, and that preservation of the land is probably the best course (Hawaii State Division of Hawaiian Homes Lands 1976:54).

In 1975 Waimanu was designated an estuarine sanctuary. This new status outlawed mining, logging, dredging and filling, construction-site clearing, the introduction of exotic flora and fauna, and the removal of native flora and fauna. A federal agency, the Office of Coastal Zone Management (under NOAA), granted the state money to buy the remaining private land in 1976. Opposition by local landholders to the plan has kept the issue in litigation for a decade, and as of 1987, the status of Waimanu Valley
as an estuarine sanctuary in anything but name is unresolved.

Waimanu, as well as the other three valleys in this study, continues to receive campers, hunters, and now, marijuana growers. The Sproat family is continuing its long tradition of periodic residence in the valley with the construction of a new cabin in Honokane Iki by Clyde K. Sproat. The construction material has been flown in by helicopter and packed in with mules.

Summary

Land-use change in Hawaii has been closely linked to the broader political and social trends unfolding after the first European visit to the isle in 1778. Hawaii evolved in a matter of decades from a socially-stratified kingdom with feudally allocated land used for subsistence agriculture to a constitutional monarchy with fee-simple land rights and a strong commercial economy. This transformation was accompanied by disease and social problems leading to decrease in the native population. Land dispossession as well as the economic and other attractions of the new order drew many of the remaining Hawaiians from subsistence farms to plantations and cities. Windward valleys were one of the last traditional Hawaiian environments, but they too were transformed agriculturally and ethnically with the establishment of Chinese rice plantations. Such valleys on all islands were gradually
abandoned in the early 20th century, coincident with the demise of the monarchy and the annexation of the islands to the United States.

The introduction of exotic flora and fauna to Hawaii was inaugurated by the Polynesians, but it accelerated with the arrival of Westerners. The very first ships to visit the islands brought the mixed blessing of goats, and dozens of organisms followed within two decades. The most common tree in the lowlands of Hawaii, the guava, appears to have become naturalized by the mid-19th century. Other tropical tree species widespread in the islands by this time were coffee, mango, papaya, and several varieties of citrus. Chinese settlement in the later 19th century encouraged the introduction of further novelties. By the late 1800's, Hawaii's reputation as a floral paradise (based largely on exotics) was being established by means of the conscious introduction of species from every continent. Foresters responded to the ravages induced by feral grazing mammals and foreign plants by planting more exotic trees to resuscitate the moribund forests.

The population history of the windward valleys of Kohala since 1778 has shown a steady downward trend that culminated in abandonment during the 20th century (Table 5-5, prev.). The beginning date of population decline is unknown. Tuggle surmised that the Missionary Census of 1835-1836 counted a population that may have represented only half its prehistoric peak size (1976:12). If
depopulation trends in Kohala followed those of the islands in general (Coulter 1931), Tuggle's guess is probably accurate. In any case, decline was the dominant trend during the 19th century, until Chinese and rice joined Hawaiians and taro in the occupation of the valleys in the 1870's. The standstill of population loss came to an end with the decline of rice, and finally the valleys lost their last inhabitants.

Each of the valleys had a distinct pattern of land-use associated with it during the prehistoric and early historic periods, and the evolution of these patterns proceeded along different lines thereafter. Nevertheless, there were also certain common features in the changes over time.

Waimanu had been a classic wet-taro valley, endowed with rich alluvium, an abundant water supply, and a fairly broad and therefore sunny cross-section. Settlement was concentrated near the beach and margins, where gardens of vegetables and tree crops also flourished. Pololu was somewhat similar, although an unreliable supply of water prohibited extensive wet-field development, and dry-fields, ironically subject to flash floods, were more common. Honokane Nui is too narrow and steep for alluvium to develop, but numerous small terraces on both slopes took advantage of the steady stream. Honokane Iki was too shady to support terraces of taro, although certain tree crops could be cultivated.
The spatial aspect of abandonment in the valleys seems to have followed the general pattern common in other Hawaiian valleys. In Waimanu and Pololu, the rear of the valleys was abandoned first, and eventually settlement persisted only on the beach and adjoining the lower west valley wall. Honokane Nui was abandoned in one piece in 1906, but Tuggle's archaeological work seems to indicate that the more inland sites were already abandoned by that date. The spatial progression of abandonment in tiny Honokane Iki is unknown, but it seems likely that no more than a family or two inhabited it permanently at any time.

During the 19th century, the introduction of new crops created the potential for a new vegetational landscape in the Kohala valleys. Citrus, coffee, guava, mango, and papaya were all noted in the valleys during this century. The style of agriculture itself was probably more conservative, at least until rice began, with taro fields occupying the most space and attention. Polynesian and exotic trees were planted surrounding the houses and in separate plots, and also encouraged to grow wild. Since 1930, the valleys have been largely ignored, and natural processes have begun to reshape the vegetational landscape, working with a novel set of elements.
THE LEGACY OF THE HAWAIIAN CULTIVATOR
IN WINDWARD VALLEYS OF HAWAII
VOLUME II

A Dissertation

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CHAPTER 6

THE ECOLOGICAL APPROACH TO THE INTERPRETATION OF VEGETATION

The establishment, persistence, and interpretation of the vegetation patterns imposed on the landscape by human actions and natural processes are what interests the historical biogeographer. To study such phenomena requires an adequate characterization of the resident plants, combining maps, statistics, and narrative. Analytical techniques relating vegetation and other factors require valid and pertinent data gathered in an unbiased manner.

Methods for organizing the collection and interpretation of vegetation data have been developed and refined by vegetation ecologists.* Furthermore, an explanation of the persistence and evolution of vegetation patterns benefits from an exploration of the ecological relationships plants have among themselves and with their environment.

However, the approach of vegetation ecology is predicated on certain assumptions that are not always appropriate to the study of cultural vegetation. An ecologist regards vegetation pattern as fundamentally a

*Vegetation ecology, as described here, means roughly the study of plant communities. The term was coined by Mueller-Dombois and Ellenberg (1974:7) to encompass a variety of sub-disciplines of biology, which all focus to some degree on the "composition, geographic distribution, and environmental relationships of plant communities" (p. 7). Vegetation ecology as defined here includes the subject area known as quantitative plant ecology (Grieg-Smith 1983).
product of environmental variation. When the structure and function of natural habitats are profoundly altered by human activities such as land-clearing and the introduction of new species, the reflection of environmental control of vegetation patterns becomes attenuated and distorted. Many other factors must be brought into the analysis to derive a clear explanation.

The methods of this thesis have been developed by adapting certain techniques and approaches of vegetation ecology to the special problems of anthropogenic vegetation in the Kohala valleys. This chapter describes the development of these methods, and begins with an account of the history of vegetation ecology, in order to make explicit the goals and assumptions of the study of natural vegetation. After history, an account of the methods of data collection and analysis employed in vegetation ecology is given.

**The Development of Vegetation Ecology**

Vegetation ecology as a discipline owes its origin to several sources. The development of measurement techniques in ecology arose partly from attempts to characterize regional vegetation and the processes that create and maintain it. This approach is often called Humboldtian, after the great German geographer, botanist, and explorer who pioneered it (Humboldt 1806). The 19th century also witnessed the germination of the systems approach in
ecology, as the analogy of an organism was invoked to explain the function of natural habitats. A natural collection of plants began to be viewed as environmentally determined, structurally organized units -- communities. Clements' (1916) systematic exposition of the concept of plant succession, a sort of ontogeny of the community, synthesized the accumulated observations of regional botanists with the prevailing philosophical orientation of the scientific naturalists. In his model, each geoclimatic unit on the earth has a corresponding vegetational community, the climax, which emerges after an inevitable series of sub-climax communities progressively modify the environment. The climax community in Clements' model is stable and relatively homogeneous under natural conditions, and self-replicating after disturbance. This is because the climax supposedly reflects the control of environmental factors distributed somewhat uniformly within defined geographical bounds.

After Clements' advances, the science of ecology developed quickly, and many of his conclusions were modified. An elaborated concept of the ecosystem (Tansley 1939) took the place of the rather limited organism analogy and signalled the birth of a new orientation, which became known as systems ecology. Some ecologists have challenged the holistic conception of the community (Gleason 1939, Whittaker 1951, 1975). They have succeeded in the sense that most ecologists now concede that communities are
less-than-discrete stages along a continuum of environmental response.

Nevertheless, the assumptions still current in ecology, upon which its methods of vegetational characterization are based, owe much to the pioneers of vegetation science. E.P. Odum’s landmark article, "The strategy of ecosystem development" (1969), incorporated the theory of succession into a functional model of the ecosystem. Odum’s views represent the predominant paradigm of modern ecology, especially as it is borrowed by other disciplines. He argues that succession is an orderly, directional process, a natural consequence of the modifications of the physical environment by the community, a sort of relay. The end result is a stable ecosystem in which nutrient recycling, symbiosis, and biomass are maximized. It is the most diverse natural community possible for any given area. An ecosystem is similar to an organism in that it grows, matures, and possesses interdependent components.

Challenges to the Holistic Conception of the Ecosystem

The holistic synthesis in ecology has its detractors. The question of whether communities are accidental meetings of plants whose tolerance ranges happen to overlap, or whether they are somehow functionally integrated wholes, continues to be problematic. Gleason’s objection (1939) that in the absence of data the prevailing emphasis
amounted to a negligent assumption has been reiterated by Whittaker (1951, 1970). As data have become more abundant, many ecologists have become convinced that the individualistic distribution theory has been under-rated (Kellman 1969:12).

The property of inherent stability in ecosystems has also been questioned more of late. The investigation of natural disturbances, ranging in scale from tree-falls to floods to volcanic eruptions, reveals that disturbance is part of the life-history of the majority of forest trees. Previously cited conclusions (Sanford et al 1985, Foster 1980, Harper 1977) concerning the importance of disturbance in the forests of Amazonia, Central America, and New England, are valid for perhaps a majority of the earth's "natural" forests. The ubiquity of disturbance coupled with apparently random fluctuations in abundance of various components of an ecosystem has recently stimulated interest in the measurement and analysis of the phenomenon of stability. Until the 1970's stability was a vague concept rather automatically attributed to "mature" ecosystems (e.g. Odum 1969). That assumption has since been called into question (Drury and Nisbet 1973) in the context of succession. Connel and Souza (1983) distinguished the concepts of resistance to change and elasticity after change. They maintained that by neither measure is stability demonstrable in real-world ecosystems: "If a balance of nature exists, it has proved exceedingly
difficult to demonstrate" (Ibid.:806). The idea of fluctuation of the quantities and types in species within certain probabilistically determined bounds is gradually replacing the notion of stability.

The "relay" conception of succession is also controversial. Vegetational succession is often likened to a relay, in which the organisms at each stage prepare the environment for the stage that will follow, which will be composed of a species mix distinct from what flourished before. Each step is vital, and disruption at any point may lead to a deflected succession, an alternate climax. The relay concept was derived from studying different-aged stands. When an individual patch is monitored over time, and the lives and growth-histories of individual trees are studied, a somewhat different interpretation may result.

Whittaker (1951; 1970) has argued that during all stages, seeds of every future or past inhabitant are present. They experience greater or less success depending upon micro-conditions, not environmental stage or community adaptation. Experiments in the rainforests of Thailand (Cheke et al 1979) indicate just such a process. Drury and Nisbet (1973) defined succession as simply the differential unfolding of the life-growth histories of the individual plants. In most forests, even the highly shade-tolerant trees are present during the earliest stages of succession. They are often long-lived, whereas the shade-intolerant plants tend to grow and reproduce quickly, and occur
thereafter on the margins, in gaps, and in the disturbed areas of the mature forest, and never disappear entirely. Under close observation the validity of the relay hypothesis is difficult to demonstrate.

Ecology, like any other scientific discipline, is dynamic. The challenges to the holistic concept of the ecosystem are being debated, and a new paradigm may soon develop. At the present time, the methods of vegetation ecology are based on the assumption that stable, recognizable communities compose mature ecosystems. Many measurement and analysis techniques are designed to uncover vegetational communities amid the chaos of plant distribution data. These techniques will probably undergo modification in the future, as the ecosystem paradigm comes to accommodate the idea of continuous disturbance. Presently, the practice of vegetation ecology is largely predicated on the existence of valid, stable, environmentally-determined communities. Whatever the future modifications to the holistic community concept, it is not entirely appropriate in the study of disturbed vegetation. Therefore, techniques developed in vegetation ecology need to be evaluated closely and often modified before they are applied to the study of cultural vegetation. The next section describes some common measurement techniques, after which their value in characterizing cultural vegetation is discussed.
How Vegetation Ecologists Measure Vegetation

Adopting the holistic ecosystem perspective immediately entails obligations for one who characterizes an area's vegetation. The complexity, unity, and stage of development of the vegetational community must be taken into account. Simply listing the tree species, ignoring their size, relative frequencies, and integration in the ecosystem, will produce meaningless results. As Mueller-Dombois and Ellenberg stress, "a plant community is not a flora," (1974:4). Vegetational ecologists have developed descriptive techniques that are for the most part consonant with the conception of the ecosystem as a valid entity.

A plant community has many aspects. Among them are functional relationships (energy and material flow), evolutionary history, and structure. The vegetational ecologist usually confines his scope to structure, a term which encompasses vegetation physiognomy, biomass, life-form, population, and flora. The characterization of a community is achieved by describing its structure. The important considerations are size and species of the plants. These factors are used to classify the vegetation by life-form (sensu Raunkiaer 1937), by floristic criteria, or by some combination of the two. The description of vegetation ecology presented in this section will concentrate on the floristic structure, because that is the aspect of vegetation upon which this thesis has been based.
A complete portrait of the floral structure of a community (or more simply, a vegetated plot) requires an enumeration of all the individuals of every size for each species. Such a procedure is usually impractical, so one must settle for a much more generalized depiction. Usually, only a few life-forms are chosen for description. Since this thesis deals with trees, only those aspects of measurement that apply to arboreal individuals will be discussed. Even when the universe of individuals of interest is restricted to trees inside a prescribed area, there are often too many individuals to be counted in a reasonable time. Sampling is the answer to characterizing the vegetation of a large area, and much of the work of vegetation ecologists has to do with obtaining a sample considered adequate on subjective and/or statistical grounds.

Mueller-Dombois and Ellenberg (1974:32) listed four essential steps in vegetation sampling: segmentation of the vegetation into units, sample selection, selection of size and shape of sample units, and decisions on what statistics to record.

Segmentation and the Selection of Samples

Vegetational segmentation is the most problematic of the steps, and one which is undertaken quite differently by individual investigators. Segmentation actually takes place on at least two levels. First, a geographical area
of interest is defined. Inside that area, vegetation is usually surveyed, and the rough boundaries of vegetational communities may be objectively or subjectively determined, or left for determination later using the results of sampling. Then, areas in which to sample the various communities may be objectively selected, either randomly or systematically, or they may be subjectively chosen according to some criteria of the investigator (Mueller-Dombois and Ellenberg 1974:32-35, Grieg-Smith 1983:19-20). On each level there are many opportunities for bias to be introduced, and the degree to which potential bias is scrupulously avoided is one distinction among the various schools of vegetation ecology. Because segmentation can pose a major problem in the case of cultural forests, it is worthwhile to examine the process further.

The selection of a geographic area of interest may reflect a desire to characterize all the plants, or one or more of the vegetational communities presumed to exist there. This is an important distinction. One may select a mountain top as the area of interest but limit one's actual efforts to the natural coniferous forests on the slopes, ignoring grasslands, alpine tundra, and roadside weed communities. Investigators often fail to make explicit in their areal studies of vegetation that one or two communities are actually the focus. To illustrate the distinction using an extreme example, no flora of alpine
Switzerland would likely include hothouse begonias, though they might be present. Published floras vary in their inclusion of non-natural elements. Ecologists readily grant the existence of atypical or non-natural elements in their study area, but often exclude areas rife with anomalies from ecological analysis. Such decisions are appropriate in the pursuit of establishing the correlation of natural vegetation with environment. Nevertheless, an ecological study of the vegetation of a large area should not be confused with a portrait of the plants included on strictly geographic grounds.

The next level of segmentation involves choosing areas in which to begin sampling. There are large differences of opinion as to which approaches are appropriately balanced between the requirements of objectivity and the production of data that reflect community structure. The individualistic approach is to sample randomly the entire selected area without further division, so that the continuum of individual species' responses to environmental gradients may be better monitored (Whittaker 1970:36). Mueller-Dombois and Ellenberg argue that the advantages of this approach in terms of objectivity are offset by the loss of information regarding ecologically significant patterns, which may go undetected because proper categories in which to sample have not been used (1974:34).

A process of familiarization involving reconnaissance,
primary survey, and then intensive survey (sampling) is recommended in the *Manual of Vegetation Analysis* by Cain and Castro (1959). Grieg-Smith (1983:20) has pointed out that much reconnaissance and subjective survey is unnecessary if sampling is both intensive and geographically referenced. The homogeneity of a group of samples from within presumed vegetation segments can be tested, and segments may then be fragmented, combined or undergo boundary changes on the basis of homogeneity testing. Objective segmentation, however, may require very intensive sampling, in some cases exceeding unity (Mueller-Dombois and Ellenberg 1974:30, citing Goodall's 1953 method study which indicated that a 200% sampling intensity was necessary to divide an Australian *Eucalyptus* stand of 640 square meters into four sub-associations).

Many fieldworkers, following the approach of Braun-Blanquet (1932), dispense with objective segmentation altogether and employ centralized non-random sampling inside of units designated on the basis of reconnaissance as typical. Such methods may be justified depending upon the goals of the investigators, but "data from such samples cannot be considered an unbiased estimator of the vegetation of an area" (Grieg-Smith 1983:20). The sacrifice entailed in departing from random or systematic sampling is the ability to employ probability statistics in support of the validity of the vegetation units discovered.
The Number, Size, Shape and Categories
Of Data Collection of Sample Units

The common parameters of interest in sampling floral structure in arboreal stands are density, frequency, and cover. These are normally measured inside rectangular sampling plots, termed quadrats, which are placed either subjectively, randomly, or systematically inside the chosen area of interest. Density refers to the number of individuals of a given species, and is most meaningful when all species are compared and density is expressed in percent. Often, density is reported separately for various size-classes, which permits an indirect examination of the population-age structure as well as abundance. Frequency is a measure of the proportion of sampling units in which a species is present. Cover is a measure of the relative area or volume a species occupies in a sampling unit, and can be expressed in terms of crown area, biomass, or basal area at breast height.

It can be demonstrated that each of these measures are sensitive to the size, number, and shape of the sampling units chosen. The variation in observed frequency with quadrat size is an obvious example. The larger the quadrat, the more likely it is to include any given species, particularly if the species is uncommon. For this reason, valid frequency comparisons between sampled areas require a consistent quadrat size. A less obvious problem associated with frequency is that a large number of samples
are required to allow valid and discriminating comparisons using probability statistics. For example, to verify that the grossly different frequency means of 27% and 73% arise from different populations at a 95% level of confidence requires over 20 samples. Grieg-Smith recommends sample sizes considerably in excess of 100 in order to obtain reliable and useful inferential conclusions (1983:37).

Density and cover sampling schemes using different combinations of quadrat number and size impose various statistical problems. In a perfect Poisson distribution, often approximated in groups of samples of species abundance in natural conditions, the variance of a set of samples is equal to the mean. The standard error estimate is thus dependent only on the number of individuals (or units of area, in the case of cover) counted, and not on the number of quadrats (Grieg-Smith 1983:27). Unfortunately, vegetation distribution is usually contagious, leading to imperfect distribution and variances greater than and independent of the mean. In such situations, the standard error estimate is highly dependent on the number of quadrats. In a non-random plant population, the ratio of patch size to quadrat size also affects the variance, with quadrats smaller in relation to patches generally yielding smaller variances (Ibid:28).

The safest course in sampling non-random populations is to employ many quadrats of the smallest sensible size considering other objectives. This yields collections of
samples with the desirable property of low variance. Rectangular plots are to be preferred, because of their advantages in representing the overall species proportions in an area with clumped populations (Bormann 1953). However, highly elongated rectangles also run the risk of increasing edge-effect errors when individuals are improperly included or excluded (Grieg-Smith 1983:29).

The size of a plot also affects density statistics in a different way. If size is reduced to the point where species of interest are more often excluded than included, i.e., where frequencies are less than 50%, the shape of the density curve for the samples becomes highly asymmetric, and inferential statistical methods become difficult to apply. If the mean is sufficiently large (e.g., over 3.0), correction factors may help normalize the distribution. A common correction for the Poisson distribution is the square root transformation. However, some highly irregular distributions are difficult to correct (Ibid:31).

A prudent sampling scheme is based on adjusting proven methods to the problem at hand. Different combinations of sizes, shapes, and numbers of quadrats may be tested and adjustments made based on the results. The overall objective is to obtain a data set that contains variables meaningful in an ecological sense, with values that reliably reflect population parameters. In practice, sampling schemes vary greatly according to the investigators, who often use methods derived from other
sources, and do not always attempt to improve them based on the quality of statistics they begin to produce. Data that derive from methods and distributions that do not meet the assumptions of probability statistics are often mistakenly applied inferentially. In some cases, appropriate methods simply cannot be practically applied, and second-best estimates must suffice. The use of data that does not meet statistical assumptions is not impermissible, providing it is clearly understood that the statistics are meaningful only in a descriptive sense. Conclusions derived under such conditions are not the equivalent of hypothesis testing in the strict statistical sense. Ultimately, sample methods should be based on their utility in answering the specific environmental questions one has posed.

