EFFECTS OF ABORIGINAL PEOPLE ON VEGETATION OF THE HAWAIIAN ISLANDS

The Hawaiian Islands were settled by ocean-voyaging Polynesians, probably from the Marquesas, an island group 4,000 km (2,400 mi) to the southeast. Evidence for the affinity of the Hawaiian and Marquesan peoples is derived from similarities of language, body type, and agricultural plants (Kirch 1985a). However, there may have been more than one wave of immigration, and contact between Hawai‘i and island groups other than the Marquesas (i.e., the Society Islands) apparently occurred as well (Dye, in press).

The time of first settlement has been variously reported. Earlier estimates were often around 800 A.D. (Green 1971; Handy and Handy 1972), but Kirch (1985a) estimated that colonization of the Hawaiian Islands occurred as early as 300 A.D., or more conservatively 400 A.D. (Kirch 1982). Kirch reasoned that such an early date for first arrival is likely because permanent settlements were distributed on all the main islands by the 6th century and such development would have required time. One of the earliest dated archaeological sites that has been excavated is the Bellows or Waimanalo Beach site on O‘ahu, which appears to have been initially occupied between 450 and 500 A.D. (Kirch 1974) or possibly as early as 327 A.D. (Tuggle et al. 1978). Another site of early human habitation is Hālawa Dunes on Moloka‘i, dated from 600 A.D. (Kirch 1974; Kirch and Kelly 1975).

Human Population Size

Although humans have been occupying the Hawaiian Islands for more than 1,500 years, the size of the original population was probably quite low, and the impact on the Hawaiian environment was correspondingly small at first. The original group settling the Islands may have been as few as 100 people (Kirch 1982). This population built up relatively slowly, and by the end of the colonization period (600 A.D.) may have amounted to only 1,000 people (Kirch 1985a). Then ensued a period of development, lasting until about 1100 A.D., in which the population increased and expanded outward until settlements were scattered throughout the lowlands of the main Hawaiian Islands. There were still lands available for agriculture and ample resources to be exploited (Kirch 1985a). Even in favorable localities, such as Hālawa Valley, Moloka‘i, human populations may have remained relatively low until the 13th or 14th century (Kirch and Kelly 1975).

After about 1100 A.D., the Hawaiian population began to increase dramatically, on the western part of Hawai‘i Island doubling every century (Kirch 1985a), and agricultural systems were expanded and intensified (Rosendahl 1974). A population peak (usually estimated at several hundred thousand) was reached around 1650 A.D., more than 100 years before contact with Europeans (Kirch 1982; Kelly 1983). It was at this population peak, or shortly before, that Hawaiians began to inhabit less favorable coastline areas (Griffin et al. 1971) and barren zones between the coast and upland agricultural sites (Rosendahl 1973) and to develop extensive dryland agricultural systems in marginal regions (Kirch 1985a).
Large-scale irrigation works and permanent field systems were developed during the expansion period. Population densities in the fertile windward valleys may have approached 250 people/km² (Kirch 1982), although densities in tablelands and elsewhere would have been much lower (Newman 1969). There is evidence from archaeological studies on West Hawai'i that after 1650 A.D. the Hawaiian population declined (Hommon 1976), or at least the rate of growth greatly decreased. In some marginal habitats such as Kaho'olawe, the human population may have declined even earlier (by 1550 A.D.), probably because of environmental degradation caused by clearing natural vegetation (Hommon 1980). Assuming that the population of the Hawaiian Islands was declining more than 100 years before contact with Europeans, Kirch (1982) speculated that the ability of the Islands to support a high human population had been surpassed and that environmental deterioration was occurring, reducing the land's carrying capacity. Abandonment of some dry coastal sites, such as Wai'ahukini in the Kaʻu District (Emory et al. 1969) and Kalāhuipuaʻa in the South Kohala District of Hawaiʻi Island (Kirch 1979), occurred in this late prehistoric period.