**Multivariate Analysis of Vegetation Data**

In vegetation ecology, investigators are usually concerned with the ecological meaningfulness of the species abundance patterns which they have abstracted during sampling. Raw species abundance data are often transformed during data analysis into derived variables, which are used for characterization of dominant species and initial comparisons among areas. Finer distinctions and more sophisticated comparisons require the use of multivariate methods, which in vegetation ecology have developed along two major paths.
The first approach is classification, which grew out of the *releve* approach introduced and refined by the European botanist Braun-Blanquet (1932). In the more traditional treatment, samples are derived differently from plot sampling. One attempts to obtain an "releve" or abstract of the community through shrewd classification techniques based on field knowledge and tabular comparisons. The *releve* method is considered by its detractors to be a process that is overly intuitive and impossible without a laborious apprenticeship (Gauch 1982:205). Computer-aided classification techniques are more common today, and they often employ variables derived from plot sampling techniques. The ultimate product is a system of vegetation units, often hierarchically related, which are of interest in themselves or as keys to the environmental parameters whose distribution they reflect.

The second major approach is based on studying the differences and similarities among vegetation samples and is known as "ordination". Rather than seeking to delineate the various sub-types within a community, many researchers wish to examine primarily the change in vegetation along environmental gradients. Multivariate analysis of the data (i.e., the size and numbers of various species) results in the ordination of the community, a low-dimensional representation of the variation present in the vegetation (Goodell 1953; Kershaw 1964; Gauch 1982). Ordination is probably the best method for analyzing the similarity or
dissimilarity of samples, and it does not require large and inclusive samples, as do many classification techniques. The advent of high-speed, inexpensive computing has encouraged new multivariate techniques more closely fitted to ecological models, and has also allowed a thorough comparison of techniques (Gauch 1982:3). However, the shift to ordinating samples has brought along with powerful techniques the problems of meeting the assumptions of inferential statistics when one attempts to apply conclusions based on samples to the population as a whole (Orloci 1975:16). Furthermore, the machine-processing of data has sometimes fostered the illusion that ordination is a completely objective exercise, when in fact, "the successful application of mathematical methods requires a number of decisions and adjustments....any decision is a subjective act," in the words of Mueller-Dombois and Ellenberg (1974:212).

Because many modern ecologists are more concerned with theoretical relationships, they eschew classification as a goal in itself, a practice often pursued by geographers and one for which they have been perhaps justifiably criticized (Kellman 1969). Ordination is seen by many as the method which best generates the hypotheses needed to explore vegetation/environment relationships (Kershaw 1964; Gauch 1982:31). However, much of the world's vegetation is as yet undescribed, and basic classification in such regions (of the nature sponsored by the International Biological
Program) is urgently needed.

Despite the differences in emphasis, classification and ordination share two fundamental goals. In the words of Mueller-Dombois and Ellenberg (1974:305):

"...the implicit purpose of both of these ordering methods is to first establish a meaningful framework of vegetation patterns to which we may subsequently relate environmental patterns and parameters. This approach from vegetation patterns to environmental is the tradition of vegetation science."

Summary

Vegetation ecology seeks to clarify the individual or collective effects environmental factors have on the distribution of plants. Vegetation is assumed to be almost wholly determined by the environment in some form, and to be part of a system involving sunlight, soil, water, the atmosphere, microbes, and animals. This system has traditionally been conceived as subdivided into discrete units, communities. In such units, there is a tendency for maximization of biomass, energy storage, species diversity, and symbiosis over time in undisturbed conditions. Disturbance, however, is now being viewed as not an abnormal and temporary interruption but as a separate environmental mechanism to which plant systems, or perhaps individual plants, become adapted. Techniques of environmental characterization are sophisticated, but probably do not take into account sufficiently such factors as disturbance and the individualistic distribution of
plants. In vegetation sampling, an evocation of the community is often still the goal and the working assumption around which methods of measurement are structured. Such variables as density, cover, and frequency of individual species are abstracted in samples selected with more or less bias. The results of sampling answer varying purposes, including the classification of natural vegetation into types, and the analysis of species abundance responses to environmental gradients. The underpinning of all methods is the fundamental assumption that ultimately environmental differences induce the differential geographic distribution of plants. This is the strength, as well as the limitation, of the approach of vegetation ecology.
CHAPTER 7
METHODS OF THE STUDY

The first goal of this thesis, to explore the physical, biological, and human setting responsible for the vegetation in the valleys of Kohala, has been accomplished in Chapters 2-5. The remaining goals, to characterize the vegetation, to assess the relative associations of environmental conditions with specific vegetation parameters, and to ascertain the legacy of the Hawaiian cultivator in the present and future forests of the valleys, require valid and useful data concerning vegetation and environment. An approach designed to obtain such data must:

1. Devise a logical segmentation scheme that provides a basis for comparison of different areas in the valleys.
2. Develop meaningful variables of species abundance for statistical and graphic comparison of the different areas of the valleys.
3. Develop measures that characterize environmental variation in the valleys.
4. Formulate measures that allow the prediction of the future structure of the valley forests.

Vegetation ecologists have developed sophisticated techniques for characterizing vegetational patterns and studying environmental variation. These approaches and
methods were reviewed in the last chapter. However, there are discrepancies between the conditions that normally precede the ecological study of vegetation and the conditions that obtain in the Kohala valleys. This chapter makes those discrepancies explicit, and explains the method which has been designed to supply the quantitative and qualitative comparisons of vegetation, environment, and history.

Applying Vegetation Ecology in Disturbed Forests

Superficially, the tasks of vegetation ecology and the type of study conducted in this thesis are quite similar. Both seek to characterize vegetation and explain its distribution. However, the assumption that environmental factors alone have been responsible for the distribution of trees in the Kohala valleys is untenable. Neither of the common models in vegetation ecology, that of discrete and holistic environmentally-determined communities, nor that of individualistic species response to a combination of environmental gradients, is applicable in the valleys. Much of the patterning of vegetation can only be ascribed to human influence. Trees were planted in certain localities and have remained and spread. The sort of vegetation segments hypothesized by many vegetation ecologists tend to be absent. A study of the vegetation of the Kohala valleys is not a study of the communities, and in fact is not a study of vegetation at all in the sense
employed by ecologists concerned with plants in a natural environment (Mueller-Dombois and Ellenberg 1974:4).

A graphic model of the dynamic factors in the history and structure of the vegetation in Kohala clarifies the distinction. In Figure 7-1, the valleys are considered as a whole and species grouped together according to place of origin. The proportions of the three groups that comprise the natural (or naturalized) flora of the valleys have changed through time. Before Polynesian settlement, all vegetation was indigenous. After Hawaiians colonized and began to settle the valleys, the proportion of Polynesian vegetation rose quickly at first, and probably began to level off as environmental disturbance stabilized somewhat (Kirch 1984). A renewed disruption occurred with European contact, when exotic species from the West quickly spread. A period of adjustment continues to this day, interrupted

![Fig. 7-1. Changing Composition of Vegetation](image-url)
by the occasional introduction of a new species capable of naturalization. The percent values in the graph are arbitrary, but they portray a conceptual average derived from balancing the vegetation of the inland slopes, where native species survive, with that of the flatter areas near the coast, which house a high proportion of exotics. The principal point is that human action has continually disrupted the establishment of a vegetational equilibrium in the lowlands. A balance of species is still developing, and vegetation communities have perhaps not yet assumed definite form.

In a realistic analysis of the vegetation of the valleys, the domain of interest is essentially a geographic area, not the communities that may be supposed to inhabit it. A method is required that can examine the trees in a region without the preconceptions that mark the approach of vegetation ecology, but one which may still portray the plant distribution and test for the influence of the physical environment as well as other sets of factors.

A Biogeographic Approach to the Kohala Valleys

MacArthur and Wilson once distinguished the approach of biogeography from ecology with this statement:

Biogeography is concerned with the limits and geometric structure of individual species populations and with the differences in biotas at various points on the earth's surface. The local, ecological distribution of species, together with such synecological features as the
structure of the food web, are treated in biogeography only insofar as they relate to the broader aspects of distribution (1967:185).

The focus on distribution is perhaps even more apt when dealing with disturbed vegetation.

One solution to the problems posed by the dual requirements of characterizing the vegetation of an area and analyzing it simultaneously in terms of historical and environmental factors is to focus on the distribution of all factors in individual locations, which is essentially a biogeographical approach. A geographically-oriented data matrix can be created and made to serve several purposes. The techniques of vegetation ecology may be adopted to gain the necessary plant information. The plant sampling quadrat can then serve as the basic geographic unit in this matrix. The dimension of environmental control can be addressed in the creation and measurement of a set of environmental variables. The distribution of these variables can be described and mapped, and hypotheses concerning relationships among them can be formulated and tested. This method dispenses with the ecological requirement of defining vegetational communities of interest. Other, geographically meaningful sub-units must be established. The influence of historical land use on species abundance measures may be identified by examining exceptions to environmental control.

A data matrix of this type has been created for the Kohala valleys. The procedure for obtaining the data
consisted of four steps, listed and then explained below:

1. Reconnaissance of Valleys
2. Division of Ribbon Forest Into Sub-Units
3. Sampling Design
4. Selection and Measurement of Pertinent Environmental Variables

Reconnaissance

The four valleys were walked and visually surveyed in a systematic manner during the summers of 1983 and 1984. The ribbon forest has been identified in Chapter 3 as the specific area of interest, due to its importance as a settlement location and the richness of its current vegetation. This forest occupies an area of diverse slopes, drainage regimes, and substrate types. The purpose of reconnaissance of the zone was to determine how it could be subdivided into smaller and more discrete geographical units and how it could be sampled effectively. A secondary purpose was to become familiar with prominent but unusual vegetational features, such as large groves or extremely large individuals of uncommon species, that might be uncounted during sampling.

Division of the Ribbon Forest Into Geographic Sub-units

Reconnaissance revealed that the region was sufficiently heterogeneous to merit subdivision, in the interest of both accurate description and more homogeneous sampling units. The region was divided first into four
units corresponding to the individual valleys, and further into fifteen units on the basis of the aspect of the slope and the distance to the sea (Table 7-1 and Fig. 7-2). In all valleys but Honokane Iki, a clear dichotomy between eastern and western sites is present. In Honokane Iki, in the side gulches of Waimanu and Pololu, and in the upper

<table>
<thead>
<tr>
<th>Sampling Area</th>
<th>Location</th>
<th>Number of Quadrats</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pololu</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>Pololu</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Pololu</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>Pololu</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>Pololu</td>
<td>47</td>
</tr>
<tr>
<td>6</td>
<td>Pololu</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Honokane Nui</td>
<td>39</td>
</tr>
<tr>
<td>8</td>
<td>Honokane Nui</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>Honokane Nui</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td>Honokane Iki</td>
<td>32</td>
</tr>
<tr>
<td>11</td>
<td>Waimanu</td>
<td>104</td>
</tr>
<tr>
<td>12</td>
<td>Waimanu</td>
<td>22</td>
</tr>
<tr>
<td>13</td>
<td>Waimanu</td>
<td>11</td>
</tr>
<tr>
<td>14</td>
<td>Waimanu</td>
<td>28</td>
</tr>
<tr>
<td>15</td>
<td>Waimanu</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 7-1
Location and Quadrat Number in Sampling Areas

section of Honokane Nui, the slope aspect changes quickly along a transect due to the narrow and twisting course of the streambeds. These areas have been categorized as gulch sub-units to distinguish them from other areas with a clear east- or west-facing orientation. The valleys have also been split into inland and seaward units, with a dividing line 1500 m from the sea. Although the line is arbitrary, the general distinction between the cloudier, narrower,
Fig. 7-2a

Waimanu Sampling Areas
Fig. 7-2b

Northern Valleys Sampling Areas
steeper, and more isolated inland portions and the seaward sites was evident in surveys of the vegetation during reconnaissance. It must be stressed that the fifteen areas that resulted from the division of the valleys often do not possess distinct boundaries. They simply serve as convenient areas in which to observe vegetational differentiation throughout the valleys.

Sampling Design

Vegetation sampling took place inside the sub-units. Prior to actual sampling, trial runs using various quadrat sizes were conducted and the running means of density values for the main species were plotted. It was found that very large quadrats would be necessary in order to measure the frequency of more than a few species. To measure the density of a reasonable number of individuals of species other than the principal two also required large quadrats. Inconveniently, many of these large quadrats would be needed to allow confirmation of all but gross differences of the mean between groups of samples compared as to either frequency or density. The cause of this quandary was an extremely heterogeneous vegetational environment, with a large number of quite distinct species combinations present in a set of highly divergent samples. It was decided that using samples to test most hypotheses about differences in species abundance would require an inordinate amount of sampling time and effort. The size,
shape, and specifications that were finally selected for the quadrats represent a compromise. The considerations were frequency, density, and cover description, hypothesis testing ability for gross differences in frequency, utility in sampling, and feasibility of surveying.

Because of the constraints of a large area and a limited projected time in the field, the density of sampling coverage was set at 8% for most of the areas sampled and reduced to 4% in the last areas to be surveyed. These rates are typical of most timber survey work (Mueller-Dombois and Ellenberg 1974:76). This resulted in a total of 554 sampling quadrats (Fig. 7-3). The quadrats measure 4 by 20 m, within the range of typical studies involving trees. The quadrats are oriented with their long sides parallel to the major local axis of variation (the cliff-to-marsh slope) in order to cut across the maximum number of vegetation clumps, which tend to align perpendicular to the slope.

All trees of each species belonging to five different size-classes (2.5 to 7.4 cm, 7.5 to 12.4 cm, 12.5 to 24.9 cm, 25.0 cm to 37.5 cm, 37.5 cm and larger, dbh) inside each quadrat were measured and enumerated. This size-class division was based on common practice in studies on natural ecology, adapted to reflect the usual correspondence between the size and age of individual species in the Kohala valleys. Most species were represented in three or more divisions. Trees smaller than 2.5 cm dbh were not
Fig. 7-3a

Waimanu Transect Locations
Fig. 7-3b

Northern Valleys Transect Locations
enumerated. The actual diameters of trees larger than 37.5 cm dbh were measured to the nearest centimeter in order to provide a more accurate estimation of basal area.

The variables described in this and later sections are listed in Table 7-2. The primary species abundance variables are named with two-character prefixes followed by a number indicating size-class. Variables derived from the arithmetic operations on the collected data include the species prefix plus a suffix. The suffixes PA, D, and C indicate presence/absence, density, and cover respectively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SP)1-5</td>
<td>Five variables that count number of individuals of species X in each size-class</td>
</tr>
<tr>
<td>(SP)PA</td>
<td>Presence or absence of species X</td>
</tr>
<tr>
<td>(SP)D</td>
<td>Number of individuals of species X</td>
</tr>
<tr>
<td>(SP)C</td>
<td>Cover area at dbh for all individuals of species X</td>
</tr>
<tr>
<td>RIC</td>
<td>Number of species per quadrat</td>
</tr>
<tr>
<td>SLO</td>
<td>Slope intensity, 3 values: High, Medium, Low</td>
</tr>
<tr>
<td>DRN</td>
<td>Drainage regime of site, 2 values: Periodically flooded or not</td>
</tr>
<tr>
<td>DSE</td>
<td>Distance to sea in 10 intervals of 500 m</td>
</tr>
<tr>
<td>SEC</td>
<td>Number of quadrats between sampling unit and cliff</td>
</tr>
</tbody>
</table>

Table 7-2: Vegetation and Environmental Variables
Selection and Measurement of Pertinent Environmental Variables

Vegetation ecologists often use patterned variation in samples to infer environmental effects. These effects are often also confirmed or independently assessed through reconnaissance or direct measurement. Detecting environmental effects through the examination of sample variability is difficult in disturbed forests, because of the added dimension of historical conditions, which adds "noise" to pattern-seeking methods such as classification or ordination. In this study a supplemental method for studying environmental control of vegetation was devised, one which measured additional variables within the quadrats.

For each quadrat it was decided to collect not only size and species data but also habitat data. Of the infinity of environmental parameters there are several that are generally agreed to account for a good deal of the variation in vegetation. Several soil measures (e.g., particle size, porosity, cation exchange ratio) are useful but difficult to collect and process for more than a few dozen samples. Soil maps may serve as proxies, but for the Kohala valleys they are usually too general to permit reliable and accurate data transfer to vegetation quadrats. There are other on-site habitat factors, however, that are both easily estimated and highly correlated with vegetation.
These environmental characteristics may be thought of as super-factors. Slope, for example, is in strict terms simply a measure of the departure from horizontal of the surface, but it is also associated with changes in soil type and depth, drainage characteristics, and indirectly with shadows and rock avalanches near cliffs. In the natural vegetation of Hawaii, areas of differing slope often tend to house different mixes of species. In the Kohala valleys, there are no pristine forests through which to run transects along a slope gradient, as a vegetation ecologist might do. Slope, of course, is nonetheless a factor in the variation of vegetation. One may employ the quadrats as spatial units in which to measure slope and other habitat variables dealing with flooding, sunlight duration, general substrate type, aspect, and elevation. These factors can be measured during vegetation sampling or calculated later using topographic maps. Though these influences by no means constitute the universe of causal factors in vegetation pattern, their frequent use as parameters in field-oriented classification methods such as Braun-Blanquet (1932) and as explanatory factors in ordination studies (Orloci 1975, Kershaw 1964) demonstrate their utility in ecological research.

The following environmental factors were measured on-site during the vegetation sampling.

1. Slope (SLO). The average slope for each quadrat was listed in one of three classes, high (greater than 30
degrees), medium (10 to 29 degrees), and low (less than 10 degrees). The measurement was an estimation based on training with a level on sites of varying slopes.

2. Drainage (DRN). If most of a quadrat appeared to be subject to occasional or constant inundation, as in sites on the edge of the marsh or near streams cutting across the talus slope from the cliffs, it was listed as wet. Well-drained, non-flooding quadrats were labeled dry.

The following environmental factors were assigned to quadrats using maps or information derived after surveying.

1. Distance to Sea (DSE). The distance of a quadrat to the sea summarized a range of environmental conditions including salt-spray, cloudiness, and shadiness (due to the constant narrowing of valleys toward their interiors). This variable was measured on an ordinal scale of 1 to 10 corresponding to intervals of 500 meters.

2. Sections in from Cliff (SEC). Because quadrats were established along transects that ranged from the cliff to the interior of the valleys, the number of quadrats interposed between each quadrat and the cliff was a simple ordinal measure of distance from the cliff. This measure is useful because it implies the likelihood of rockfalls and the duration of shading.

Formation of a Matrix Formatted for Computer Processing

The creation of a data matrix based on the methods reviewed here and suitable for computer processing required
several steps. First, field sheets were printed for each quadrat with spaces for tallying species occurrences by size-class, as well as the environmental variables to be estimated in the field. A space was also left for comments. After the fieldwork was completed, the values for the remaining environmental variables were calculated from maps and attached to the field sheet for the quadrat. Finally, the variable values were converted to digital code on computer coding sheets and input using a micro-computer word-processing program to files that resided on floppy disc. The files were then uploaded to Louisiana State's IBM mainframe computer and stored on disk. The summation of species totals from size-class data and the calculation of many other derived variables in the final data matrix was accomplished using SAS data management programs.

Some General Comments on the Use of the Data

The data produced from the samples of individual areas inside the ribbon forest of the four valleys are meant to help answer the principal questions of this thesis by enabling accurate description, map production, and statistical comparison. The specific analytical techniques are discussed in the chapters corresponding to each major question. Some general characteristics of the data set and its use are discussed here in the context of data collection.
Data Characteristics

Despite the attempts to design a sampling scheme in which certain combination of quadrat size, quadrat number, and segment boundaries balanced sampling practicality with data quality, the data possess some undesirable properties. For individual areas, the variance of variables is high. This could be foreseen for most species abundance variables because values are naturally low for less common or rare species (Grieg-Smith 1983:29). For the more common species, however, on which most of the comparison between areas is based, more normal distributions and lower variances were expected. The cause of the high sample variability lies in the extreme heterogeneity of the vegetation, ultimately an expression of the idiosyncratic effects of human interference. No scheme of segmentation enclosing adjacent areas could manage to delimit homogeneous vegetation units in the talus zone of the Kohala valleys.

Data Analysis

The undesirable distributional properties of the data meant that multivariate pattern-seeking methods would be overwhelmed by statistical noise, and that the assumptions of parametric inferential techniques would not be met. This situation engendered the formulation of novel methods to describe the vegetation and explain its associations with environmental variation.
The primary use of sampling in ecological studies has always been for the purpose of description. The density of the network of samples in the Kohala valleys insures adequate data for descriptive purposes. The quadrats and the areas they represent are described in this thesis in two ways: comparison of mean species abundance statistics and mapping. The use of species abundance statistics is relatively straightforward, but mapping with the quadrat data obtained in the area approach is a problematic issue.

Displaying the abundance of species within large mapping units (e.g., the west side of a valley containing 100 samples) is only slightly more informative than a tabular summary. And yet constructing a point map with the data from individual quadrats invites criticisms concerning the validity of the representation. An individual quadrat's data are not actually representative, in a statistical sense, of the general area from which they came. Nevertheless, their display is informative, stimulating, and often approximates reality. The value of such point maps increases as the sampling density becomes greater. This thesis makes extensive use of point maps for purposes of illustration and comparison, with full acknowledgement that they have limited inferential use, but also with the knowledge that they do represent reality fairly faithfully.

Multivariate descriptive techniques such as
classification and ordination are not employed in this thesis, although sampling areas are qualitatively classified in a number of ways. Ordination relies on such methods as principal components to reduce variation to a few dimensions. This was essayed on the Kohala data in the exploratory phase of data analysis but rejected because of the inability, despite data transformation, to produce fewer than six components explaining greater than 75% of sample variation. Obviously, the effects of human interference were not regular enough in pattern for such a method to be effective.

Hypothesis Testing

Part of the data analysis in this thesis involves the testing of differences between means of samples and also tests of association between variables. The act of testing hypotheses using sample data is an inferential technique requiring the fulfillment of certain assumptions concerning the data. In data with distributional problems, transformation techniques such as logarithmic and exponential functions are often used to help "normalize" the data. In highly skewed samples containing many sampling zeroes, such techniques often have only limited success and furthermore tend to distort the data into somewhat meaningless indices. After carefully examining the data, it was decided instead to use certain non-parametric methods possessing less testing power than
parametric methods but better suited to the reality of the situation. The precise treatment of the data and the formulation of hypothesis testing methods is detailed in later chapters.
This chapter details the distribution of frequency, density, cover, general dominance, and species richness data for the valleys of Kohala. The mode of examination is to map quadrat measures at as large a scale as practicable, and to highlight the differences among the fifteen areas through tables and graphs. Most of the statistics presented in this chapter are primarily descriptive, a means to illustrate general patterns of vegetational variation, to produce data to assess the impact of Hawaiian farmers on the valley landscape, and to suggest hypotheses connecting environment, historical land use, and vegetation.

**Species Frequency**

The presence or absence of a species in a quadrat or in a larger ecological unit is often considered a significant fact by ecologists studying natural communities (Grieg-Smith 1983:9). Ecological factors such as soil type can often be inferred rather quickly through the indirect evidence of species frequency values (Chikishev 1965). In a study of cultural vegetation, frequency assumes even greater importance. The presence of certain species, even in low absolute numbers, is often highly indicative of former land use.

In Kohala, the mapping of frequency data confirmed the
impression gained during vegetation reconnaissance that each valley, each area, and each geomorphological zone was vegetatively distinct. Individuals from a total of thirty-three species were enumerated during sampling, a figure only slightly smaller than the thirty-six sighted during reconnaissance (Table 8-1). The distribution of species throughout the areas was far from random, as the occurrence of both common and rare species reveals.

The Geography of Frequency Data

The large number of quadrats made display of frequency information for each species problematic. In order to reduce the number of maps required to display this information, frequency data for all quadrats belonging to each transect were pooled, and presence/absence of each species was evaluated on a transect-by-transect basis (Figs. 8-1 to 8-11). This method has the advantage of representing the occurrence of every species in all sampled locations with a less cluttered map than would be possible if all quadrats were displayed. It also has a bias towards making a species appear better-represented in transects containing many quadrats, and caution is needed when interpreting these figures. Nevertheless, broad patterns are clearly and validly depicted by this technique.

Several species are widespread, and their presence or absence shows little patterning, at least on the level of the transect. Others are notably common in certain areas
<table>
<thead>
<tr>
<th>Common Name</th>
<th>Haw. Name</th>
<th>Percent</th>
<th>Latin Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guava</td>
<td>Kuava</td>
<td>75.99</td>
<td>Psidium guajava</td>
</tr>
<tr>
<td>Candlenut</td>
<td>Kukui</td>
<td>66.42</td>
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<td>Noni</td>
<td>Noni</td>
<td>42.96</td>
<td>Morinda citrifolia</td>
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<td>'Ohi'a 'ai</td>
<td>12.77</td>
<td>Eugenia malaccensis</td>
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<td>Hala</td>
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<td>Pandanus odoratissimus</td>
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<tr>
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<td>08.66</td>
<td>Schinus terebinthifolius</td>
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<tr>
<td>Hau</td>
<td>Hau</td>
<td>06.68</td>
<td>Hibiscus tiliaceus</td>
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<tr>
<td>Breadfruit</td>
<td>'Ulu</td>
<td>06.68</td>
<td>Artocarpus communis</td>
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<tr>
<td>Java Plum</td>
<td>?</td>
<td>06.14</td>
<td>Syzygium cuminii</td>
</tr>
<tr>
<td>Papaya</td>
<td>Mikana</td>
<td>04.51</td>
<td>Carica papaya</td>
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<td>Sour Bush</td>
<td>?</td>
<td>04.15</td>
<td>Pluchea odorata</td>
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<tr>
<td>Rose Apple</td>
<td>?</td>
<td>02.89</td>
<td>Syzygium jambos</td>
</tr>
<tr>
<td>Dombeya</td>
<td>?</td>
<td>02.89</td>
<td>Dombeya wallichii</td>
</tr>
<tr>
<td>Mango</td>
<td>Manako</td>
<td>02.34</td>
<td>Mangifera indica</td>
</tr>
<tr>
<td>Mamaki</td>
<td>Mamaki</td>
<td>01.80</td>
<td>Pipturus albidus</td>
</tr>
<tr>
<td>Pride of India</td>
<td>Inia</td>
<td>01.44</td>
<td>Melia azedarach</td>
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<td>False Kamani</td>
<td>Kamani</td>
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<td>Terminalia catappa</td>
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<td>Avocado</td>
<td>?</td>
<td>00.72</td>
<td>Persea americana</td>
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<td>Lemon</td>
<td>Lemi</td>
<td>00.72</td>
<td>Citrus limon</td>
</tr>
<tr>
<td>Ironwood</td>
<td>Paina</td>
<td>00.72</td>
<td>Casuarina equisetifolia</td>
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<tr>
<td>Vervain</td>
<td>?</td>
<td>00.54</td>
<td>Stachytarpheta jamaicensi</td>
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<tr>
<td>Papala</td>
<td>Papala</td>
<td>00.54</td>
<td>Charpentiera obovata</td>
</tr>
<tr>
<td>Canthium</td>
<td>?</td>
<td>00.36</td>
<td>Canthium odoratum</td>
</tr>
<tr>
<td>Star Apple</td>
<td>?</td>
<td>00.36</td>
<td>Chrysophyllum cainito</td>
</tr>
<tr>
<td>Strawb. Guava</td>
<td>Waiawi</td>
<td>00.36</td>
<td>Psidium cattleianum</td>
</tr>
<tr>
<td>Lipstick Plant</td>
<td>?</td>
<td>00.36</td>
<td>Bixa orellana</td>
</tr>
<tr>
<td>Kolomona</td>
<td>Kolomona</td>
<td>00.18</td>
<td>Cassia glauca</td>
</tr>
<tr>
<td>Umbrella Tree</td>
<td>?</td>
<td>00.18</td>
<td>Brassaiia actinophylla</td>
</tr>
<tr>
<td>Giant Bamboo</td>
<td>Ohe</td>
<td>00.18</td>
<td>Bambusa vulgaris</td>
</tr>
<tr>
<td>Fan Palm</td>
<td>?</td>
<td>00.18</td>
<td>Washingtonia ?</td>
</tr>
<tr>
<td>Coconut</td>
<td>Niu</td>
<td>00.18</td>
<td>Cocos nucifera</td>
</tr>
</tbody>
</table>

Table 8-1
Species Sampled in Kohala Valleys, With Percent Frequency
Fig. 8-1

Species Presence, Waimanu (a)
Fig. 8-2
Species Presence, Waimanu (b)
Fig. 8-3

Species Presence, Waimanu (c)
Species Presence, Waimanu (d)
Fig. 8-5a

Species Presence, Waimanu (e)
Fig. 8-5b

Species Presence, Waimanu (f)
Fig. 8-6

Species Presence, Northern Valleys (a)
Species Presence, Northern Valleys (b)
Fig. 8-8

Species Presence, Northern Valleys (c)
Fig. 8-9

Species Presence, Northern Valleys (d)
Fig. 8-10

Species Presence, Northern Valleys (e)
Species Presence, Northern Valleys (f)
and notably scarce in others. Frequency distribution is discussed valley by valley at this point for purposes of clarity.

Waimanu Valley (Figs. 8-1 to 8-5)

Guava, *kukui*, *noni*, and *ti* are abundant in most transects and show no clear patterns of distribution using the transect as the scale of analysis. Most other species are distinguished by presence on either the east or the west side, or less commonly, in either the inland or the seaward portions of the valley. The breadfruit, rose apple, *hau*, *Melia*, coffee, and mango were all sampled exclusively on the western side, while *mamaki* was sampled only on the eastern side. *Hala* and papaya were present more often in the seaward transects, while *'ohi'a 'ai* was found more commonly inland. Avocado, fan palm, lipstick, *Pluchea* and the lemon were rare, but also were found exclusively on the western side of Waimanu.

Honokane Iki Valley (Figs. 8-6 to 8-11)

Small and narrow Honokane Iki does not possess the range of environmental conditions found in Waimanu, and the maps of species frequency reflect that monotony. However, certain rare species were sampled only in Honokane Iki: the green-stemmed giant bamboo (also present but not sampled in Waimanu), and two introduced ornamentals, *Chrysophyllum cainito* and *Brassaia actinophylla*. *Canthium odoratum*, a native species moderately common in the uplands, was
sampled here and also in one quadrat in Pololu Valley. Honokane Iki is also notable for its absence of coffee, a plant common in all other valleys.

Honokane Nui Valley (Figs. 8-6 to 8-11)

The seaward fringe in Honokane Nui showed few signs of recent disturbance and was thus, unlike the beachfronts in all other valleys, judged suitable for sampling during the fieldwork portion of this study. The common strand trees ironwood and kamani were present in several transects. Rose apple, *Schinus*, *Pluchea*, and mango appear somewhat more widespread in Honokane Nui than in other valleys, and 'ulu somewhat less.

Pololu Valley (Figs. 8-6 to 8-11)

Much of the lower half of Pololu Valley is disturbed by cattle and pig-raising operations, and no transects were laid out in these areas. Because of this situation, the dichotomy between inland and seaward portions so apparent in Waimanu is difficult to observe in Pololu. The east-west distinction is somewhat clearer, but here it involves different species, *Dombeya walichii* and hau, both of which are concentrated on the eastern slopes. The rare indigene *Charpintiera obovata* is represented only on the west side, but during reconnaissance it was seen in equal if small numbers in side-gulches on both sides of Pololu.
Unusual Vs. Common Species

The bivariate analyses to be encountered in Chapter 11 employ data concerning the common species, because they supply larger samples. However, it is worthwhile to summarize some of the facts pertaining to the more localized or uncommon species at this point. The data concerning these plants also serve as markers, if less tractable to inferential analysis than might be desirable.

In particular, the abundance of sites containing 'ulu, avocado, mango, and papaya in Waimanu; mango, java plum, Schinus and rose apple in Honokane Nui; and 'ulu in Pololu is noteworthy. The absence of coffee in Honokane Iki also merits renewed mention. The isolated groves of relatively unusual trees such as mango, Melia, Chrysophyllum, lemon, Brasaiia, and Bixa are of interest. The locational patterning of isolated trees of papaya, ti, and Charpentiera, which tend to occur in transects near the cliffs, also deserve a note. The significance of the distribution of frequency data concerning all these species is highlighted and discussed in Chapters 10 and 11.

Species Dominance

Frequency data by itself reveals only whether a species is present or absent; an idea of the general importance of this species in an area is gained through the addition of density and cover information. The individual measures of dominance - density, cover, and frequency -
produce different dominance rankings in any vegetation community. Density is based strictly on the numbers of individuals and tends to highlight the more diminutive species that cluster densely, or species with many juveniles. Cover, whether calculated by stem number, crown area, or as in this study, by trunk area at breast height, favors large trees. Frequency figures reflect a bias towards representing species whose individuals are widespread, as distinguished from numerous or large.

The frequency, density, and cover rankings for the pooled group of quadrats in the Kohala Valleys illustrates these distinctions (Table 8-2).

<table>
<thead>
<tr>
<th>DENSITY</th>
<th>COVER</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guava</td>
<td>5700</td>
<td>Kukui</td>
</tr>
<tr>
<td>Ohia ai</td>
<td>1441</td>
<td>Guava</td>
</tr>
<tr>
<td>Kukui</td>
<td>1376</td>
<td>Ohia ai</td>
</tr>
<tr>
<td>Noni</td>
<td>1032</td>
<td>Noni</td>
</tr>
<tr>
<td>Coffee</td>
<td>530</td>
<td>Mango</td>
</tr>
<tr>
<td>Hau</td>
<td>359</td>
<td>Hau</td>
</tr>
<tr>
<td>Schinus</td>
<td>262</td>
<td>Hau</td>
</tr>
<tr>
<td>Ti</td>
<td>202</td>
<td>Ulu</td>
</tr>
<tr>
<td>Java Plum</td>
<td>184</td>
<td>Melia</td>
</tr>
<tr>
<td>Hala</td>
<td>166</td>
<td>Java Plum</td>
</tr>
</tbody>
</table>

Density values represent number of individuals, cover values represent square centimeters of trunk at breast height, and frequency values represent number of quadrats inhabited by species.

Table 8-2
Top 10 Species by Density, Frequency, and Cover

Guava is dominant in both density and frequency, while kukui is the dominant species in terms of cover. These two species jointly account for over 59% of the individuals,
and almost 68% of the cover value. Guava is present in almost 76% of the transects, while kukui is present in over 66%. Guava and kukui are clearly the dominant species in the valleys, although not necessarily in each area. Two other species are of secondary importance: 'ohi'a 'ai and noni. Jointly they account for over 20% of the individuals and almost 12% of the cover value. All other species have density and cover values of less than 4%.

The differences among species in the three rankings are partially explained by size and growth habits. Guava, coffee, 'ohi'a 'ai, and ti are small species that tend to cluster and produce many surviving juveniles, yielding high density values. Several trees represented almost exclusively by large, often senescent individuals are mango and Melia. It is a testament to the size of these species that they figure so prominently in cover values, since they are represented in the 554 quadrats by only 18 and 10 individuals respectively.

The Importance Value as a Measure of Dominance

The term dominance has often been equated with cover (Mueller-Dombois and Ellenberg 1974:95), but Grieg-Smith maintains that a better definition of a dominant species is "the species which exerts the greatest influence on other species in the community and is influenced least by them" (1957:4). Clearly, a wider assessment of dominance is called for under this definition.
This chapter examines the distribution of valley trees in terms of the three principal measures of dominance (density, cover, and frequency), and summarizes them into two variables to facilitate analysis. Each of the three measures is considered ecologically important, and any one alone does not adequately substitute for the other two. Curtis (1959) developed the concept of an "Importance Value" for comparing species abundance among different areas sampled by many quadrats. This value weights each of the three measures equally by comparing the density, cover, and frequency values of each species to those of all species in the area. The importance value is thus a measure of a species' relative, rather than absolute, presence in an area. This investigation adopts and modifies the importance value. Species dominance in individual quadrats has been summarized by a variable called predominance (PRE) in this thesis. Predominance has been calculated in this way:

\[
\text{PRE for species } X = \left( \frac{\text{density sp. } X}{\text{density all species}} \right) + \left( \frac{\text{cover value of sp. } X}{\text{cover value of all species}} \right) / 2 \times 100
\]

The values range from 0 to 100 and may be interpreted roughly as percent dominance. For larger areas, which are composed of many quadrats, the dominance measure can incorporate frequency data. It is called in this thesis the importance value (IV), and is calculated identically to the importance value of Curtis:
IV species \( X = \)
\[
\frac{\text{density sp. } X}{\text{density all species}} + \frac{\text{cover value of sp. } X}{\text{cover value of all species}} + \frac{\text{frequency of sp. } X}{\text{frequency of all species}} / 3 \times 100.
\]

The predominance variable is used in comparisons of individual quadrats; the importance value serves for comparisons among areas. Both measures may be considered equivalent to dominance, and the terms are used interchangeably.

The relative rankings of the various species on the importance value (Fig. 8-12) correspond well to the rankings on the three independent measures of dominance (Table 8-2).

**Fig. 8-12**

**Principal Species by Importance Value**
Distribution of Predominance Values

The dominant species as determined by the predominance measure (Figs. 8-13 to 8-18) show a distribution that mirrors that of the frequency values considered above. Again, the situation is discussed valley by valley for reasons of clarity.

Waimanu Valley (Figs. 8-13 to 8-15)

Kukui and guava are overwhelmingly the dominant trees in Waimanu Valley. Kukui is particularly prevalent in the lower west side of Waimanu, while guava predominates on the east side and in the inland half of the valley, beginning with the first major side gulch on the west side, Waiilikahi Stream. In those transects in which both kukui and guava are dominant in one or more quadrats, kukui tends to be more commonly dominant in the cliffward, steeper quadrats.

In the back of the valley ʻohiʻa ʻai is also well represented. Noni is found primarily on the lower west side, along with coffee. The other dominant species are only sporadically represented. Of interest are the groves of kamani, avocado, mango, Bixa, and mamaki depicted on the maps by one or a cluster of symbols. It must be reiterated that a map derived from a relatively small number of sample points cannot pretend to represent fully the vegetational makeup of a region. Nevertheless, on the basis of
Fig. 8-13

Dominant Species, Waimanu (a)
Fig. 8-14

Dominant Species, Waimanu (b)
Fig. 8-15

Dominant Species, Waimanu (c)
Fig. 8-16
Dominant Species, Northern Valleys (a)
Dominant Species, Northern Valleys (b)
DOMINANT SPECIES

S — SCHINUS
H — HAU
P — PAPAYA
U — ULU
I — IRONWOOD
Y — CHRYSOPH.
K — KAMANI
J — JAVA PLUM
X — PLUCHEA
R — ROSE APPLE
M — MANGO
O — BAMBOO

Fig. 8-18

Dominant Species, Northern Valleys (c)
intensive reconnaissance, the author can testify that the
distribution on the map reasonably displays the true
distribution of these species.

Honokane Iki (Figs 8-16 to 8-18)

Guava and *kukui* do not constitute the dominants of the
majority of quadrats here as they do in other valleys.
Guava is concentrated in the central lower area of the
valley, while *kukui* is more prominent in the higher and
steeper upper valley, along with *'ohi'a 'ai*. Only a few
other species are dominant in any quadrat, including
*Schinus* and two other species. The quadrats dominated by
*ulu* and the giant bamboo are parts of two large groves of
these species, which are mostly absent elsewhere in the
valley.

Honokane Nui (Figs. 8-16 to 8-18)

*Kukui* is not common in Honokane Nui, and most quadrats
are dominated by guava. In the lower quarter of the
valley, two species of *Syzygium*, the rose apple and the
java plum, replace the guava as the dominant species. On
the strand, ironwood and *kamani* are important. In several
quadrats which extend partially into the wide streambed,
*Pluchea* dominates. The widespread mango achieves dominant
status in several mid-valley transects, but its importance
in Honokane Nui as a whole was probably under-estimated by
the sampling.
Pololu Valley (Figs. 8-16 to 8-18)

Guava and *kukui* are again the dominants in Pololu. As in Waimanu, the steeper, shadier, cliffward, and more inland quadrats appear more likely to be dominated by *kukui*. Among other species, a cluster of hau-dominated quadrats is prominent, along with the *ulu* grove at the top of the valley. *'Ohi'a 'ai* is consistently dominant in some of the shadier side-gulches and in the narrow upper valley. The miscellaneous species that dominate the scattered remaining quadrats do not reveal any obvious geographical pattern.

Variation in Importance Values Among Areas

The fifteen areas in the four valleys exhibit different patterns in species dominance rankings when species with importance values greater than 5% are compared (Fig. 8-19). In general, *kukui* and guava dominate. Guava is the dominant in eight of the areas, and *kukui* in four. The second-ranking species is either guava or *kukui* in nine of the areas. In only one case, Area 8, is neither guava or *kukui* among the top two species. Area 8, along with Area 10, which is dominated by *'ohi'a 'ai*, have species abundance patterns significantly distinct from the other areas.

Several species have distributions that merit emphasis. *'Ohi'a 'ai* has importance values of over 15% in Areas 2, 3, 6, 10, 14, and 15, i.e., in the rear of valleys
Fig. 8-19

VALUES, AREAS 1-3

IMPORTANCE VALUE

AREA 3

SPECIES PERCENT

IMPORTANCE VALUE

AREA 2

IMPORTANCE VALUE

AREA 1

IMPORTANCE VALUE

IMPORTANCE VALUES. AREAS 1-3

SPECIES PERCENT
Fig. 8-19b
Fig. 8-19c
Fig. 8-19d
Figure 8-19e

Importance Values, Areas 13-15

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>PERCENT</th>
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<tbody>
<tr>
<td>A: KUKUI</td>
<td>49.28</td>
</tr>
<tr>
<td>B: HAU</td>
<td>14.90</td>
</tr>
<tr>
<td>C: GUAVA</td>
<td>13.60</td>
</tr>
<tr>
<td>D: OHIA AI</td>
<td>7.70</td>
</tr>
<tr>
<td>E: TI</td>
<td>5.90</td>
</tr>
<tr>
<td>F: NONI</td>
<td>2.90</td>
</tr>
<tr>
<td>G: OTHER</td>
<td>2.90</td>
</tr>
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</table>

Area 13

Importance Value

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: GUAVA</td>
<td>46.28</td>
</tr>
<tr>
<td>B: KUKUI</td>
<td>27.00</td>
</tr>
<tr>
<td>C: OHIA AI</td>
<td>12.12</td>
</tr>
<tr>
<td>D: OTHER</td>
<td>6.60</td>
</tr>
</tbody>
</table>

Area 14

Importance Value

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: GUAVA</td>
<td>39.40</td>
</tr>
<tr>
<td>B: KUKUI</td>
<td>22.50</td>
</tr>
<tr>
<td>C: OHIA AI</td>
<td>21.80</td>
</tr>
<tr>
<td>D: OTHER</td>
<td>6.30</td>
</tr>
</tbody>
</table>

Area 15

Fig. 8-19e
and in Honokane Iki. In these areas, shade and steepness are possibly important factors. Hala is also abundant in Honokane Iki. Coffee is quite abundant in Honokane Nui, especially on the eastern side. Hau has importance values of over 10% in Areas 5 and 13, which lie in inland sections of the larger valleys. Kukui shows relatively low values in Honokane Nui, which could be associated with the high sun and low moisture prevalent in the broad but relatively inactive central stream section. The ti plant has importance values of over 10% in only Area 12, which has a narrow, steep talus slope. The uneveness of the distribution of importance values in these species suggest that various environmental and historical conditions may help explain the identity of the dominant species in individual quadrats.