The population of the Hawaiian Islands at the time of initial European contact has been variously estimated at 200,000 (Schmitt 1971) to greater than 1 million (Stannard 1989). Captain James King, who was on Cook's voyage to Hawaiʻi in 1778-79, used settlements along Kealakekua Bay to project a population of 150,000 for the island of Hawaiʻi alone and calculated a total of 400,000 people for all the Hawaiian Islands (Schmitt 1968). Stannard (1989) based his population estimate of 800,000 to 1 million on a re-evaluation of estimates and assumptions of early European visitors to Hawaiʻi and on a comparison with accepted population estimates in similar areas of Eastern Polynesia.

Stannard (1989) speculated that a great decrease in the Hawaiian population began immediately after the first arrival of Europeans (1778), who brought with them diseases such as syphilis, tuberculosis, and influenza. Since the isolated Hawaiian people had no acquired immunity to these and other diseases, the result was a devastating loss of perhaps more than half the pre-European contact population in less than 25 years. Stannard postulated a population decline ratio of 20 to 1 within 100 years of western contact.

Missionaries began taking censuses of the Hawaiian population in the 1830s, and by the 1850s the records indicated a dramatic decline. The district of Kaʻu on Hawaiʻi Island, for example, lost half its population between 1835 and 1853, and the censused number of people in Kaʻu in 1855 is thought to be only about 15% of the projected population in 1778 (Kelly 1969). Schmitt (1968) estimated that the population of the island of Hawaiʻi decreased from 120,000 in 1779 to 46,000 in 1831 because of diseases and disruption of the Hawaiian economic system. With the change to a money economy, centers of population shifted, and many formerly productive agricultural areas and fishing villages were depopulated or completely abandoned. For example, during early historical times, Hālawa Valley on Molokaʻi supported 400 people (Griffin et al. 1971); today it is almost uninhabited. Likewise, fishing villages all along the Kaʻu coast, such as Kealakomo where William Ellis reported more than 300 people gathering to hear a sermon in 1823 (Ellis 1827), were deserted by the end of the 19th century.

Agriculture

Kirch (1985a) called vegetation alteration for agriculture "the greatest force leading to environmental change in pre-contact times." Permanent agriculture in Hawaiʻi
took two main forms: wetland taro or kalo (Colocasia esculenta) cultivation, and dryland cultivation of sweet potato (Ipomoea batatas), taro, and other crops. Irrigation systems in valleys of the Hawaiian Islands were both intensive and sophisticated; they are among the largest recorded in Polynesia (Kirch 1985a). In essentially every valley with a permanent stream, taro fields were irrigated (Handy and Handy 1972; Kirch 1982). Irrigation systems varied in size and complexity in the different valleys of the islands, but most were composed of pondfields or terraces (lo'i) constructed of stone, and ditches or 'auwai. The earliest dated irrigation system is that of Hanalei, Kaua'i, estimated at 600 A.D. (Kirch 1982). There is some disagreement among archaeologists about the meaning of this early date for Hanalei. Some believe that the 7th century date represents habitation in the area before pond and terrace construction, and that large-scale irrigation works were developed much later, in the 13th to 15th centuries (Kirch 1985a). Occupation of other nearby Kaua'i sites has been dated to the 10th century, with speculation that intensive irrigation agriculture did not begin until the 15th century (Hammatt et al. 1978; Kirch 1985a). Many other valleys on O'ahu and Moloka'i were first irrigated between 1400 and 1500 A.D. (Yen et al. 1972; Kirch and Kelly 1975). While wet cultivation of taro probably began with the earliest Hawaiian colonizers, major irrigation works were relatively late developments dating from the 15th to the 19th century (Kirch 1985b).

Valleys of windward Kaua'i, Moloka'i, Maui, and Kohala District on Hawai'i Island, as well as both windward and leeward valleys of O'ahu, show abundant evidence of Hawaiian irrigation farming (Kirch 1985a). Some sites, such as Ke'anae on Maui and Waipio on Hawai'i, have never ceased taro cultivation. However, some of the most productive taro lands today (in the lowest alluvial plains of valleys) were only marginal or not used by prehistoric Hawaiians because of limitations in their drainage technology (Spriggs 1985). Since it was only in the 1960s that remains of agricultural systems were recognized as important archaeological sites, many important agricultural areas of the past have been urbanized and developed, such as Makaha, O'ahu (Yen et al. 1972).