**Species Richness**

Richness values vary throughout the valley region from a minimum of zero to a maximum of seven species per quadrat (Fig. 8-20). These values show a patterned geographic variation, detectable on a map of the entire valley region on a quadrat-by-quadrat basis (Figs. 8-21 and 8-22). The most obvious pattern, discernible in inland and seaward areas of all valleys, is the tendency of the cliffward quadrats to exhibit higher richness values. It also appears more likely for inland rather than seaward areas to have high values. These patterns suggest that the
environmental variables DSE, SLO, and SEC should be evaluated for relationships with species richness.

Richness value means if the fifteen areas range from a minimum of 2.16 to a maximum of 3.75 per quadrat. This range is rather low. In order to ascertain whether the means of the populations represented by these samples truly differ, the 95% confidence intervals for the means were calculated (Fig. 8-23). Although the limits of the means in some of these areas overlap, two general groups are fairly separable. Areas 1, 3, 4, 5, 10, 11, and 12 each have average richness that almost certainly exceed 3.0, while the other areas (except 2, 6, and 13, which have very wide confidence intervals and cannot be categorized) most likely have values well below 3.0. The highly rich areas
Fig. 8-21

Richness Values, Waimanu
Fig. 8-22

Richness Values, Northern Valleys
comprise most of Pololu Valley, Honokane Iki, and lower Waimanu. Upper Waimanu and Honokane Nui seem to possess distinctly less rich local assemblages.

**Summary**

A total of 33 species were counted in 554 quadrats established in the 4 Kohala valleys under study. As is normal in natural communities, the species were not equally represented, nor were they evenly distributed. The abundance of any given species varies as a function of valley, or at a finer scale, of area, and also shows patterning that suggests links between factors pertaining to the environment and historical land use. Two aspects of pattern in the Kohala vegetation worthy of further examination are the environmental/historical response characteristics of the more abundant species, and the locational character of the rarer species.

Studying relationships in a data matrix consisting of hundreds of observations and scores of variables has been simplified by an iterative process of information reduction. The first step in this reduction has been to narrow the focus of study to a subset of the species, and to streamline the battery of species abundance parameters. Richness and frequency have been retained intact, while density, cover, and (to some extent) frequency have been combined in two joint measures of species dominance, the importance value and predominance.
The variation in predominance values of the principal species and in richness values among quadrats is the springboard for much of the analysis contained in Chapter 10. The associations of abundant guava with low-slope and high richness values with high-slope are two of the most apparent environmental relationships that merit investigation. Rare species are more difficult to associate with environmental or historical factors in a mathematical analysis because of computational problems associated with many zero values. Qualitative explanations linking the idiosyncratic distribution of species with unique historical information also provide a valid and valuable mode of analysis. Chapter 11 relates the information on the frequency maps to the data of historical land use.

Fig. 8-23
Richness Value by Area, Confidence Interval
CHAPTER 9
GEOGRAPHICAL DETERMINANTS AND INTERACTION PATTERNS
OF TYPICAL HAWAIIAN LOWLAND VEGETATION

The distributional patterns of species present in the ribbon forests of the valleys of Kohala have been outlined in the previous chapter. Subsequent chapters explore the relationships between environmental and historical factors and the vegetation parameters just described. To best interpret these distributions requires a knowledge of the habitat preferences of each species. Systematic studies in this area do not exist, but other works detailing plant geography in the Hawaiian Islands, both past and present, do contain useful information. These sources also elucidate the human element in propagation, which should not be ignored. Also, a review of the possible patterns and determinants of species interaction taking place in the valleys helps explain associations among species. In this chapter, habitat preference information concerning individual species is presented, along with a statement of how the actual distribution patterns in the Kohala valleys depart from ideal distributions. Next, an assessment of the most prominent interspecific interactions that seem to occur in Hawaiian lowland forests is presented. Finally, several hypotheses concerning the relationships between environmental factors and species abundance parameters are offered.
Species Habitat Preference

1) Guava. The guava tree in the Hawaiian islands had become so common by the mid-20th century that a biogeographical classification of that era included closed and open guava woodlands as two of the ten vegetation zones (Ripperton and Hosaka 1942). If anything, guava has expanded its range since then. It can become dominant in areas with annual rainfall as low as 1000 mm and as high as 10,000 mm. Its elevational range extends from sea level to roughly 1500 m. Guava forms dense thickets in some areas, and open parkland in others. It flourishes in soil that is well-drained to flooded, in areas that are flat to steep. It is intolerant to shade, however, and is often absent in narrow ravines or under the canopy of large trees. Fruit is harvested from wild trees in some areas for preserves and juice on a household or commercial basis. Most fruit simply drops below the tree. Birds such as the Chinese dove, mynah, rice bird, and sparrow consume the fruit and readily scatter seeds in their droppings. Goats, pigs, and cattle also consume guava, and animal dissemination helps explain the rapid expansion of the guava on cleared land (MacCaughey 1917b). A close relative of the common guava is the wai‘awi, Psidium cattleianum, which is also widespread and prefers much the same habitat as its larger cousin. Guava is as widespread in the valleys as it is elsewhere in Hawaii. The distribution maps reveal that it
is somewhat more common in flat sites near the marsh or on the flanks of streambeds.

2) **Kukui.** This tree is common in all Hawaiian windward valleys, and is noteworthy for forming a line along streambeds and in narrow ravines (Wester 1983:110), and in sheltered glens (Lydgate 1884:30). Purposefully planted by Hawaiian in groves (Krauss 1974:n.p.), the **kukui** also spreads rapidly along the course of streambeds and down cliffs because of its large, roundish nut. The use of **kukui** for medicine, food, and lamp oil was common in rural districts of Hawaii until the 1860’s. During the early 19th century, **kukui** oil was a valuable export commodity, primarily to Russian American settlements, further encouraging the species’ growth (Degener 1930:199). Since the mid-19th century, the use of **kukui** has declined, and most of its propagation has been of the natural variety. In the valleys, the abundance of **kukui** seems to vary greatly from place to place, for reasons that defy cursory appraisal.

3) **Noni.** Another prominent Polynesian import, the **noni**, prefers fairly dry, low elevation habitats (MacCaughey 1918a). Degener noted in 1930 that "it now grows chiefly near abandoned native dwellings." In a small monograph on the genus **Morinda** written in 1918, MacCaughey opined that the **noni** had probably been much more abundant formerly than at present, owing to its former culture by Hawaiians for dye and food. **Noni** is distributed in the
Kohala valleys fairly evenly, although seemingly with more abundance in well-drained sites.

4) 'Ohi'a 'ai. The 'ohi'a 'ai has flourished in the same sheltered, shady habitats of narrow, windward ravines for probably a millenium. Although it is presently cultivated around homes in full sun, it tends to be absent from such locations in the wild. It forms dense, often monospecific stands on all islands. Hawaiians considered it a wild plant, and reportedly gathered its fruits wherever it happened to grow rather than establishing groves (Handy 1940:215). 'Ohi'a 'ai is found in all valleys, but with much greater abundance in Honokane Iki and the rear of Pololu and Waimanu.

5) Hala. The hala, source of innumerable products for the Hawaiian people, thrives at low elevations within several kilometers of the ocean. Krauss reported that it was propagated by seed and by cuttings, and that it was also planted near homes or elsewhere in large groves (1974:n.p.). Hala also flourished in the wild, as it does today. The system of buttresses that project from the trunk of the hala provide it with a firm footing on steep slopes, where it often exists in monospecific patches. Hala cloaks much of the cliff zone in all valleys, and is also found in steeper sections of the ribbon forest, and occasionally even in flat areas.

6) Hau. Useful for cordage in prehistoric and historic times, hau was encouraged to grow near homes and
near working areas. Handy accepted isolated hau clumps in the forest as almost indisputable evidence of native cultivation sites (1940:196). Its natural habitat appears to be poorly-drained or flood-prone areas, where it often forms dense thickets. In at least one windward Hawaiian valley, it has been noted to spread rapidly and choke out other vegetation (Kirch and Kelly 1975:14). It is now particularly prominent in many windward valleys at the interface of the marshy valley floor and the talus slope, although it may extend a good way up the slope and into the valley center as well. Clumps of hau appear in Waimanu and Pololu but are absent in the other two valleys.

7) Coffee. As noted in the chapter on historical land use, much of the coffee that was harvested in the late 19th century came from wild trees in shady locations (Whitney 1875:14). Cliffs provide a natural source of shade in windward valleys, and coffee can form dense stands near cliffs or under kukui trees. Coffee is absent in many shady, well-drained areas in the valleys where it might be expected.

8) Ti. Although ti plants still play an important role in ceremony and food preparation in Hawaii, they were even more highly utilized until the late 1800's (Degener 1930:97). Ti was planted around homes and temples, and encouraged to grow wild on the slopes. Today, the bright green leaves are highly visible on the slopes of ravines and steep hillsides throughout the windward portions of the
isles.

9) 'Ulu. Degener concluded in 1930 that the 'ulu, despite its naturalized condition, must have been introduced, since it does not propagate from seed. 'Ulu thus tends to form localized clumps when allowed to grow naturally. The Hawaiian Islands are near the poleward limits of the distribution of breadfruit, and although it flourishes in some locations, it does not become weedy. The distribution of this tree in the valleys is highly patchy.

10) Coconut. The coconut in Hawaii is another tree near the northern limits of its range. Although in equatorial latitudes it is known at moderate altitudes, coconuts appear restricted in Hawaii to low elevations. It propagates from seed most readily on the beach, but the large groves of coconuts for which the islands are famous are the result of careful tending. Inland coconut groves rarely develop naturally (Degener 1930:72). Aside from the beach at Waimanu, coconut is rare in the Kohala valleys, but several individuals in less-than-ideal inland habitats were sampled.

11) Mamaki. This mulberry relative is a native tree whose fruit was used as an emetic and whose bark was fashioned into kapa, or bark-cloth. Krauss said that it was not cultivated, but rather harvested wild (1974:n.p.). MacEldowney maintained that mamaki was indeed cultivated (1983:425), but that it also readily colonized open or
disturbed areas on its own (1976:26). She hypothesized that mamaki became more abundant after Hawaiians settled the islands and began to disturb virgin forests during gathering. It is common in clearings, active talus areas, and cliffs suffering from erosion. Mamaki is fairly regularly distributed, if uncommon, in the valleys.

12) Papaya. The ability of papaya to develop sturdy roots in a substrate of crushed rock is exploited by farmers on the Big Island, who bulldoze recent lava flows and plant papayas. This same quality seems to adapt the papaya to colonize the talus slopes of windward valleys. Hillebrand noted in the mid-1800's the tendency of papaya to appear in waste areas (1888:139). Papaya is present on the slopes of Waimanu and Pololu, but it is also concentrated in several groves in flatter areas.

13) Mango. Large mango trees are a common sight in both windward and leeward Hawaii. Commercial mango production is restricted to dry locations free from the insect problems to which the tree is quite susceptible (Neal 1965:521). Mangos can propagate in the wild from seed, but do not tend to form groves in this manner. Mango distribution is clumped and not regular in the valleys.

14) Syzygium spp. The java plum and rose apple are two closely related species forming weedy thickets in windward locations, particularly in occasionally flooded streambeds. Their fruits are eaten by birds and mammals and are also transported by water. In addition, foresters
have broadcast seeds belonging to several species in this
genus throughout the islands for reforestation purposes
(Nelson 1965:5). In Pololu, Waimanu, and Honokane Nui,
 thick groves of these species are present in some places.

15) Schinus terbinthifolius. The Christmas berry,
native to Brazil, is a weedy tree found in semi-humid
lowlands throughout the islands. Birds eat the bright-red
fruit and disseminate the plant (Neal 1965:525). Schinus
is not found in Waimanu Valley, though present and somewhat
evenly dispersed in the other three valleys.

16) Ironwood and kamani. These shore-dwelling trees
are found on the strand and rocky shores throughout
windward coasts in Hawaii. Ironwood is reported to exhaust
the soil and prevent the growth of other species nearby
(Ibid:289). They are confined in the Kohala valleys to the
immediate coastal area.

17) Melia. The Pride of India tree, Melia azedarach,
is said to be naturalized in Hawaii. It generally forms a
very large tree with weak wood (Ibid:492). Dissemination
of the small ovoid seeds is accomplished by gravity and
consumption by birds and cattle. A few individuals are
scattered in Waimanu and Pololu.

18) Lemon. The distribution of the lemon in Hawaii,
as well as other citrus trees, is probably attributable to
human action rather than natural dissemination, although
citrus can propagate by seed. Insect and fungal problems
make windward valleys less than ideal locations for citrus,
but orange trees were reported to thrive during the 19th century under the care of Hawaiians (Bird 1890:88, 98).

19) Avocado. Avocado flourishes in Hawaii in humus-rich soil in moist locations sheltered from extreme wind (Neal 1965:363). The high volume of seed production makes rapid spread of the avocado possible, but seedlings are thereby highly subject to predation by mammals. The only avocado occurrence in the valleys is a small grove in Waimanu.

20) Giant Green-stemmed Bamboo. This tree-like grass is known in both cultivated and wild states throughout Hawaii (Ibid.:62). It is a clumping bamboo, and propagates slowly from the center of the clump. It is often found adjacent to streams.

21) Weedy Species. Pluchea and Stachytarpheta are two shrubby perennials whose woody stems occasionally develop a diameter of over 2.5 cm and thus meet the criterion for a tree in this study. Both species are common in areas disturbed by grazing, and also along the interfaces of forests with coastal flats or streambeds (Ibid.:835).

22) Charpentiera and Canthium. Habitat information regarding these native species is scarce. Hillebrand noted that the latter occurred on dry, open slopes (1888:175). They are apparently relatively uncommon in the wet forest, as neither are mentioned by Carlquist in his lists of such trees (1970). Charpentiera is confined to gulches in Pololu, but the location of Canthium is less specific.
23) Other Species. There are five other species (Brassaia actinophylla, a fan palm, Cassia glauca, Bixa orellana, and Chrysophyllum cainito) that occur in just one location each in the valleys, and their habitat preferences will not be discussed. Brassaia and Cassia are both naturalized in at least some locations in Hawaii (Neal 1965:427; pers. obs.)

Species Interaction in Introduced Hawaiian Trees

In a natural environment, species abundance levels may be interpreted as the expression of the varying suitability of the component species for the habitat, as mediated through the mechanisms of interspecific interaction. Chief among such mechanisms is competition. The principle of competitive exclusion works to shape the genetic makeup of a species and the population structure of an ecosystem over millenia (Kormondy 1976:121). If the tree species present in the Kohala valleys were native and co-evolved, competition would have helped generate species adapted to distinct niches. The melanges of species in the talus forest of the valleys is a situation altogether different. Competitive exclusion occurs at a much more rapid rate, too quickly for significant adaptation at the species level. The rapid "evolution" of plant communities in these valleys is somewhat akin to secondary succession, in which the lifetimes of individual trees encompass great community change. Unlike secondary succession, however, the
development of weedy tree communities in Hawaii is less predictable. In the words of Wester and Juvik

Weedy plant assemblages in habitats heavily disturbed by people frequently display intricate patterns of variation in space reflecting the complex interaction of both cultural and natural influences...the underlying ecological relationships of a particular system may be difficult to identify or extrapolate (1983:307).

Because weedy forests in Hawaii often contain patches of human-introduced species assembled in highly idiosyncratic patterns, generalizations about their present or future composition is difficult. Conversely, these forests provide opportunities to observe on a human time-scale the operation of competition. Homogeneous emergent forests composed of introduced trees will provide examples of competition at work, should they be demonstrated to exist. Such forests seem to be developing.

Wester described the guava forest in Hawaii as highly variable but often composed of Schinus and kukui in addition to guava, with typical understories of ti, coffee, ginger, and certain forbs, ferns, and grasses (1983:107-108). Judging from the uniformity of certain portions of the guava forest in Hawaii, some convergence in species composition does seem to occur in cultural forests.

The Kohala valleys provide a unique opportunity to observe competition among a variety of species in a heterogeneous environment. The factors affecting competition are more complex than simple nutrient requirements. Some of the relationships among trees,
animals, and environmental parameters are outlined below.

An Interpretation of Interspecific Relations

Among Trees in Kohala

The elucidation of interspecific relationships among the introduced trees of Hawaii has never been attempted. What knowledge exists is based on deductions from the structure of the resulting assemblages. This section presents some observations and hypotheses concerning the individual species and the environmental factors affecting the covariation of species abundance levels in the valleys.

Of the thirty-three species sampled in the valleys, guava is the most abundant, a reflection of its competitive ability throughout the islands. It not only displaces native trees, but most introduced species as well. It is found on both inland and seaward sites, on steep and flat terrain, and flood-prone or well-drained substrate. What is most intriguing about the distribution of guava is the few habitats in which it does not achieve dominance; species composition in such sites is investigated in this thesis.

Kukui has the ability to attain a large stature, and this feature allows it to become the dominant upper-canopy tree once established. The intolerance of many other species seedlings to low solar radiation levels often leads to an understory devoid of other large trees. However, noni and ti, with their large evergreen leaves, are adapted
(as is coffee) to shady conditions and flourish at moderate to dense levels under the *kukui* canopy.

The fact that guava and *kukui* possess a competitive edge is obvious. Even in areas that were substantially clear of vegetation fifty years ago, as were the lower sides of Waimanu Valley, these trees have colonized and become dominant. More subtle factors affecting the success of these trees have to do with tree spacing, seed predation, reproductive style, colonization rates, and mammal activity.

**Tree Spacing**

Much recent attention in professional ecology has been directed towards the spacing of trees of the same species (Janzen 1970, 1970a; Forman and Hahn 1980, Whipple 1980, Clark and Clark 1984). The tendency of species to clump together in a contagious distribution has long drawn comment and attempts to quantify real-world departures from random or systematic patterns (Grieg-Smith 1957:51-84). Clumping has been attributed to micro-topographic variation (Whipple 1980), or to other features on the level of the micro-habitat (Forman and Hahn 1980). One critical factor seen to be affecting clumping is seedling predation, which is most effective around large, fertile trees. Janzen (1970a) concluded that clumped distributions are actually much less strongly expressed in tropical forests than would be expected given the seed-shadow of most species. A
developing consensus among ecologists seems to be that the tendency towards contagious distributions is mitigated by the effects of predators, particularly where seedlings become extremely dense (Clark and Clark 1984).

The research in this thesis was not directed towards describing the geometrical spacing of trees, and the heterogeneous ribbon forest makes this sort of analysis difficult. Nevertheless, aggregation in species such as 'ohi'a 'ai and guava is apparent on the frequency and dominance maps of the previous chapter. There are several species in the valleys that reproduce primarily by vegetative means, including the'ulu and banana. The distribution of these species is understandably clumped, although in the case of 'ulu, the runners fostering new shoots are often tens of meters long. It is possible that clumping in these species poses a disadvantage as regards predators. The effects of predation on seeds or seedlings of any species in these valleys has not been investigated. Differential preference by insect predators may be in part responsible for the variation in success of the many species. The interaction of habitat type, seed shadows, and predation is undoubtedly a complex affair in Hawaiian valleys.

Colonization Rates

Rapid colonization is a characteristic of pioneer species, which are often maintained in mature ecosystems by
virtue of rotating patches of disturbance (Long and Knight 1983, Putz 1983). One of the apparent attributes of guava is its ability to quickly establish itself in an area.

The banks of actively shifting streambeds in Pololu are often exclusively inhabited by guava, which arrives first and maintains dominance until the bank collapses and the process is renewed. Some other disturbed valley environments are not inhabited to any great extent by guava. The species found in these habitats may be less relics of human presence than efficient colonizers. In particular, the presence of papaya (Fig. 9-1) and mamaki on very steep talus slopes, and the presence of hau in areas subject to frequent and lengthy inundation, are perhaps examples of the serendipitous adaptation of an introduced plant to a disturbed environment.

Mammal Activity

One final aspect of competition among species in the valleys is disturbance by mammals. Pigs and rats are present in all valleys, and cattle roam Pololu. The extinction of banana by free-roaming donkeys in Honokane Iki has already been mentioned. According to Handy, rats were responsible for the spread of much of the wild taro he observed in windward Hawaii (1940:8). Cattle in Pololu crop noni trees to about one meter in height, and are probably the principal factor affecting noni distribution there. By far the most influential mammal in terms of its
Fig. 9-1

Papaya-colonized Slope
effect on vegetation is the pig, which is both numerous and active. A study of the stomach contents of Hawaiian pigs, which happened to be conducted on specimens from Waimanu and Honokane Nui valleys, found that guava accounted for 70% of the weight. Papayas, noni fruit, kukui nuts, passion fruits, and grasses were also present, along with sundry inverterbrates (Giffin 1977). The effect of the rooting of pigs in the soil beneath the aforementioned species undoubtedly contributes to the increase of those trees. In the native forest, pigs fell tree ferns to obtain starch inside the trunks, and they have thus diminished the numbers of these ferns (Mueller-Dombois, Bridges, and Carson 1981:310). Pigs may inflict similar destruction on introduced species in the Kohala valleys through rooting, wallowing, and seedling predation. The net effect of pig activity on different species is difficult to assess.

Species/Environment Hypotheses

The correspondence or conflict of species distribution patterns as described in the botanical literature of Hawaii and as encountered, sampled, and mapped in the Kohala valleys in this thesis has stimulated the formulation of several hypotheses.

1) The mapped range of guava in Hawaii shows almost universal presence in the lowlands. In the Kohala valleys, a distinct affinity of guava for certain habitats was
observed. Hypothesis: Guava is more abundant in lower-sloped, poorly-drained sites than in steep, well-drained sites.

2) The habitat of the naturalized 'ohi'a 'ai is reckoned to be shady, steep gulches. Hypothesis: Steeper sites closer to the cliff are more likely to contain abundant 'ohi'a 'ai.

3) Papaya appears to naturalize in many locations in Hawaii on steep slopes, although flat sites also contain remnant papaya groves. Hypothesis: Papaya abundance shows a positive association with slope.

These hypotheses are addressed in the next chapter, along with similar tests for other species on the same environmental factors.
CHAPTER 10

SPECIES ABUNDANCE AND THE ENVIRONMENT

Introduction

The two previous chapters have outlined the distribution of species abundance parameters in the Kohala valleys and provided information on the general habitat preferences and expected locations of the species present in the valleys. During these descriptions several hypotheses concerning species abundance parameters and the environment were suggested. Specifically, such conditions as high slope, periodic flooding, distance inland, and distance to the cliff seemed to be associated with species composition and richness. Because many different combinations of environmental conditions were expressed in the sampling quadrats, clear patterns of environmental control were impossible to assess directly. However, the sample data can be employed in inferential tests to verify hypotheses. This chapter describes the formulation of species abundance/environment hypotheses, the transformation of the data, and the design of statistical tests to explore such relationships.

Linking species abundance and environmental data serves two purposes. First, species distribution can be partially explained as a function of environmental control. Where such explanations do not succeed, it may be
appropriate to attempt to explain distribution by resort to the facts of historical land use. This approach is rather naive in some ways, for the obvious reason that no combination of four simple environmental factors such as the slope, drainage, and the two distance measures used here can ever encompass the full range of environmental control. Indeed, many of the causal mechanisms behind vegetation pattern remain obscure in this study as well as in most vegetational work. Nevertheless, a great deal of variation can be explained by testing with simple factors, leaving a residual that is often easier to interpret.

The Need to Reduce The Number of Variables

The number of potential statistical relationships to be examined in a data set composed of fifteen sampling areas, four independent variables and several hundred response variables is astronomical. Part of the accomplishment of describing the distribution patterns and habitat preference patterns of the species has been to narrow the field of interest by formulating specific hypotheses. The variation of guava and 'ohi'a 'ai abundance with slope and drainage factors, and richness values with slope and cliff distance, have emerged as particularly prominent. However, other less obvious relationships also merit exploration. As a compromise between wholesale hypothesis-testing and unduly restricted analysis, this chapter reduces the scope of concern to ten
species (guava, kukui, 'ohi'a ai, noni, hala, hau, coffee, ti, 'ulu, and papaya) in four specific geographical areas. The variation in richness values and in predominance values for each species are the vegetation variables under consideration.

Revised Geographical Areas

Because only portions of the valley region were sampled, a valid statistical picture of the entire ribbon forest is not available. Furthermore, the pronounced heterogeneity of the individual areas makes examination of subdivisions of the valley representing discrete and somewhat homogeneous units desirable. However, many areas contain only a small number of samples, making multivariate or even bivariate analysis troublesome. For these reasons, the geographic area of concern for the purposes of testing species abundance hypotheses has been reduced to four areas each composed of one or two of the original sampling areas: Honokane Iki Valley (Area 10), Lower Honokane Nui Valley (Areas 7 and 8), Lower West Waimanu Valley (Area 11), and East Waimanu (Areas 12 and 15) (See Fig. 7-2 and Table 7-1). These areas are each discrete, geographically meaningful units with medium to large (32 to 104) numbers of sampling quadrats. Conclusions made in this chapter are apt only for the specific areas from which they have been made, and cannot be validly applied in other areas or concerning the region as a whole. The nature of
relationships among factors of environment and species abundance does, however, shed light on the processes operating in all the valleys, and indeed, in Hawaii in general.

**The Correlation of Predominance and Richness With Environmental Variables**

Insight into the general variation of species abundance is provided by examining the correlation matrix of abundance and environmental factors (Table 10-1). The predominance values for the top eight species in terms of importance value in the valleys (Fig. 8-1) were correlated with the ordinally-valued environmental factors using Spearman's rank-order correlation method.* The figures provided in the table are derived from all 554 quadrats in the valleys. Because sampling areas differ in many respects, the relationships that emerge from a joint analysis may not be true of individual areas, which may have reverse tendencies in some cases.

Several general trends are evident. First, the association of species richness (RIC) with slope (SLO), drainage (DRN), and distance to cliff (SEC) is noteworthy. Quadrats that are closer to the cliff, steeper in slope, or well-drained tend to have higher richness values. Note

*DRN, the assessment of drainage conditions, is a dichotomous variable and is thus not ideally suited for Spearman correlation. The method is actually robust enough, however, to yield meaningful results when only one variable has a low number of levels, as in this case.
**Table 10-1**

<table>
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<th>VEGETATION</th>
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<th>SEC</th>
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Correlation method is Spearman's rank-order.
R is coefficient of correlation.
P is significance probability.
N=554.
that the table reveals only bi-variate relationships, and
that higher order interaction among the independent
variables is not accounted for.

Guava predominance climbs with distance to the sea,
distance to the cliff, poorer drainage, or decrease in
slope. *Kukui* predominance displays almost precisely the
opposite pattern. Distance to the sea, proximity to the
cliff, high slope, and a non-flooding environment
contribute to increase in the predominance of *'ohi'a 'ai*.
Noni shows similar associations, but the correlation
between proximity to cliff and predominance is not so
strongly expressed. *Hala* predominance values tend to
decrease with distance to the sea and distance from the
cliff, and to increase with slope. Ti also seems to show
the highest values in high slope or near cliff
environments. *Hau* and coffee values show no clear
patterning in relation to these environmental factors (at
least when the areas are considered together). This of
course does not imply that environmental gradients
influencing abundance of these two species are lacking in
the valleys, only that either such gradients went
unmeasured in this study, or that disturbance has
interfered with the species' tendencies to vary in
abundance in response to the measured factors.

The high correlations of species abundance parameters
and environmental factors makes it interesting to examine
intercorrelation among the independent variables (Table
Drainage (value 2 of DRN indicates tendency to flood, value 1 is opposite) appears highly associated in a positive direction with SEC, and negatively with SLO. In other words, quadrats that flood are more likely to be located away from the cliff and on sites with low slopes. DSE is somewhat independent from SLO and SEC, more so from SEC than from SLO. SLO and SEC are highly negatively associated, which is a natural consequence of having steep talus deposits near the cliff. However, the existence of medium and even low slope sites near the cliff merits the retention of both variables. Considering the four independent variables, some combinations of levels are more likely to have high frequencies (i.e., more quadrats) than others. For example, high slope/far from sea/near the

### Table 10-2
**Intercorrelation Among Environmental Variables**

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</table>

Correlation methods is Spearman’s rank-order.
R is coefficient of correlation.
P is the significance probability.
N=554.
cliff/no flooding is a more likely combination than low slope/far from sea/near cliff/periodically flooding. However, no combination is impossible, and thus no variable is redundant. Since each variable contributes information, they were all retained for further analysis.

Creating a Data Matrix of Categorical Variables

Bivariate correlation analysis on the entire data set provides an initial set of clues as to the relationships among a set of variables. A natural extension of such analysis when working with interval-level data from a somewhat normal distribution is to fit a multivariate regression model that identifies the parameters and variances associated with each independent variables as it regresses on the dependent variable (Steel and Torrie 1980:74, SAS Inst. 1985:7). However, the nature of the data in this analysis makes such an extension inadvisable. The predominance values contain many sampling zeros and are highly positively skewed, making any predictions concerning the precise numerical value highly inaccurate. In any event, the independent variables in this thesis are at an ordinal or nominal scale, and are thus unsuitable for regression, which works best with interval-level data. Therefore, a method of analysis that accounts for the properties of such data is called for.

A family of techniques developed around the analysis of contingency tables tests for the independence of the
frequencies of occurrences of one phenomenon measured at various levels with the frequency of occurrences measured on the various levels of another phenomenon. Such techniques are primarily designed to analyze nominal variables with a small number of levels or categories and high frequencies in each cross-classified category (Mattson 1981:168-169). Some techniques are able to accommodate higher numbers of categories each containing low cell frequencies (Ibid.:184). Multivariate categorical methods, however, usually function best with cell sizes greater than at least five (SAS Inst. 1985:205). Hence, an analysis dealing with three variables with four levels each and no structural zeros requires a minimum practical sample size of one to two hundred. These requirements have prevented the application of multivariate categorical hypothesis-testing in this thesis. Nevertheless, because of the mixture of interval, ordinal, and nominal variables in the Kohala data set, categorical data analysis is quite fitting. Bivariate contingency methods such as Pearson's chi-square can test hypotheses in data with the magnitude of sample sizes encountered here. Multivariate contingency tables can also be constructed, and their information, despite the inability to test hypotheses, is instructive. Some transformations and modifications of the data have been undertaken in order to take full advantage of the ability of these techniques to detect and test associations.
Transforming Data For Optimal Use With Categorical Methods

The limited sample sizes in each area posed a problem in terms of generating categorical cells with fairly high frequencies. One way to solve this problem is to reduce the number of levels on which a variable is measured. Such an action requires caution so that information content and comparability are not unnecessarily lost. The procedure of category reduction thus cannot be done arbitrarily. One goal of the transformation is to render marginal totals (i.e., the number of observations at each level of a variable) roughly even. This was accomplished by examining the distribution of values for each individual variable in each area independently, and partitioning the values of the refined categorical variable somewhat equally among the new levels. For example, in Waimanu East, the distribution of values in the variable SEC (distance to cliff in units of quadrats), which originally possessed five levels, was 16-11-9-8-5, counting from level one to level five. The new distance-to-cliff measure, SEC2, preserved level one, and combined levels two and three for new level two, and level four and five for new level three. This yielded a sequence of 16-20-13 for levels one, two, and three respectively. The information content of the variable was thus slightly reduced, but the potential power and validity of the association tests to be performed using this variable were increased. The basic premise of the variable, a measure of distance from the cliff, was
unaltered. Note, however, that the recombination of levels was unique to Waimanu East, and each area had a data distribution that required a unique restructuring. Thus, the design of better categories entailed a sacrifice of the ability to compare areas.

Just as the independent environmental variables were transformed, species abundance data was also converted to a nominal/ordinal scale. The transformation of the richness values to a reduced number of levels was relatively simple because they already happened to be discrete integers from zero to seven. The predominance value was more difficult to convert, since it was distributed at an interval scale with values ranging from 0 to 100%. The same principle of deriving a variable with two or three levels containing roughly equal numbers of values was followed. In some cases, this partitioning resulted in a variable whose lower value encompassed all the zeros and whose upper level included all values greater than zero. This, in effect, amounted to a measure of presence or absence, and in such cases, the frequency value was substituted.

In sum, the mixture of interval, ordinal, and nominal level variables was reduced to a uniformly nominal collection of variables (some of which still preserved their ordinal organization), each with two or three levels. The original variables and those resulting from the transformation are listed in Table 10-3.
Species/Environment Hypotheses in Individual Areas

It is useful to summarize the preparatory steps that were undertaken before species/environment hypothesis testing could proceed. First, using the data of cover, frequency, density, predominance, and richness, predominance values for ten species and richness were selected for analysis. Second, several areas of interest were defined. These were subsets of the original data, subsets that were geographically meaningful, sampled uniformly, and composed of sufficiently large sample sizes. Finally, the data were transformed from a mixture of nominal, ordinal, and interval level data to few-level categorical data, allowing fairly powerful statistical tests of association free from the distributional and data-level assumptions common in many other testing techniques.

For each area, a series of tests of hypothesis was conducted using the full battery of environmental variables against richness (RIC2), the most abundant species’ predominance values ([SP]PRE2), and sometimes, with a
frequency variable for a species absent in most quadrats but having a high total importance value in the area. The purpose of these tests was to establish whether variables were independent or whether the values of one variable could be partially predicted with knowledge of the values of another. Hypotheses were tested using the Pearson's chi-square and Mantel-Haenszel chi-square routines available in the SAS statistical analysis programs (SAS Inst., 1985). Both techniques test independence, but the latter is more powerful at detecting directional relationships in ordinal data with three or more levels.

Each area is discussed individually, and a table accompanies each discussion (Tables 10-4 to 10-7). The rows of the table are occupied by vegetation variables, and the columns are occupied by environmental variables. Each cell in the table presents the outcome of a test of hypothesis:

Ho: The frequency of values at the various levels of Vegetation Variable X are independent of the frequency of the values at the various levels of Environmental Variable Y.

The outcome was judged to be positive, i.e., the null hypothesis is confirmed, if the two-tailed level of probability for Type I error was greater than 5%. If such is the case, then the cell is marked "Y", and no further information is presented in the cell. If an entire row or column showed no significant associations, then that row or
Table 10-4 Honokane Iki
Outcome of Species/Environment Tests of Hypotheses
### Table 10-5 Honokane Nui

**Outcome of Species/Environment Tests of Hypotheses**

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\[ S = 6.1 \quad P = 0.048 \]

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\[ S = 6.0 \quad P = 0.050 \]

**Table 10-6b Waimanu East**

*Outcome of Species/Environment Tests of Hypotheses*
Table 10-7a  Lower West Waimanu

Outcome of Species/Environment Tests of Hypotheses

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### Table 10-7b Lower West Waimanu

**Outcome of Species/Environment Tests of Hypotheses**

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Table 10-7c Lower Waimanu Valley
Outcome of Species/Environment Tests of Hypotheses
column has been eliminated from the table to save space. If the null hypothesis of independence was rejected, then the contingency table is presented, along with the chi-square value and the probability of Type I error. In addition, if the variables being tested are both ordinal, then the Mantel-Haenszel chi-square, is also given, along with the Type I error probability associated with that statistic.

Honokane Iki

In this valley two vegetation variables, GUPRE2 and OAPRE2, were demonstrated to vary with any environmental variables (Table 10-4). The relative dominance of guava appears to be highly related to distance to the sea, distance to the cliff, and to slope. In general, the prescription for high guava predominance in Honokane Iki appears to be proximity to the sea, gentle slopes, and distance from the cliffs. 'Ohi'a'ai predominance seems to be related only to distance to sea, the more inland locations having higher OAPRE2 values.

In quadrats with low slope, guava predominates, while other species prevail in medium and high slopes. This relationship is significant at a high level of confidence. Honokane Iki, abandoned well before 1900 but re-occupied for twenty years in the 20th century, contains vegetation that appears undisturbed, especially in the upper reaches. The dominance of guava along the stream and 'ohi'a'ai in
the upper slopes so apparent on the maps in Chapter 8 is borne out statistically. This evidence suggests that the vegetation of Honokane Iki may be near equilibrium, in which two exotic trees, one Polynesian and one Western, have established somewhat stable, environmentally determined ranges.

Lower Honokane Nui

The variables RIC2 and GUPRE2 exhibited strong relationships with certain environmental factors in lower Honokane Nui (Table 10-5). The null hypotheses of no association with richness was rejected for SLO2, SEC2, and DRN. High richness values were associated with quadrats high in slope, free from flooding, and close to the cliff. Guava predominance showed little association with these factors, and instead appeared to vary as a function of distance from the sea.

Honokane Nui Valley, at least in the lower, formerly densely settled areas, has a distinct vegetational pattern. Guava has not become the overwhelming dominant, perhaps because the valley lacks the water, flat ground, and flooding conditions in which guava flourishes best. The half of the valley nearest the sea houses a number of other exotics, including Syzygium spp. and Schinus, which occupy the habitats normally assumed by guava. Large mango trees also densely shade the terraces, prohibiting guava growth. The numerous settlements that persisted into the 20th
century here probably involved the introduction and nurture of many examples of the burgeoning exotic flora available to farmers and gardeners. The lower part of Honokane Nui contains a unique combination of trees, but the average quadrat does not show an increase in species richness as a result. The vegetation of this area reflects greatly human influence in the variety of cultivated trees surviving and even spreading with various degrees of success.

Waimanu East

The eastern ribbon forest of Waimanu is in general narrow, confined between the main stream and the towering cliffs. This is in part responsible for the paucity of settlements in this area, which were located on some of the few wide shelves along the eastern wall. The low species richness value for this area and quadrats it contains was remarked on in Chapter 8. It is interesting to examine the outcome of the tests of hypotheses in this light (Table 10-6). Richness appears highly associated with all environmental factors measured. Quadrats are likelier to be richer if they are closer to the sea, closer to the cliff, steeper, and non-flooding. The locational prescription for richness here is perhaps a joint function of human and natural causes. Disturbance in historic times in this isolated area has been more prominent near the sea, including taro and rice cultivation and occasional forays by hunters during the 20th century. It is near the sea
that Polynesian exotics such as ti are found, and TIPA (ti presence or absence) shows a high degree of association with DSE2. The low richness of Waimanu East is enhanced in places by the presence of just one extra species, ti. The inland transects traverse wide expanses of medium slope where guava, kukui, and 'ohi'a 'ai predominate, often in monospecific stands, reflecting both the low degree of interference and perhaps the less variable environment. The association patterns of GUPRE2 show a high degree of affinity for low slopes, sites far from the cliff, and poorly drained or flooded areas.

Lower West Waimanu

This area contains 104 quadrats, and is thus well-suited to contingency table analysis (Table 10-7). Variables describing richness and the predominance values of guava, kukui, coffee, and 'ulu all have significant associations with environmental variables. The relatively large number of cells showing association in Table 10-7 is partly due to the richer species mixture in Waimanu West, which provides more individuals of different species, and also partly due to the larger sample size, which gives the hypothesis tests greater power. This part of Waimanu Valley was a focus of settlement in prehistoric times, and continued to house inhabitants until well into the 20th century. The main path to the interior of the valley currently runs along the west wall, promoting low-level
Species richness shows little association with distance from the sea, perhaps reflecting the fact that the entire lower slope area was inhabited. Higher-sloped sites close to the cliff tend to have more diversity of species. Tree crops such as 'ulu, papaya, avocado, and mango are present in this area. The lower zone is occupied principally by guava, hau, and rose apple, often in large stands containing few other species. Guava itself shows significant association only with distance to the sea, being more common inland, away from the cultivated shelves near the sea.

The presence of coffee is also associated with increasing distance from the sea. An analogous pattern is encountered in Pololu, where the west side of the valley houses dense stands of coffee at distances greater than 1500 m from the sea. This distribution probably is a legacy of the plantings of the 19th century, with some expansion down the valley. Perhaps this zone was, for reasons of sunlight, slope, and lack of drainage problems, ideally suited to coffee cultivation.

Kukui predominance is most highly associated with distance to the sea, and somewhat weakly with proximity to the cliff. As mentioned in Chapter 8, neither kukui nor guava is as dominant here as in other areas, and they are displaced by exotics uncommon elsewhere. The noni tree, free from the ravages of cattle that control it in Pololu
Valley, is common in Waimanu, and shows significant positive associations with high slope, near-cliff, well-drained conditions. The presence of the 'ulu tree likewise is associated with higher-sloped sites near the cliff.

Summary

Each area showed somewhat different associative patterns between environmental and species abundance variables, partly due to sampling size differences, chance, and also, perhaps, to genuinely different response patterns to measured or unmeasured environmental gradients. However, some uniformity of response was indicated by the consistent rejection of the null hypotheses of no association between certain sets of variables.

Guava in Honokane Iki and Waimanu East was significantly more predominant in conditions of poor drainage and low slopes distant from the cliff. This pattern was also evident for the whole valley region in the correlation matrix presented earlier. In Honokane Nui and lower West Waimanu, this pattern was not statistically significant, though it is apparent on the dominance maps of these areas.

Certain other species also seemed to have distributions that highly reflected environmental gradients. 'Ohi'a'ai, whose preference for shady, steep, and well-drained areas in Hawaii was remarked on in Chapter
9 and also observed in the general correlation matrix, is present in abundance in only Honokane Iki of the four areas examined. There 'ohi'a 'ai also showed a significant tendency to predominate in the inner portions of the valley, which due to its narrowness are extremely shady. In lower West Waimanu, where the only numerous populations of noni, 'ulu, and coffee in the four areas were found, all these species showed tendencies to prefer steep, near-cliff, well-drained environments. Variation in papaya abundance with slope, a hypothesis developed in the last chapter, failed to emerge as a significant relationship in any of the areas in this study, possibly due to the low power of tests of association when dealing with small sample sizes.

The variation of richness in response to environmental factors is of particular interest. Richness showed a consistent pattern of positive associations with proximity to cliff, increasing slope, and good drainage. This tendency was revealed in the general correlation analysis (Table 10-1), and in the individual areas. The richness of this zone, which can be more marked inland or near the sea, depending on the valley, might be explained as a combination of several influences.