Because of the great production of food available from irrigated taro fields, or perhaps because of the number of people required to construct and care for such irrigation systems, important sites of irrigation farming were also centers of population in ancient Hawai'i. On Kaua'i, these centers were located at Kapaa, Nawiliwili Bay, Waimea, Hanapēpē Valley, and along the Nā Pali coast. O'ahu, which had the greatest amount of irrigated taro-producing land in the Islands, had its densest human population at Waikiki and the large valleys nearby. Other heavily populated irrigated taro lands were found along the North Shore and in windward valleys between Lā'ie and Kāne'ohe. The most populated areas of Maui were streams between Kahakuloa and Waikapū, including Wailuku; Lahaina and adjacent small valleys; and the northern shore of East Maui near Ke'anae and Hāna (Handy and Handy 1972). Kahikinui, on the south slope of Haleakalā, apparently supported a large population in both coastal and upland agricultural zones (Kirch 1985a). Moloka'i inhabitants were concentrated in the windward valleys of the eastern half of the island, particularly Hālawa, Wailau, Pelekunu, and Waikolu (Kirch 1985a). Excepting Waikiki, Kāne'ohe, Lahaina, and Wailuku, most of these early centers of habitation do not correspond with modern cities.

The smaller islands of Ni'ihau and Lāna'i, as well as western Moloka'i, had no wetland taro cultivation, and the relatively low human populations of these areas depended on the sweet potato and yam (Dioscorea alata) as major crops (Handy and Handy 1972). The sweet potato or 'uala was the most important crop of dryland
cultivation systems because of its high yields under dry conditions and the ease with which it could be propagated (Yen 1974; Kirch 1985b). The uplands of Kaho‘olawe were apparently cultivated in the past, but dryland farming ceased there long before Europeans arrived to record it (Hommon 1980; Kirch 1985a).

Hawai‘i Island may be used as an example of the sequence of Hawaiian agricultural development, as much archaeological work has been done there. The first humans to colonize the island of Hawai‘i probably settled initially along the Kona coast and in valleys of the eastern part of the Kohala District (Newman 1969). West Hawai‘i was settled by 750 A.D., if not earlier (Kirch 1974). The general pattern for settlement in North Kona began with the occupation of the coast, where the exploitation of marine resources was more important than farming. Later, the center of habitation moved upland to an area with greater rainfall, and extensive agriculture was the main way of life (Rosendahl 1973). The farmers of the uplands then traded with the fishing communities, exchanging agricultural produce for fish and shellfish.

Kirch (1985a) outlined the sequence of agricultural development and the corresponding population growth and cultural development on the island of Hawai‘i. When the population was small, agriculture was primarily shifting cultivation (slash and burn or swidden) with long fallow periods. As the human population increased, the amount of area cultivated increased, cultivators moved upland, and the fallow period between crops decreased. Eventually, permanent agriculture displaced swiddening over most of the Island (Newman 1969).

**Hawai‘i Island Field Systems.** Two main permanent agricultural zones existed on the island of Hawai‘i: the eastern valleys of the Kohala District, in which irrigation was practiced on a large scale, and tablelands, which were primarily sites of dryland farming. The dry farming areas may be further divided into scattered fields of the lower windward slopes of the Hāmākua, Hilo, and Puna Districts, and large field systems of Kohala, Waimea, Kona, and Ka‘ū (Newman 1969). The four large field systems occurred in the only regions of leeward Hawai‘i with soils suitable for agriculture and annual rainfall greater than 500 mm (20 in.) (Kirch 1985a). These leeward sites also originally supported open vegetation more amenable to clearing (with stone tools and slash and burn techniques) than the dense rain forests of the windward slopes. Sophisticated dryland field systems were developed primarily on leeward Hawai‘i, but also on leeward East Maui, and were intensifications or extensions of past shifting agriculture (Kirch 1985a). The areas supporting the large field systems, particularly Kona and Kaʻū, which also had rich fishing grounds offshore, were centers of population on the island of Hawai‘i.