First, guava does not seem to flourish in this zone, thus preventing a monotonous guava parkland from developing. However, guava is present here at lower abundances. Second, many other trees are well adapted to
this zone, permitting a more diverse flora to develop. Also, floral elements from the cliff zone above, such as ti, hala, and mamaki, colonize this zone, often passively transported in mass movements. Finally, Polynesian and Western tree crops, including ti, 'ulu, and papaya, have also successfully colonized this zone. It is suggested that the highly rich forest in this area is thus a product of natural and human contributions.

Evaluation of the Method

Despite the clear environmental control revealed by the test of hypotheses regarding the distribution of species richness and the predominance values of guava, 'ohi'a 'ai, and, to a some extent, coffee, ti, 'ulu, kukui, and noni, the methods employed have had limited success in illuminating environmental influence on the vegetation of Kohala. Predominance value variation for the majority of species analyzed in the hypothesis-testing tables was left unexplained. A combination of several reasons may account for this failure. The variables measured may have been too few, or inappropriate. Also, clearly, the effects of human disturbance have masked to some extent environmental control, even half a century after abandonment. Another possibility is that bivariate contingency table analysis is not sophisticated enough to detect environmental control. If interaction among variables is significant, multivariate analysis is necessary. Attempts were made at multivariate
categorical analysis using the CATMOD procedure in SAS, but they consistently failed because of the twin problems of low cell frequencies and sampling zeros, which greatly reduce the ability to the procedure to estimate parameters with any degree of precision.

A renewed effort to ascertain the control of the environment on the vegetation of the valleys would benefit by three improvements on my method: increased sample size, an increase in the number and precision of environmental variables, and a reduced sampling area, which would facilitate the above. Although the goal of this portion of this thesis has not been greatly successful, enough information has come to light to contribute to a discussion of the mark of the Hawaiian in the valley forests, the subject of the next chapter.
CHAPTER 11
THE VEGETATIONAL LEGACY OF THE HAWAIIAN CULTIVATOR

The mark of the Hawaiian cultivator in the vegetational landscape of the ribbon forest of the valleys is obvious from even a cursory examination of the species abundance data. Many of the most common trees, e.g., kukui, noni, and 'ohi'a 'ai, are Polynesia introductions. The legacy is also apparent in more subtle ways, and at finer scales, than this. The previous chapter attempted to derive ecological explanations for differential species abundance patterns. The tests showed in many cases significant species/environment response patterns, but most variation in species abundance was not explained by any of the environmental factors tested. At least some of the problems encountered in this effort were due to the less predictable human factor in the biogeography of the valleys.

This chapter assesses the impact of the Hawaiian in a general and qualitative way. This assessment is derived from analysis of the data discussed in the three previous chapters. Three main aspects of this impact are considered: the mix of species classed by place of origin, the differential distribution of such species classes inside the valleys, and the location of large, unusual trees. The objectives are to point out the most prominent anthropogenic features, the idiosyncratic element of the
vegetation that pattern-seeking methods often dismiss as "noise."

The Species Mix of the Valleys

Species present in Kohala may be grouped into three classes: native, Polynesian, and Western (which actually includes European, Asian, African, American, and some Oceanian exotics; Table 11-1). The native flora of the valleys has all but disappeared, with the exception of hala, and to a limited extent, mamaki. Some of the

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Table 11-1
Valley Species Grouped by Place of Origin

elements that have replaced this flora have little to do with cultivation. Guava and Schinus, for example, are weedy trees whose seeds are scattered by mammals and birds and whose ranges have expanded throughout lowland Hawaii with little debt to humanity other than their original introduction. One side effect of the Hawaiian occupation has been the promotion of guava through the actions of the descendants of domestic pigs (hybridized with European
animals). The most far-reaching result of this occupation is the fact that much of the valley vegetation is clearly composed of the less aggressive plants introduced by Polynesians during prehistory. The survival of these plants is probably less a result of weedy characteristics than a legacy of their widespread cultivation. Similarly, there is a large component of introduced trees of Western origin adopted by Hawaiians during the 19th century.

The importance value for native species in the sampled region as a whole is 2.6%, compared to 48.2% for Polynesian introductions, and 49.2% for later exotics. Given the success of such species as guava, Schinus, Pluchea, and Syzygium spp. in dominating vegetation in Hawaii, this proportion of Polynesian species seems remarkably high.

**Distribution of Trees by Class of Origin**

**Inside the Valleys**

The valleys' flora has changed from strictly indigenous, to a mixture of Polynesian and indigenous species (relative proportions unknown,) to a mixture of Polynesian and later exotics. From the 17th to the 20th century, most of the land in the Kohala valleys was cultivated, inhabited, or utilized in some other fashion. The valleys were progressively abandoned from the rear to the front during the 19th century. By late in that century, when many Western plants had been firmly adopted by Hawaiian farmers, settlement was concentrated on the
lower valley margins and on the beachfronts. Given such a scenario, Western trees that disseminate only slowly should today be more abundant near the front than the back of each valley. Such appears to be the case, although it must be remarked that other influences, such as differential environmental suitability, may also be responsible for such a pattern. Aside from the weed trees, guava, *Schinus*, *Syzygium* spp., and *Pluchea*, most Western introductions are concentrated in the fronts of the valleys (Figs. 8-1 to 8-11). Mango, avocado, *Melia*, *Chrysophyllum*, *kolomona*, *Brassaia*, and the fan palm all follow this pattern. However, the lemon and *Bixa* are found somewhat anomalously in inland regions only, and coffee and papaya are present along the entire length of the valleys. The limitation of Western species to the front of the valley appears to be more of a tendency than a strict rule. Some of this deviation is explainable. Both papaya and citrus were among the earliest Western tree crops adopted by Hawaiians (Vancouver 1798, Vol. 2:156, Neal 1965:600). Their presence in the further reaches of the valleys might be a consequence of the cultivation of these species near homesteads in the early 19th century, when such outlying areas were still inhabited. Coffee was a cash crop in the valleys in the late 1800's, and was probably planted in the locations that suited its culture best. The patch of *Bixa* in the back of Waimanu Valley, however, remains a mystery. The Dove Map of 1896 (Fig. 5-4) indicated that this area
was uninhabited and uncultivated, an unlikely location for a dooryard ornamental to be planted.

The sequence of abandonment of the four valleys began with Honokane Iki sometime before the late 1800's and ended with Pololu, which retained inhabitants until the mid-1920's. A meaningful statistic, if the valleys had all been comprehensively sampled, would be the mean number of Western species per quadrat, which could be compared valley by valley. Given the limitations of the sampling scheme, such comparisons are unwarranted, but a clear distinction exists between Honokane Iki, with a total of only six Western introductions (all but guava very minor floral constituents), and Pololu, with eleven Western introductions, including *Schinus, Dombeya, Pluchea, Stachytarpheta*, and *Syzygium* spp., all present at high levels. Such a comparison may confound the diversity of habitats (quite high in Pololu) with the prime factor under consideration, contact during the era of abandonment. In reality, both factors operated simultaneously.

Environments such as Honokane Iki and the upper gulches of other valleys were marginal environments for Polynesian horticulture, and the suite of mostly sun-loving tree crops and ornamentals introduced after Western contact made those areas not more but perhaps less useful. Among papaya, mango, lemon, avocado, and coffee, only the latter is shade-tolerant, and even it has difficulty in perpetually shady and moist sites.
In sum, it appears that species frequency in the valley region echoes the trends of back-to-front abandonment and the particular sequence of valley abandonment that has been interpreted from documentary evidence. Also, the abundance of Western introductions in Pololu and Waimanu Valleys is perhaps directly attributable to the longer duration of settlement in those locations in historic time. The physical contrasts of the four valleys make such comparisons difficult.

Large and Uncommon Trees

The vegetation of the valleys is dominated by three species, guava, kukui, and 'ohi'a 'ai, which combined account for an importance value of over 65% in the samples. The major vegetational variation consists of the alternation of patches dominated by one of these three species. However, several areas are exceptions to this rule, and thus merit special attention.

Mango

Mango trees were planted for their fruit and shade throughout the Hawaiian islands after their introduction during the early 19th century. Large mango trees occupy several sites on the western side of Waimanu and an eastern terrace of lower Honokane Nui. When the distribution of the trees located and mapped during surveillance is compared with the location of kuleana awarded by the Land Commission around 1850, a large degree of correspondence is
apparent (Fig. 11-1). For reasons stated in Chapter 8, it is unlikely that all the kuleana actively inhabited and cultivated in 1850 were actually claimed, awarded, and mapped. It is thus interesting to note how faithfully mango trees mark claimed kuleana. The age of these trees is difficult to determine, but their size (often 15 m in both height and crown diameter) indicates that they were planted in the 19th century. Could it be that unawarded kuleana in the valleys were abandoned and left unplanted? Dove’s map of Waimanu in 1896 shows dwellings outside the area of awarded kuleana, a pattern reaffirmed on a 1913 U.S.G.S. map (Figs. 5-2 and 5-5). The reason for the lack of mango trees in this area is unclear. Perhaps there were less unclaimed kuleana than is indicated by the seeming incongruity of high population figures and few awarded land parcels. Perhaps the unclaimed kuleana were marginal for agriculture, encouraging their inhabitants to remove during the late 19th century to other local sites or out of the valleys altogether. In any case, the correspondence of mango groves and awarded kuleana is striking.

Melia

Another large and even less common tree is the Melia, or Pride of India. Also valued for shade, this weak-wooded tree grew well in the sheltered sides of the Kohala valleys. The several large trees sampled (Figs. 8-5 and 8-8) represent the general geography of the tree well.
Mango Groves, Waimanu
Fig. 11-1b

Mango Groves, Northern Valleys
Melia is restricted in range to the east side of Pololu and the west side of Waimanu, in the seaward halves of both valleys. Both these areas were inhabited well into the late 19th century, the era in which the trees now becoming senescent were probably planted. They undoubtedly mark former dwelling sites, as they are invariably surrounded by walls, platforms and artifacts.

Coconut

Outside the beachfronts of the valleys, coconuts are rare. One individual was sampled on the lower west side of Waimanu, and another found during surveillance deep inside Pololu, in a highly unlikely (in terms of habitat preference) location at the base of a gulch. Like Melia and mango, coconuts are indicative of former habitation sites.

'Ulu

Breadfruit, or 'ulu, is scattered in all four valleys (Figs. 8-2, 8-8), often near former house sites. Unlike the trees just considered, it propagates readily, through root suckers. This tall, dominant tree is possibly expanding its range in the valleys, and it will probably continue to vaguely mark the locations of Hawaiian households after the other large trees have died without progeny.
Brassaia

Although only two individuals of Brassaia were enumerated during sampling, reconnaissance revealed a large cluster of these trees at the mouth of Honokane Iki valley. This ornamental was probably introduced by the Sproat family over fifty years ago. Most of the trees are perched on the cliffs, from where they have apparently dispersed into the forest below, perhaps as a result of large treefalls. Although unimportant in the valley flora as yet, in the future this species may become naturalized throughout lower Honokane Iki, and it may even spread over a low ridge into Honokane Nui. The success of this species is a clear example of a point introduction with a radial extension pattern. This phenomenon undoubtedly occurred with other species as well, but the passage of time has obscured the evidence.

Summary

Hawaiian cultivators of history and prehistory have left their mark on the valley landscape in a number of ways. Stone terraces, platforms, and walls constitute a semi-permanent legacy. A more subtle and mutable element of a landscape is its flora, and few places have a vegetational landscape more evocative of the culture that inhabited and created it than the fruit-tree forests of the Kohala valleys.

Only a small native element persists, a consequence of
clearing for agriculture and two major episodes of exotic introduction. A strong Polynesian element survives in the vegetation, and it reflects the complete and long-standing use of the valley space in its diffuse and extensive geography.

Western introductions are of two types: ubiquitous weeds such as guava and Schinus, which have invaded diverse habitats, and less aggressive but prominent relics of 19th century cultivation such as mango and papaya. In contrast to the somewhat evenly dispersed weed trees and the trees of Polynesian origin, these Western species are for the most part located near the fronts of the valleys, where settlement persisted into the late 19th century.

Large trees planted and prized by the Hawaiians still mark former habitations. Mango, Melia, coconut, and 'ulu trees tower above smaller yet more successful trees. Many of these giants are no more than cultural relicts, destined to perish, and possibly 'ulu will remain the lone signpost of Hawaiian households in an increasingly wild vegetational landscape. The next chapter makes some predictions about the future structure of the forest based on size-class data obtained during sampling.
The preceding chapters have defined the legacy left by Hawaiian farmers in the vegetation of the valleys, a mark that is being modified by natural environmental processes. This chapter considers how prominent that mark will be in the future forests of the Kohala valleys. The information used to evaluate this question is the size-class data collected during sampling, along with general observations concerning species interaction as reviewed in Chapter 9.

Each tree enumerated was assigned to one of five size-classes. This procedure enabled cover to be estimated more efficiently than by measuring the exact diameter of each tree. It also allowed the construction of size-class histograms that reflect the age structure of the samples, and through inference, the population.

Size-class analysis, to be useful, must take into account several factors. Sample size must be large enough to merit trust in any quantitative conclusions. The correspondence of the age of a species to its diameter must be understood. Ideally, then, size-class intervals can be made to represent a meaningful division of the growth continuum peculiar to a given species in a given habitat.

This study incorporated over 550 quadrats and counted more than 10,000 individuals of 33 species distributed in a variety of habitats. Despite the magnitude of the sample,
there were quite naturally some species that appeared uncommonly, rendering small samples. Also, designing flexible size-class intervals that accounted for both species and habitat variation was impractical. Because of these limitations, size-class data are less useful for some species than for the majority. Inferences concerning the status of uncommon species, such as the fan palm, *kolomona*, and *waiawi*, simply cannot be reliably made. Other species are somewhat more common but still present in insufficient numbers to make reliable judgements about their size-class structures. Several species, especially *ti*, *hala*, and bamboo, have growth habits that make the chosen class intervals less meaningful in expressing age structure. Most of the species, however, are fairly numerous and have growth habits that assure a correspondence of size and age.

Size-Class Structure for All Samples

Pooling the quadrats provides an approximation of the size-class structure of all the species in the valleys as a whole (Table 12-1). These data may not be considered a representative sample of the region, as they are derived from stratified random samples of different densities from only parts of the valleys. Subsets of these data, representing single or adjacent sampling areas with identical sampling densities, are examined inferentially in a later section. The entire data set is first considered as a unit in order to gain a general picture of size-class
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Table 12-1  
Species by Size-Class, All Quadrats Pooled
relationships.

Guava, *kukui*, *'ohi'a* 'ai, *noni*, and *hau* possess size-class structures that indicate not only abundant but also healthy, self-reproducing populations. In each of these species juveniles significantly outnumber mature trees (classes one and two of the large tree *kukui* both represent juveniles), and a classic pyramidal distribution is present. *Ti* and coffee rarely exceed the 12.5 cm threshold of class three, and thus display little variation on this scale. *Hala* has a special growth history, as instead of remaining small during its juvenile phase, it rapidly develops a trunk of 10 cm, and then begins to develop an extensive system of aerial roots while it slowly expands in diameter (Degener 1945:43).

Many less common but still relatively abundant species show similar distributions. Notable in this respect are *'ulu*, papaya, java plum, *Schinus*, rose apple, *Pluchea*, and *kamani*. All appear to be reproducing their numbers. A few other species of secondary prominence show somewhat different size-class distributions. Mango and *Melia* both have top-heavy distributions. Although the small size of the sample in both cases mitigates against making definite conclusions, this impression had also been obtained during reconnaissance. Both populations consist of large, senescent trees. Some hypotheses regarding this phenomenon are presented later.

Four native species, *hala*, *mamaki*, *Canthium*, and
Charpentiera, were sampled in the valleys. Analysis of their size-class structure reveals that hala is thriving, and mamaki is probably reproducing itself as well. The other two trees were so rare in the valley as to be inconsequential, and no inferences about their future status can be made from the data.

**Size-Class Data From Discrete Areas**

Analysis of the data of discrete areas has the disadvantage of dealing with smaller numbers and the advantage of having confidence that the data describe a specific area. As such, the proportions of trees of each species falling in each size-class are assumed to be roughly representative of the population. Confidence intervals around these proportions can thus be calculated using multinomial probability functions. The population histograms presented in this section are displayed graphically (Figs. 12-1 to 12-4) in order to exhibit the estimated proportions and the 95% confidence limits of these estimates.

The areas under consideration here are identical to those analyzed in the section concerning environmental control factors in the previous chapter: Honokane Iki, lower Honokane Nui, the east side of Waimanu, and lower west Waimanu.

**Honokane Iki**

Guava, kukui, 'ohi'a 'ai, noni, hala, and 'ulu are the
Selected Size-Class Structures, Honokane Iki
Selected Size-Class Structures, Honokane Nui
Selected Size-Class Structures, Low. W. Waimanu
Fig. 12-4

Selected Size-Class Structures, East Waimanu
trees numerous enough to permit confident discussion of size-class data (Fig. 12-1). The first four trees on this list show classic size-class pyramids, indicating a steady supply of juveniles as trees mature and die because of senescence, predation, disease, or disasters such as rockfalls, treefalls, or erosion of the root base. Hala, here as elsewhere, lacks members of the smallest class, and even displays an inverted pyramid whose shape can be said to fundamentally the same at a 95% level of probability. There is no evidence that this condition indicates impending extinction of hala. A relatively small sample of 16 'ulu was enumerated in Honokane Iki, making reliable statements about the size-class distribution difficult. There is at least no evidence that 'ulu is on the decline in Honokane Iki.

**Lower Honokane Nui**

Five species, guava, **kukui** coffee, java plum, and rose apple, were sampled in abundant numbers in the lower portion of Honokane Nui Valley. The size-class histograms (Fig 12-2) of guava, **kukui**, and java plum exhibit healthy shapes. Coffee is difficult to analyze because of its tendency to remain between 2 and 5 cm dbh even when mature, although a specimen over 10 cm was measured in Honokane Nui. The size of the sample for rose apple is not quite large enough to provide narrow confidence intervals at the 95% level, but its basic shape appears to indicate a
self-reproducing population as well.

Lower West Waimanu

This set of samples was derived from over a hundred quadrats, and it thus provided a sufficient number of individuals of each size-class for a large number of species (Fig. 12-3). Guava shows the smallest proportion of individuals in size-class one \((0.30 + or - 0.05)\) of any area under examination in this section, and is indeed at less than half its size-class one mean of 0.686 for the valleys as a whole. The skewed distribution is noticeable even under the most liberal interpretation given the 95% confidence limits. Kukui exhibits a remarkably similar departure from its normal class one mean of approximately 0.35 with a value here of 0.101. All other species (except hala and papaya, which because of growth habit, do not exhibit the normal size-class/count fall-off) show the typical diminution of numbers with increasing size-class. The large samples obtained in this area indicate that the interpretation that kukui and guava are declining, and other species advancing, is valid. Nonetheless, guava and kukui are the second and third most abundant trees in the area.

East Waimanu

This area stretches from the sea to several thousand meters inland but is relatively poor in species, with a mean of near three per quadrat. Furthermore, only six
species total were present along the entire east wall. This number is rather small, considering the size of the area sampled and the density of sampling. Guava, *kukui*, *'ohi'a 'ai*, and *noni* all exhibit the normal patterns of self-reproducing populations, while papaya and *hala* show distributions that are unremarkable considering their growth habits (Fig. 12-4). All these trees appear to be flourishing.

**Aspects of the Future Composition of Forests**

**Success of Individual Species**

The continued survival of guava, *kukui*, *noni*, and *'ohi'a 'ai* seems certain based on their current size-class structure. The evidence concerning the other major species, *ti*, *hala*, *hau*, and coffee, is less easy to interpret because of their unusual growth habits, but they would seem to be thriving as well. Papaya, *'ulu*, java plum, rose apple, *mamaki*, and *Schinus* have smaller absolute numbers but general size-class structures that indicate healthy populations. Most of the other species in the valleys are represented by too few individuals to make reliable judgements about their future abundances. The *Melia* tree will probably disappear or become extremely scarce within a few decades; mango may have a similar fate somewhat later. Certain trees with localized distributions but numerous juveniles, including avocado, *Chrysophyllum*, *Brassaia*, and *Bixa*, may become more widespread in the
future, or may remain localized. Disasters such as treefalls, landslides, and floods may tend to eventually extinguish cultural relicts such as these, concentrated as they are in only one location.

Effects of Large Relict Mangos on Species Composition

In several areas in the valleys large mango trees form thick stands that clearly mark former homesteads. These trees at present show no sign of reproducing themselves, but their very presence seems to have an effect on other species.

The lower west side of Waimanu and the lower part of Honokane Nui contain 50% and 27% respectively of all the mango trees sampled in the valleys. Mango canopies there are thick and extensive, and several trees together create a shady environment on the forest floor. In both areas, guava and *kukui* are less dominant than normal and show inverted size-class histograms. In lower west Waimanu, there are an inordinate number of *noni*, which perhaps tolerate lower light regimes than *kukui*, and certainly than guava. In Honokane Nui, java plum and rose apple are prevalent. None of these smaller trees actually grow directly under mango trees, but instead seem to do well on the margins of the canopy, thus gaining a foothold. There are many possible explanations that could account for the unusual abundance levels and population structure of guava and *kukui*, but the effect of mango canopies probably plays
a role. If these large trees perish and leave no offspring, guava and *kukui* may assume the dominant status they attain in most of the other areas.

Evidence for Zonation in the Forest

After the cessation of human disturbance, distinct and stable communities based on different combinations of environmental factors may begin to emerge. Such communities are already hypothesized to exist in some locations in the Hawaiian lowlands (Wester 1983:107). It may be possible to view this development in the size-class data for the Kohala valleys. One aspect of this situation was explored in Chapter 11 in the contrast of steep with flat environments inside individual areas. The general variation of species predominance values with environmental factors revealed that 'ohi'a 'ai had high values in steep areas and that guava tended to be most abundant in flatter areas.

This observation led to the hypothesis that not only do guava and 'ohi'a 'ai display different abundances in high versus low slopes, but that they also exhibit different size-class histograms. Specifically, it was hypothesized that guava would show a greater number of smaller trees than larger trees in low-slope quadrats and that 'ohi'a 'ai would have a similar size structure in high-slope quadrats. To test this idea, all quadrats of high slope in the valleys were contrasted with all
low-slope quadrats, with medium slope quadrats excluded. The size categories were reduced from five to two by collapsing all the categories higher than size-class one into one category, "large" trees. Density counts were then cross-classified on the basis of these newly-defined slope and size-class criteria in a contingency table (Table 12-2). A slightly higher proportion of smaller 'ōhi'a 'ai

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Chi-Square

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GUAVA

'OHI'A 'AI

Table 12-2
Guava and 'Ōhi'a 'Ai Size-Class Distribution by Slope Type

trees was found to be present in high-slope quadrats than in low (69.81 versus 64.29%), but this difference is not statistically significant at the 0.05 level Guava, however, proved to have a much higher proportion of small versus large trees on low versus high-slope quadrats (69.93% versus 59.00%), a contrast significant even at the 0.001 level.

One explanation for the difference may be the
considerable colonization powers of guava. The valleys after abandonment possessed a vegetational landscape bare in some places and inhabited in others by cultural relicts poorly suited for propagation, competition, and survival without human care. This situation gave trees of many species the opportunity to colonize the talus slopes. Guava is a quick colonizer, and it likely moved into some environments for which it was ultimately poorly suited (such as shady gulches) and in which it was eventually mostly displaced by better-adapted but slower-colonizing species. The persistence of guava at low levels, and with less healthy size-class structures, is explained by such a scenario. 'Ohi'a 'ai, being a slow colonizer, flourished in the high-slope areas and also gained a slight foothold in more marginal areas, where it continues to reproduce and maintain a presence at low population levels. This scenario is not the only possible explanation for the contrasting size-class ratios of guava and 'ohi'a 'ai in habitats of differing slope, but it seems a likely one.

A Polynesian Forest

The ribbon forest, an interface of the marsh and the periodically flooded terraces below with the cliffs and 'ohi'a lehua dominated forests above, is a mixture of elements reflecting human interference and subsequent species interaction. Even if in most cases, a truly stable structure has not yet emerged, the basic nature of the
structure to come is apparent. Guava will continue to be dominant, especially on the margins toward the center. At least a dozen other species will continue to be present, some prominent, some uncommon. One surprising feature of this forest is that, despite two centuries of plant introduction from six continents, the most important floral elements remain the Polynesian introductions. *Kukui*, *ti*, *noni*, *'ohi'a 'ai*, *hau*, and *'ulu* account for the vast majority of the species density and cover in the valley region.

East Waimanu, which was abandoned probably a century ago and reflects more than any other area the results of competition over a moderately long interval, serves as an example of what the emerging forest may resemble. Species of Polynesian origin make up over 68% of the importance value. The breakdown of individuals by Polynesian species shows a fairly balanced assemblage of four trees: *kukui* (164), *'ohi'a 'ai* (183), *ti* (92), and *noni* (26). *Hau* and *'ulu* are absent in the eastern side of Waimanu. Sixteen *hala* trees (possibly another Polynesian import) were also sampled. Although the exact combinations of minor species and the proportions of the major species may vary within different parts of the valleys, it seems likely that the composition of the future forests of the Kohala valleys will be decidedly Polynesian.
The Fate of Native Species

Hala is the only native species truly abundant in the valley region, and there is of course considerable question as to whether it is truly indigenous. Mamaki is somewhat uncommon, but it appears effective as a colonizer in the most active talus deposits, and will probably continue to be present. The fact that it was sampled in some of the less disturbed areas of the valley region points to a possible resurgence over time. Charpentiera was found in two extremely shady gulches, nestled in 'ohi'a 'ai groves, and may continue to persist in that habitat. Canthium is an inconspicuous tree that may have escaped reconnaissance in many locations. In the two sites in which it was sampled, it was present as a single small individual in thick groves of exotics. It is abundant at higher elevations, at least near Waimanu Valley, and isolated seedlings, probably the result of dissemination of the berries in bird droppings, will probably continue to emerge. There were undoubtedly a few other native species present that did not happen to be sighted or sampled, but their presence may be considered insignificant.

The native forest as an entity, or even as scattered, abundant elements, is completely defunct in the valleys. There is no evidence that it will ever revive.

The Potential for Land Use Change

The valleys of Kohala, which once supported hundreds of
Hawaiians, are now considered unsuitable for settlement and agriculture and lie abandoned. In the next century, land use in the valleys may change. Waimanu Valley, assuming it becomes a full-fledged estuarine sanctuary, will probably remain much as it is. Honokane Iki has part-time residents once again and their clearing and planting activities may have an effect. Honokane Nui will probably be used solely for hunting in the future. Pololu Valley, with its magnificent situation and ready access to a rapidly developing tourist area, seems destined to change. Currently, a lessee of the central portion of the valley is felling trees and allowing their trunks to remain prostrate. This has promoted a virtual jungle of secondary growth and an abundance of pigs. Future lessees or owners may develop grander schemes, including hotels or condominiums.
CHAPTER 13

SUMMARY AND CONCLUSIONS

Summary

This thesis is concerned with the ribbon forest, the vegetation at the interface of valley floors and cliffs, in the valleys of Waimanu, Pololu, Honokane Nui, and Honokane Iki on the island of Hawaii. The constituents of the flora are almost exclusively naturalized relicts of cultivation. The forest of fruit trees has a geography that signifies both the human content in its vague reflection of historical land use, and ecological interaction in the differential abundance patterns of the generations of descendants of the original cultivated plants.

Several general topics of concern have generated the study design of the paper: the interaction of indigenous, Polynesian, and exotic trees after abandonment; the status of the native component of the forest; the variation of vegetation with environmental parameters; the existence and interpretability of the legacy of the inhabitants in the vegetation; and the question of the future composition of the forests.

In order to examine the interplay of human and natural influences, the physical, biological, and historical aspects of the valleys have been investigated. The geographical method of focusing on spatial relations and locational characteristics has inspired this work.
influencing the approach to vegetation measurement, information presentation, and statistical analysis.

The Physical Setting

First, the physical geography of the valleys, including variation in the geology, geomorphology, hydrology, climate, and soils of the area were detailed. This helped delimit and understand an area that was termed the ribbon forest, which had been somewhat apparent to the author during several reconnaissances of the region.

The valleys are erosional features initiated over a million years ago, as streams began to wear down Pololu Series lava and ash deposits on the Kohala Shield Volcano. Eventually these valleys developed an extensive base level surface, which was flattened and alluviated during episodes of sea level rise and fall, especially in Waimanu and Pololu valleys. Honokane Nui and Honokane Iki retain V-shaped profiles and steeper upvalley gradients. Wave action has carved sea cliffs as high as 400 m in between the valleys. Lateral walls in the valley are often as high as 500 m, and like sea cliffs, are often steeper than 40 degrees.

The ribbon forest occupies a zone between the cliffs, marshes, and streambeds of all four valley interiors. Talus, colluvial deposits, and stream terraces present an area of slopes of between 5 and 30 degrees, formerly the principal site for Hawaiian households and garden patches.
It is distinguished from the surrounding area by moderate slope and a constant forest cover, which is often lacking in the cliffs, marshes, and streambeds. However, a great deal of internal variation is present in this zone. Aside from slope, substrate type, drainage conditions, shadiness, and susceptibility to mass movements also vary here.

The entire area lies below 100 m in elevation, and thus experiences typical Hawaiian sea level temperatures, with a mean of near 22 degrees C in February and over 24 degrees in August. Even though temperature varies only slightly through the day and over the year, the quality and quantity of solar radiation is highly variable in the valleys due to the towering cliffs. Shady zones abut the cliffs and the gulches.

Northeasterly trade winds are dominant, as on most windward Hawaiian coasts, and these generally have sustained speeds of less than twenty meters per second. Strong winds arise during squalls and winter storms, and during very infrequent hurricanes. Winds pose little threat to vegetation in the valleys. Annual rainfall varies from near 2000 mm to over 2500 mm, creating a mesic to humic moisture regime. Local xeric conditions can occur on well-drained slopes, especially facing sea cliffs. Infrequent droughts also contribute to dry conditions in some sites. More common are floods caused by heavy orographic precipitation in the interior, during which streams overflow their terraces for periods as long as
twelve hours.

Soils in the valleys are derived from material ranging from lava and ash, marine sediments, and alluvial deposits. Knowledge of valley soil geography is only approximate, partly due to extreme local variation. Drainage characteristics, determined by particle size and local elevation, are probably the major factors in soil variation. Most valley soil is poorly drained, mucky, and acidic. The subsurface is an active zone of groundwater flow, especially in the interiors and near side gulches and springs.

Geomorphologic zones offer a convenient scheme for dividing the diverse valley environment. Beaches are sunny, well-drained, and subject to intense wave action. Flat valley floors are confined to Pololu and Waimanu, where they support slightly brackish marshes that border forests on the sides and grade into parklands in the interior. Boulder and cobble-strewn streambeds incise valley floors as deeply as three meters in the upper valleys, often branching into multiple courses. Even when dry, these mark areas of significant groundwater flow. Terraces adjoin these streams, the results of both natural and human action. A talus slope borders the cliffs and the terraces, or occasionally the floor or streambed directly, and ranges in slope from 10 to 45 degrees. Partly talus and partly colluvium, it houses a dense forest despite the frequency of mass movements. Side gulches are relatively
uncommon, but several in Waimanu and Pololu incise the cliff at acute angles. Due to almost constant rockfalls, this zone is hazardous for man and plant alike.

All geomorphic zones except the beach are possible along the length of the valleys, but they differ internally in their characteristics from the front to the back. Valleys narrow toward the back, eventually eliminating floors. The backs of valleys are cloudier, rainier, narrower, steeper, and less windy than the fronts.

Natural Vegetation

The natural flora of the Hawaiian Islands is the product of the adaptive radiation of perhaps less than three hundred immigrant species introduced over the course of several million years. Ninety-five percent of the almost two thousand species native to Hawaii are endemic. Evolution has favored the loss of thorns, poisons, and secondary compounds, producing a flora without defense against invading plants and predators. In the Kohala Mountains, a rich native forest still flourishes above five hundred meters in elevation, but in the valleys themselves only a few natives survive, notably hala (screwpine) and mamaki. The forest that currently occupies the valleys and skirts along the edge of the cliff and marsh has almost totally exotic affinities.

Human Influences: Prehistory

Assessing prehistoric land use and vegetational change
in any location in Hawaii is difficult. Initial archaeological survey work in windward valleys is far from complete; detailed knowledge of individual sites and major cultural processes is just beginning. On the other hand, the recent prehistoric period is better known, and ethnographic accounts of the contact period (post-1778) abound, providing a glimpse into prehistoric Hawaiian society and geography. The use of such materials, however, is complicated by the rapid transformation undergone by Hawaiian society after contact.

Of the distant past, it is known that Polynesians settled the Hawaiian Islands by canoe, probably setting forth from the Marquesas Islands, and in a later migration, from Tahiti. The suite of Hawaiian crops observed at contact, which included taro, sweet potatoes, yams, bananas, and among trees, *kukui* (candlenut), *'ulu* (breadfruit), *noni*, *'ohi'a 'ai* (mountain apple), *hau*, coconut, and *ti*, had certainly been present on the islands for centuries. Early radiocarbon dates have arisen mostly from leeward sites, but windward valleys were probably also settled fairly early. By the 14th century, Waipio Valley (the largest of the Kohala valleys, still occupied today and thus not considered in this thesis) definitely housed wet taro culture and numerous inhabitants.

Social organization was intimately tied to land use. Ultimate ownership of the land is said to have belonged to the paramount chief or king. An increasingly stratified
and feudal society developed, involving the allocation of areas of land in a hierarchy. Common people sometimes specialized in crafts, but generally they farmed land allotted to them by the ali'i or chiefs. Land tenure was somewhat stable for these farmers. The lowest basic social unit associated with management of land in Hawaii is still a matter of investigation. The ohana (i.e., relatives by blood, birth, and marriage, in one interpretation of the term) is often associated with this responsibility. Perhaps smaller units, such as an extended family residing together, constituted the actual management unit, or perhaps both systems were in operation in different parts of the islands.

Land use in windward valleys most simply described consisted of taro patches, either irrigated or dryland, with intercropping on the banks involving bananas, sugar cane, and other crops. Dooryard and outlying gardens, with the talus slopes planted in tree crops, were also important agricultural plots. Gathering took place in wild and semi-wild areas, either in the valleys or in the mountains above them, where such plants as olona, mamaki, hau, koa, and 'ohi'a lehua were harvested for fiber, medicine, dye, ceremonial items, and timber.

The specific prehistoric geography of Kohala is not known with any certainty, although an archaeological survey was undertaken in three of the valleys. The most prominent findings of that research were that taro was cultivated in
both irrigated and non-irrigated patches in Honokane Nui and Pololu, and that tree crops were cultivated on terraces in all valleys. Settlement was denser near the beach, but the cliff margins contained numerous dwelling sites as well.

Waimanu is less well investigated, but during vegetational reconnaissance for this study, dozens of sites were observed on both sides of the valley, from the beach to the base of the interior cliffs. Even with the author's limited expertise in classifying stone remains, it was obvious that many sites represented prehistoric habitations.

The first Western observer in the valleys was Rev. William Ellis, and his writings concerning population, residential, and agricultural patterns are invaluable, despite their late date (1823). From Ellis' accounts it appears that over two hundred people lived in both Honokane Nui and Waimanu; he did not remark on Honokane Iki or Pololu, though he passed through both. The prominence the sandalwood trade in Waimanu occupies in his accounts illustrates the already profound effects of Western contact.

Land Use Change in the 19th and 20th Centuries

The era of Western contact ushered in by Captain James Cook's arrival in Hawaii in 1778 brought with it diverse consequences. Of immediate relevance to a study of
vegetation and land use was the new set of crops available to the Hawaiian cultivator. These new species were simultaneously unleashed on the vegetation, which had possibly reached some sort of equilibrium after the disruptions caused by Polynesian plant and animal introduction. Papaya and citrus were among the first tree crops to be adopted, followed soon by mango, avocado, coffee, and guava. Many of these trees naturalized in Hawaii to some extent, but guava managed to become a widespread weed by the 1850's.

Other effects of Westernization were less salutary. Disease ravaged the population, migrations emptied many rural districts, and the social system virtually collapsed, creating decades of confusion. Social breakdown involved land use, and the ties of the commoners to the land weakened. The establishment of fee-simple land titles in Hawaii in the mid-1800's was a boon to Westerners, who could finally feel secure in their holdings, but a disaster for the Hawaiian common people. Their unfamiliarity with the principle of land ownership and difficulty in following the procedures required to validly register and receive claims led to wholesale dispossession of Hawaiian commoners in the space of fifty years. Plantation agriculture, hired labor, taxes, and a money economy conflicted with Hawaiian values and customs, and the Hawaiian kuleana or farmstead all but disappeared.

The effects of Western contact were slow in reaching
the valleys. Though described from the vantage of many a
ship's deck, the valleys apparently had no visitors until
Ellis in 1823. After that time, accounts concerning the
valleys near Waipio increase, including traveler's
writings, surveyor's journals, censuses conducted by
missionaries or the government, and tax records. From the
fragments of the records that survive it has been possible
to construct a brief history of the region.

In many ways events in the valleys appeared to have
been a microcosm of conditions at large in Hawaii.
Population declined by over half from the early 1830's (by
which time it had probably already been severely reduced)
to the 1870's. The Land Commission awarded only twenty-six
kuleana in the valleys, representing undoubtedly only a
fraction of the land under cultivation. Rice culture
introduced a new Chinese element in the population, but
Hawaiians continued to decline in number. Honokane Iki,
always small in population, was the first to be abandoned.
The water above Honokane Nui was diverted in 1904 to
irrigate cane plantations, and inhabitants were summarily
obliged to relocate. In Pololu and Waimanu, rice
cultivators took over many existing taro fields.
Settlements in the backs and eastern sides of the valleys
were slowly abandoned, according to evidence from tax
records, maps, and archaeological surveys. By 1900 in
Waimanu and Pololu, only the beach area and the seaward
western valley flanks were inhabited. By 1930, neither
valley retained inhabitants. Since then, occasional hunters, campers, and landowners have visited the valleys for short periods. A forest has emerged in all valleys on the talus slopes and terraces, areas that appeared cleared in many places in photographs of Waimanu and Pololu circa 1920. This forest is a secondary product of Hawaiian cultivators.

Methods Used in This Study

The study of cultural vegetation has rarely been practiced on anything but a general scale. The methods of vegetation ecology, which seek to identify and describe vegetation communities and the environmental causes that underlie vegetation, offer the best initial source of techniques to a historical biogeographer.

The paradigm that dominates vegetation ecology is somewhere between a holistic view of communities and the belief that vegetation is the product of individual plant species' differential responses along a number of environmental gradients. Continuous disturbance is being increasingly accepted as a major shaper of vegetation. However, most methods in vegetation ecology attempt to describe discrete environmental communities, in terms of their life-form or floral structure. In the area of floristic structure, the concern of this study, vegetation ecologists have developed a number of measures of species abundance along with sophisticated sampling schemes to
obtain these measures. Species information usually collected in sampling quadrats includes frequency, density, and cover. One of the major tasks of this thesis was to adapt these procedures to the study of cultural vegetation. Discrepancies between conditions that normally precede ecological studies of natural communities and the constraints imposed in the Kohala valleys made substantial alteration necessary.

The factor of human influence in cultural vegetation distorts environmental influences and creates anomalous locational patterns. Many species ill-adapted to natural conditions are planted and nurtured, and many species capable of surviving in the wild are planted in locations that eventually become less than ideal when the area reverts to wild. A period of adjustment ensues, during which the "signal" of vegetation response to the environment is lost in the "noise" of human interference.

The solution devised in this thesis for abstracting vegetation information in such conditions is to suspend any search for vegetational gradients or communities, and to concentrate on areas instead. This approach was inspired by biogeography, which focuses on geographical patterns as an organizing tool for other vegetation research.

The valleys were divided into fifteen sampling areas which were each geographically meaningful if floristically heterogeneous. Major distinctions serving as the rationale for division were front vs. back, east vs. west, valley vs.
valley, and side gulches vs. main branches. Areas with widespread recent disturbance such as pig-raising, land-clearing, or campsites were excluded from study. Inside each area, transects four meters wide were established at systematic intervals comprising 8% of the area in most of the areas, which was reduced to 4% as field time grew scarce. The transects were oriented to run from the cliff to the marsh, along the major local axis of variation. Sampling quadrats were twenty meter segments of these transects. Optimal quadrat size and shape were empirically determined in the field following the general guidelines of Grieg-Smith (1983).

Quadrats served several purposes. First, they supplied species abundance data that would represent in an inferential way the vegetation of the area in which they were located. Second, four environmental factors, slope, distance to cliff, distance to the sea, and drainage type were assessed for each quadrat. The correspondence between these factors and the data of species abundance could be used to test hypotheses concerning environmental control. Also, the species data measured or calculated for the quadrats, including frequency, density, size-classes (and thereby, cover), dominance, and richness, could be displayed in maps as qualitative evidence of vegetation pattern, helping illustrate both environmental and historical influences.
The Data of Species Distribution

Thirty-three species were sampled in the quadrats. The geographical distribution of the abundance data was highly irregular, as expected, and thus suggested a diversity of causal factors.

Frequency data was mapped for each species and each valley on a transect basis. Guava, *kukui*, *noni*, *Schinus*, and *ti* proved to be widespread. Most other species, even fairly abundant ones such as *hau*, *hala*, and coffee, showed much more clustered distributions. Many were confined to individual locations, including the Western ornamentals *Bixa*, *Brassaia*, *Chrysophyllum*, *kolomona*, *Dombeya*, and the fan palm. Several large trees, the mango, *Melia*, and a lone coconut, seemed to be located on the sites of 19th century habitations.

The concept of dominance, or the most important species in a quadrat or area, is difficult to directly measure. This research combined the values of frequency, cover, and density to develop an importance value (after Curtis 1959) with which to assess species dominance in sampled areas. Species inside individual quadrats, which cannot incorporate frequency data, were assigned a predominance value, basically the average of a species' density and cover relative to the total density and cover values for all species in the quadrat.

Importance value rankings for species in the valleys considered as a whole showed guava, *kukui*, *noni*, 

'ohi'a 'ai, coffee, hau, hala, and ti to be the most important species, in that order. Considerable variation from that pattern was noted when the fifteen areas were individually examined. Rankings changed, and certain other species showed locally higher importance values. Guava and kukui tended to dominate in most areas. Several areas in narrow, shady valley segments had 'ohi'a 'ai as the dominant species.

Coffee was abundant in three areas only, all associated with 19th century settlement. Hau, a tree useful for cordage in Hawaiian prehistory, was most abundant in early abandoned inland areas. In lower west Waimanu, site of the latest intensive habitation of the valleys, guava and kukui were much less important than in other locations. These observations generated a number of hypotheses about the relation between environment, history, and species abundance.