**Kona Field System.** The Kona field system was the most highly developed agricultural area of Hawai‘i Island (Handy and Handy 1972) and may have supported more than half the total population of the island at the time of European contact (Kelly 1983). Although it has not been completely mapped, the Kona field system was a band 5 km (3 mi) wide and 29 km (18 mi) long, located above Kailua and Kealakekua (Newman 1970). This single cultivated area covered an estimated 139 km² (56 mi²) (Kirch 1985a), more than 1% of the entire land area of the island of Hawai‘i. This is even more significant when one considers that greater than 86% of the Island’s area is currently considered unsuitable for agriculture (Schmitt 1989). The best-preserved portions of the system are in the uplands of Kealakekua (Kirch 1985a), where stone and earth walls run both perpendicular and parallel to the slope, defining long.
rectangular fields. The Kona field system is depicted in early drawings of Kailua by the missionary William Ellis and by Lucy Thurston (Ellis 1827; Kelly 1983).

Four distinct zones of cultivation at Kona were described by Kelly (1983). The first was the *kula* lands, the dry coastal plain up to about 150 m (500 ft) elevation. Where soil was sufficient, sweet potatoes (*Ipomoea batatas*) and *wauke* (*Broussonetia papyrifera*) were cultivated. The kula zone was also the area in which fields of *pili* grass (*Heteropogon contortus*), used for thatching by Hawaiians, were encouraged through the use of fire (Kirch 1985a). Above this, up to about 300 m (1,000 ft) elevation, was the *kalu‘ulu* zone, where plantations of *‘ulu* or breadfruit (*Artocarpus altilis*) were prominent, but sweet potatoes and wauke were also planted, apparently among the trees (Kelly 1983). The botanist Menzies (1920), passing through this zone above Kealakekua in 1793, described the kalu‘ulu zone in some detail, commenting on the beauty of the breadfruit trees and the industry displayed in Hawaiian cultivation. More than any other aspect of the Kona field system, intensive breadfruit plantations are indicative of organization and central planning and suggest participation of some central authority in their development (Kelly 1983).

At an elevation above the kalu‘ulu zone, from 305 to 760 m (1,000-2,500 ft), was the *‘apa‘a* zone, perhaps the most intensively cultivated and productive of all the zones (Kelly 1983). Primary crops there were dryland taro (*Colocasia esculenta*) and sweet potato. A detailed description of the mulching technique of dryland taro cultivation was given by Menzies (1920). Menzies also mentioned ‘*ti* (*Cordyline fruticosa*) and sugar cane (*Saccharum officinarum*) on the rocky field boundaries.

The uppermost zone of the Kona field system was the *‘ama‘u*, named for the native ferns (*Sadleria* spp.) that grew there (Kelly 1983). This area was still partially forested and was planted with bananas (*Musa x paradisiaca*). Other activities of the Hawaiians in this zone included felling trees for canoes, catching birds for feathered apparel, and collecting *mamaki* (*Pipturus albidus*) and other wild plants (Kelly 1983). Early explorers such as Captain King in 1778-79 estimated that the edge of the "wood" above Kealakekua was 10 to 11 km (6-7 mi) from the shore, although parts of the forest separated by cultivated lands reached to within 3 km (2 mi) of the coast (Beaglehole 1967).

**Kohala Field System.** Although the Kona field system may have been the largest and most developed on Hawai‘i Island, the Kohala field system has been more intensively studied (Kirch 1985a). At its greatest extent, the Kohala system was 3 km (2 mi) wide and stretched for 20 km (12 mi) along the western flank of the Kohala Mountains from ‘Upolu to Kawaihae-uka (Rosendahl 1974). By the time of European contact, the field system was conspicuous even when viewed from the sea: Menzies noted the land laid out into small fields and commented on the sign of "industrious cultivation" while sailing to Kawaihae from Hamākua with Captain George Vancouver in 1793 (Menzies 1920).