Richness values in the quadrats varied from zero to seven: in the sampling areas from a minimum of 2.16 to a maximum of 3.75. The richer quadrats were concentrated on high slopes near the edges of cliffs, and the richest areas were in Pololu, Honokane Iki, and lower West Waimanu.

Habitat Preferences of the Sampled Species

In order to better comprehend the distribution of species, to distinguish the relative importance of environmental versus historical influences in the patterns
evident on the map, habitat preferences of the various species were researched. In addition, references to cultivation practices of Hawaiian farmers were sought out for clues as to distribution.

Much of the habitat information was well-reflected in the data of species abundance. Guava was found in abundance, as literature sources had emphasized. However, the bias towards flat, poorly-drained areas was not explicit in literature describing guava. A hypothesis was made that this association was significant, to be tested later. The connection of mammals to guava distribution was also appropriate with regards to the valleys, where pigs can often be seen feeding on guavas.

Kukui trees are noted for a dominating presence in Hawaiian gulches, and their abundance in the valleys thus seemed explainable. 'Ohi'a 'ai is reported in narrow ravines throughout the islands, in essentially similar conditions to its Kohala habitat. That noni thrives in semi-arid climates in the islands offered a clue as to the seeming preference of noni for well-drained slopes. Many other species were reported to have habits that were congruent with their distribution in the valleys. Mamaki, a native tree, is a good colonizer of disturbed habitats, which helps explain its presence on slopes. Papaya trees are also apt to colonize slopes (with the aid of pigs), and their presence in exceedingly steep talus slopes in the interior of Waimanu, Honokane Nui, and Pololu, often
half-buried in jagged rocks, was thus deemed possibly a product of natural and not cultural dispersal.

The spotty distribution of such species as mango, *Melia*, and lemon is also partially attributable to the difficulty with which each of these species propagate.

Guava and *kukui* are known to out-compete most other lowland species in the islands, and thus their general dominance in the valleys is not unusual. Guava colonizes quickly, and the abandoned valleys offered extensive cleared areas as late as fifty years ago into which guava could establish itself. Slower-growing *kukui* eventually develops a canopy that shields out many other species. Guava and *kukui* are probably still undergoing range adjustment in the valleys.

Tree clumping, apparent especially in guava and *‘ohi’a ’ai*, may be limited to certain dimensions by the effects of seedling predation by mammals. It was observed that cattle cropped *noni* trees to waist height in areas of Pololu, especially where both *noni* and cattle are abundant.

Distribution of species in a naturalized state is a function of habitat preference, colonization rates, competitive ability in any given soil-climate situation, and external factors such as predation and disturbance or dispersal by animals. The analysis of species distribution attempted in this thesis only touches on the complexities of such processes.
Hypothesis Tests Concerning Species/Environment Relationships

Some patterns of environmental control apparent in the maps of this thesis are commonly observed throughout Hawaii, and were explicitly stated as hypotheses after examination of the data. Other patterns were vaguely evident but eluded identification without a careful scrutiny of the data. Spearman's rank-order correlation between environmental factors and predominance and richness data for all valley quadrats was conducted in an effort to identify major trends of variation. Slope and proximity to cliff were found to correlate highly with species richness, and high predominance value in kukui, noni, 'ohi'a 'ai, hala, and ti. Guava predominated under the reverse conditions.

Next, a method was sought by which to actually test the significance of the control apparent in the correlation analysis. The mixture of interval, ordinal, and nominal data types, with positively skewed distributions containing many zeros, presented an obstacle to pattern-seeking methods. Three steps were taken to ensure valid tests of the hypotheses. First, the species abundance variables of concern were reduced to richness plus predominance values for the major ten species. Second, the geographic areas were revised. The number of areas was reduced to four, with some recombination of subsets when justified in terms of geographical integrity. Honokane Iki, lower Honokane
Nui, East Waimanu, and lower West Waimanu were focused upon. Finally, the data were transformed from a mixture of levels to a uniform nominal level (preserving ordinal organization when possible) to facilitate bivariate contingency table analysis. This involved the categorization of the interval-level species predominance data, and the reduction of categories in the ordinarily-valued environmental data.

A standard null hypothesis was constructed, postulating no association between the levels of each environmental variable and the levels of each species abundance variable in the areas under consideration. SAS Pearson's chi-square and Mantel-Haenszel chi-square computer programs enabled the lengthy computation involving several hundred tests of hypotheses to be accomplished quickly. A cutoff level of significance of 0.05 (two-tailed) was imposed, and the contingency tables of the rejected null hypotheses examined for interpretation.

The most consistent relationships that emerged in all areas were associations between species richness and high slope, proximity to cliff, and good drainage. Also prominent was the association between guava predominance and low slope, poor drainage, and distance to cliff. Clearly these phenomena were related. The explanation offered in this paper for these patterns is that a combination of natural and cultural reasons are responsible. First, guava is less competitive in soils
with good drainage. Second, many other trees flourish in this habitat. Third, species from the cliff zone above are easily dispersed as seeds, or sometimes even transported in mass movements, into the talus zone. Finally, this zone was an area of tree crops in prehistoric and historic times, and it still houses many cultural relicts that occupy habitats identical or adjacent to those of their cultivated ancestors.

Other relationships between species and environmental data were also discovered. Coffee’s tendency to abound in the back of valleys, and the preference of noni, 'ulu, and kukui for steep slopes near cliffs were validated statistically. The association of 'ohi'a 'ai with shady, steep locales was also confirmed at a high level of probability.

Most species in most areas, however, were judged as unrelated significantly to measured environmental factors. Some of this is undoubtedly due to the interference of cultural patterns. Much environmental control over species abundance, however, was completely missed by the data collection and analysis techniques. A renewed attempt at assessing environmental control of vegetation would benefit from larger sample size, more precise and numerous environmental variables, and complete coverage of small, discrete areas.
Traces of the Hawaiian Cultivator

The mark of Hawaiians is visible throughout the valleys in the many stone walls, platforms, and terraces they have left. Vegetation constitutes another legacy, one perhaps more subtle but potentially more enduring. Three major categories of this legacy are the flora itself, the differential distribution of Polynesian versus other components of the flora, and the groves and patches of large and uncommon trees.

In the sample areas, the Polynesian component accounted for 48.2% of the importance value, compared with 2.6% for indigenous species and 49.2% for Western species. The magnitude of the Polynesian presence is striking considering the competitive ability of Western weeds such as guava, *Schinus*, and others. Also the Polynesian component is diffuse and extensive, reflecting the complete and long-standing use of the valley during prehistory. Western species seem to be of two types: aggressive weeds, which have rapidly spread throughout the ribbon forest, and less aggressive species, whose geographical inertia enables them to serve as time and space markers of Hawaiian usage. Most Western species are today concentrated near the valley fronts, where they were introduced and cultivated in the late 19th century, after more inland sites were abandoned. *Brassaia, Chrysophyllum, Dombeya*, and *kolomona* are examples. As time goes on, these species may spread and become integrated with the flora of the valleys in general,
but for now their latecomer status is signified in both their low total numbers and their geography.

The distribution of several uncommon species with large individual trees probably mirrors the location of late 19th century settlements. Mango groves are associated with successfully claimed kuleana in the valleys, perhaps indicating that these areas were more favored agricultural sites, or that they were inhabited longer or cultivated more intensively than unclaimed farmsteads. Coconuts, 'ulu, and Melia also mark former homesteads. Melia seems to correspond to late 19th century habitation in eastern Pololu and western Waimanu, while coconut and 'ulu are indicative of sites of that era along with sites probably abandoned before that period. While coconut, mango, and Melia show signs of disappearing, 'ulu appears to be surviving or even spreading, and it will perhaps remain the clearest symbol of the Hawaiian cultivator on the vegetational landscape.

Brassaia (octopus tree), probably introduced in the 1930's, is confined at present to Honokane Iki. This ornamental seems to be expanding its range from a cluster on the cliffs to the forest below (in reality, the original introduction was probably near the Sproat house on the stream terrace). The geography of Brassaia is a perfect example of a point introduction radially expanding its range, a phenomenon undergone by many of the other exotics, the traces of which have mostly been obscured by time.
Future Forests

Size-class data from the sampling quadrats provided a comprehensive, descriptive assessment of the age-structure of the species in the valley region as a whole, as well as data for inferential statistical analysis of individual sampling areas.

In general, the major species in terms of importance value all display size-class structures that indicate a healthy replacement of adults by juveniles. Many of the minor species, however, are represented by large, senescent individuals and are destined to local extinction. Mango, Melia, and lemon will probably not persist into the 21st century unless human activity interferes. Other large trees, including 'ulu, appear to be flourishing, and their diffuse geography helps insure survival. Some very minor floral constituents display healthy size-class structures: Bixa, Brassaia, and Chrysophyllum. Although the future of these species seems assured judging from size-class data, their unilocal geography could mean extinction should a major disturbance such as a large treefall, rockfall, fire, or flood affect the small area which they occupy.

The vegetation of the valleys seems to be adjusting towards some sort of equilibrium, although precisely when it will be reached and what it will be like can still only be a matter of conjecture. Despite the aggressive nature of many Western species, Polynesian trees will probably
retain their predominance in the flora. Kukui, 'ohi'a 'ai, noni, hau, ti, and to some extent, even 'ulu, appear to be viable forest trees.

One indicator of a mature cultural forest is zonation of species to different environmental areas for which they are best suited. The pronounced response of the major species to environmental gradients in long abandoned areas such as East Waimanu and Honokane Iki seem to demonstrate this zonation in process. Another piece of evidence in a developing pair of zones is differential size-class distribution based on habitat suitability. The hypothesis that guava would possess proportionately more juveniles in flat areas and that 'ohi'a 'ai would have more juveniles in steep areas was proposed. Comparison of the independence of size-class proportions of "large" vs. "small" guava and 'ohi'a 'ai trees (compressing five size-classes into two) with flat vs. steep quadrats using Pearson's chi-square constituted a test of this hypothesis. Guava showed a significantly higher proportion of juveniles in flat areas, but the variation in 'ohi'a 'ai was not significant. Guava, being an effective colonizer, had probably extended its range into steep territory, from which it is now retreating due to competition from 'ohi'a 'ai and kukui.

Conclusions

The floral composition of the ribbon forests in the valleys of Kohala demonstrates an enduring legacy of
Hawaiian settlement and cultivation. A minute indigenous remnant persists amid the complex mixture of Polynesian and Western species. There is evidence of environmentally-determined species location in the diverse habitats present in the ribbon forest, but much sorting out is still taking place, and idiosyncratic species occurrences still vividly reflect the human influence.

The forests possess aspects of both jungles and gardens. The almost universal presence of guava is an example of a cultivated species that has completely naturalized and overrun the landscape. Differential abundance of guava in various habitats demonstrates environmental control. Polynesian species such as *kukui*, *ti*, *'ohi'a 'ai*, and *noni* are also very widespread, and somewhat "tuned" to environmental variation. Other species show distributions that are localized, not because of unique environmental conditions, but rather because they are relict trees of occupation and cultivation.

Despite the unusual composition and arrangement of species in the ribbon forests, there is vegetational pattern. This organization contains potential information that can be made explicit by means of precise description, mapping, sampling, and mathematical analysis. The information resident in this and similar forests worldwide can be tapped and used in many types of research, including historical geography, archaeology, ecology, and forestry.
Cultural Forests, Historical Geography and Archaeology

Both historical geography and archaeology attempt to develop explanations for patterns on the landscape, patterns that have been successively imposed, altered, and erased in a fashion reminiscent of a palimpsest, or continually re-used parchment. Many sources contribute to the ultimate explanation, and a potentially valuable source is vegetation. In addition to documentary evidence and physical remains, vegetation may be treated in some ways as an artifact, a concept whose utility is enhanced by considerations given to artifacts by archaeologists.

An archaeologist's perspective is useful when making the leap from acknowledging the similarity of a forest to a garden to inferring the actions that created the components of that garden. An artifact may simply be appreciated as such, or it may be read as a somewhat jumbled text, an approach which entails all the risks of garbled translations, transposed lines, and misattributed quotations. An artifact supplies evidence of the best quality when its proper original location with respect to time and space is well known, and when it can be compared to other, similar artifacts.

Archaeologists call the relative position of an artifact its provenience, a concept that encompasses information on the artifact's site, its physical orientation and attitude, and if buried, its depth and
enclosing strata (Schiffer 1976:133). To capture the meaning of a site requires not only summing the various artifacts but also linking the evidence of proveniences together. The success of this technique suggests several principles to the historical biogeographer.

First, the analysis of location on the micro-scale is of great importance. Although the total flora of a large forest is an important fact, the variation of individual patches is just as important, particularly with respect to how patches reflect the human division of space in each location. The individual artifacts, in other words, the trees, must be understood in relation to each other and to other artifacts: houses, fields, stone walls, and scattered litter. A second principle is that the age of the artifact, its depth in the time strata, is important information. For the recent historic past and for long-lived species, the size of a tree is perhaps the best indicator of its age. Other evidence, more clearly analogous to the archaeologist's provenience, is the superposition of a tree upon house remains, or the appearance of artifacts imposed on the trees (e.g., nailed boards or ropes of a known age), or the position of a tree relative to a stream's cutbank or an avalanche whose era is known.

There is another archaeological concept that has great utility to a historical study of biogeography. Taphonomy is the study of what happens to a bone or other zoological
remain after it is deposited. It may decay, compress, distort, undergo chemical replacements, fossilize, or disappear, depending on the material, the environment, and the duration of its residence. The wood of fallen trees undergoes identical processes, but it is with living matter that this study is concerned. The forest itself, the trees and their generations of seedlings, may be treated as artifacts undergoing physical change. Growth, death, change of aspect, and propagation are some examples of how the original historic or prehistoric tree may have become distorted by the time it is studied. A single tree may over time foster a grove, or a group of intensively-tended cultivated trees may become a group of towering but offspring-less forest giants. A distinct hedgerow may evolve into a vaguely linear grove. And of course, many types of trees simply perish altogether without human care. Understanding the potential destinies of tree species in the human-modified forest benefits from an appreciation of the taphonomy of artifacts.

Applying the idea of the artifact to the individual trees and general flora of an area is useful. For example, the occurrence of large relict trees may indicate a specific land use during a particular period. Such evidence in an archaeological study of an area is circumstantial, but it could also economize excavation siting once survey work has taken place, and also corroborate other evidence.
The Kohala ribbon forest offers several examples of time markers that may have validity and utility throughout Hawaii. *Hau* and *ulu* trees are distributed in inland areas far from the focus of activity of the 19th century and later. Precise maps of their location in an archaeological study might prove as valuable as maps of terraces and walls in delimiting the activity zones of inhabitants of the prehistoric period. Adjustments would have to be made for the subsequent alteration of the geography of the trees. Similarly, mango groves offer an interpretation opportunity because of their apparent correspondence with claimed *kuleana*. The incidence and meaning of this phenomenon in other lowland Hawaiian locations is also worthy of investigation. Trees such as tamarind, lemon, and *Melia* might also be good historical markers. Later exotics, particularly if their date of introduction to an area can be documented, might also prove valuable indicators of a site's latest possible date of abandonment, much as dated coins do in historical archaeology. A knowledge of the habitat preferences and ecological behavior of a species naturalized in Hawaii would be necessary to interpret intelligently distributions of such exotics. Confusing weed trees with relict groves displaying inertial centrism is a possible source of error that could be avoided with such information.

Not only the location of unusual individual trees or groves, but also general floristic makeup is an informative
artifact. The distinction between Polynesian-plus-guava and Polynesian-mixed Western areas in the Kohala ribbon forests probably reflects the differences between areas inhabited after the late 19th century and those abandoned earlier. Precise floral indices could be developed that would make measurement and comparison of such differences useful.

Much of the species patterning uncovered in this thesis is specific to Kohala, but much is applicable throughout windward, lowland Hawaii. The principles investigated here are undoubtedly in operation throughout the world. More attention to the subtleties of current vegetation could contribute to studies of historical geography and archaeology everywhere.

Principles of Ecological Interaction in Cultural Forests

Ecologists have a unique opportunity to observe species interacting in a diversity of habitats in the abandoned regions of the Hawaiian Islands. This interaction is taking place, of course, in an arena entirely distinct from a natural setting. Such disturbed forests represent, however, the most common forests on earth today and in the future.

When a cleared area is abandoned, the ensuing evolution of vegetation is labeled succession, regardless of whether it involves natural or introduced elements. In fact, much research on natural succession has had to rely
on studies of flora that is slightly or substantially non-natural. The observation of the results of succession in the Kohala ribbon forest offers some interesting immediate insights and research opportunities pertaining to ecological theory in a wider sense.

Data from this study may serve as evidence in the issue of whether succession is a floristic relay or simply the differential unfolding of trees with varying life-histories. Guava seems to have quickly colonized many cleared areas, but its range is retreating now that slower colonizing and growing species have successfully established themselves in those habitats to which they are highly adapted. At least in the limited context of an example using exclusively exotic species, the latter model of succession appears more applicable. Research directed specifically at this question in the valleys would be productive.

Mechanisms involved in the operation of succession are also available for scrutiny in these forests. Competitive exclusion of one species by another, either directly, by means of rapid canopy development, or indirectly, through differential susceptibility to predators, is evident in the valley forests. The rapid colonization rate of guava, the stature of kukui, and the tolerance to low light levels of 'ohi'a 'ai all represent competitive advantages that are probably operating currently to create vegetational zones in the forest. The presence of gradients of certain
environmental conditions, especially shadiness (expressed along the dual axes of cliff-to-marsh and inland-seaward lines), also help explain species distribution and offer excellent experimental situations for ecologists.

The location of the ribbon forest in an active talus zone also susceptible to periodic flooding and stream-bank erosion exemplifies continuous disturbance. An interesting question is the degree to which the exotic ribbon forest will achieve stability in the face of such disturbance. In light of the observations made in this research, rapid colonizers such as guava will retain high abundance levels, and less abundant species such as mamaki and papaya will continue to maintain a foothold in the valley flora by capitalizing on the regime of disturbance.

Disturbance seems to promote species richness in the exotic ribbon forest, just as it is postulated to do in natural vegetation (Campbell and Frailey 1984). The richest assemblages in Kohala are in the steepest environments, the product of both human and natural actions. Whether this will be perpetuated as the vegetation evolves, and whether this is a common pattern in exotic forest, is an interesting research question.

The ecological study of disturbed forests may contribute to the improvement of forestry knowledge and practices in Hawaii. The degree to which various species tend to displace native vegetation should be important information for foresters concerned with selecting
appropriate trees for replanting. Regulation of agricultural enterprises involving new species near native forests could benefit by such research. The fact that guava is a risk near native forests is patently obvious -- and yet new hybrids of guava that take advantage of Hawaii's diversity of climates are being planted at higher altitudes. Even if such obvious dangers are averted, more subtle threats exist unnoticed because of the relative lack of concern with exotic forest ecology.

Another intriguing phenomenon is the differential success of introduced species in lowland (up to 750 m) vs. upland Hawaiian forests. To what extent is lack of disturbance responsible for the maintenance of native forests at altitude? Were the competitive advantages possessed by upland species, many of which are the products of adaptive radiation from the lowlands, of benefit in the preservation of native forests? Or is the phenomenon just an artifact of the relatively less intense disturbance experienced in the uplands? How susceptible are these forests today to exotic incursion, and which lowland exotics pose the most danger? The interaction patterns of lowland exotics may provide crucial data for the survival of the remaining native forests.

The native forest in the valleys is gone, and will probably never revive, despite the lingering presence of a few hardy species. The ribbon forest of fruit trees in Kohala remains as a reminder that the abandoned valleys
once were a focus of Polynesian settlement and agriculture, and are thus uniquely Hawaiian.
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### APPENDIX

#### Cross-index of Species Names

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<td>mamane</td>
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<td>?</td>
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<td>Syzygium jambos</td>
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<td>wi<code>awa</code>awa</td>
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<td>Terminalia catappa</td>
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<td>Touchardia latifolia</td>
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<td>Washingtonia sp.</td>
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</table>
VITA

Ron Terry was born in San Diego, California on November 16, 1953. His family moved to Utah and then back to California, where he graduated from Redlands High School in 1971. A fascination with the tropics led to travels to Mexico and the island of Hawaii, where he began college in 1977. The diverse physical and cultural landscape of the Hawaiian Islands inspired an interest in the study of Geography. He came to Louisiana State because of its strong reputation as a field-oriented school. The stimulating academic environment there caused him to look with renewed appreciation at Hawaii, where he returned to research cultural vegetation in windward valleys. Between field seasons he worked as an instructor in Adult Education in the Louisiana Public Schools. Later, while writing this dissertation, he was employed as a Geographic Information Systems specialist by the Louisiana Division of Coastal Management. Out of these varied experiences Mr. Terry has developed interests and expertise in Tropical Biogeography, Geography and Education, and especially Remote Sensing and Geographic Information Systems. He began work as Assistant Professor of Geography at the University of Hawaii at Hilo in August of 1987. He currently resides in the village of Volcano.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Ronald Norman Terry

Major Field: Geography

Title of Dissertation: THE LEGACY OF THE HAWAIIAN CULTIVATOR IN WINDWARD VALLEYS OF HAWAII

Approved:

[Signature]
Major Professor and Chairman

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Dean of the Graduate School

EXAMINING COMMITTEE:

[Signature]

[Signature]

[Signature]

[Signature]

Date of Examination:

Nov. 9, 1987