The most extensive archaeological work on the Kohala field system has been carried out at Lapakahi, an *ahu‘pua‘a* (land division) 1 km (0.6 mi) wide and 7 km (4 mi) long. Lapakahi was settled around 1300 A.D., possibly by people from the windward Kohala valleys; its population was first centered in small coastal communities primarily engaged in fishing (Griffin et al. 1971). For 200 years, the population increased and the uplands were developed for agriculture. Until about 1500 A.D., agriculture was shifting cultivation using slash and burn techniques and long fallow periods. Between 1500 and 1800 A.D., agriculture expanded, intensified, and became permanent (Rosendahl
At the peak of population and production, the settlement pattern of the ahupua'a was characterized by a coastal zone of fishing villages; an intermediate, largely unoccupied zone directly upslope; and the upland agricultural zone about 3 km (2 mi) from the coast, where annual rainfall was 410 mm (16 in.) (Griffin et al. 1971; Rosendahl 1974). The upland and coastal zones were connected by a series of trails, indicating a close association of the two inhabited areas (Griffin et al. 1971).

The primary crop of the narrow, rectangular Lapakahi fields (and thus the Kohala system) was the sweet potato or 'uala (Ipomoea batatas), but at least a dozen other food and fiber plants were cultivated there (Rosendahl 1974). Carbonized remains of some of these crop plants have been recovered from excavations at Lapakahi (Griffin et al. 1971). Although the population supported by agriculture (and fishing) was quite large in 1850, and habitations were numerous both in the uplands and along the coast, the agricultural system and economy collapsed in the second half of the 19th century, due to severe decline in the Hawaiian population, destruction of planted fields by cattle, and economic upheaval with the conversion to a cash economy. By 1900, Lapakahi was abandoned, its remaining inhabitants moved elsewhere, and the area was incorporated into cattle ranches (Griffin et al. 1971; Rosendahl 1974).

**Waimea Field System.** Another major field system of the Island occurred at Waimea (Waimea-Lalámilo). Early European visitors to Waimea such as Menzies (1920), who passed through the area in 1793, commented on the "plantations" and apparent fertility of the region. Thirty years later, Ellis (1827) described four villages of Waimea surrounded by plantations and estimated the population as 1,100-1,200. Some of the Hawaiian farms of Waimea were still cultivated as late as 1935 (Handy and Handy 1972), and numerous old Hawaiian fields and waterworks are known from the region (Barrera and Kelly 1974).

The Waimea agricultural system was located in an arc to the west and south of the present village and was composed of four separate complexes. One of the complexes is on the slopes above Waimea village, while the other three are on the plains near streams. Unlike the field systems of Kona and Kohala, the Waimea fields were irrigated, as indicated by the many remains of 'auwai or ditches, which diverted water from streams to the fields. However, this irrigation system was not the typical pondfield development such as is found in the windward valleys, but rather a "supplemental" system to allow periodic watering of fields or terraces (Clark 1983a). Only a few actual stone-constructed pondfields or lo'i for wetland taro cultivation have been found in the Waimea complex. In the upslope fields, ditches were constructed, apparently to drain the fields (Clark 1983a). The main crops were taro (Colocasia esculenta) and bananas (Musa x paradisiaca) (Clark 1983b). Stone mounds for the cultivation of sweet potatoes (Ipomoea batatas) and gourds (Lagenaria siceraria) have also been found (Clark 1983a).

The Waimea agricultural complex was occupied from the 13th or 14th century (Clark 1983b). At lower elevations between Kawaihae and Waimea, archaeological remains (mounds, cairns, and terraces) of dryland cultivation of sweet potatoes and gourds have been dated from 1600 to 1800 A.D. (Welch 1983). That Kawaihae was an important Hawaiian village is indicated by the immense Pu'u Koholā Heiau built nearby (Barrera and Kelly 1974). In 1824, Ellis (1827) estimated that Kawaihae had a population of 500.

In a discussion of early historic (1792-1850) vegetation patterns for the Kawaihae/Waimea area, McEldowney (1983) recognized 12 vegetation types. The dry lowlands
upslope of Kawaihae were called pili lands and were described by early European visitors as "barren" and treeless. These were grasslands, perhaps of the indigenous pili (Heteropogon contortus) and were probably maintained by Hawaiians through the use of fire. Above and to the north of the pili lands were the cultivated kula lands and a region called ulu lā'au, in which fields and homes were scattered among native trees, probably ʻōhiʻa (Metrosideros polymorpha). During this historic period and the previous period of Hawaiian occupation, native forests were still present on the Waimea plains and the slopes of Mauna Kea and the Kohala Mountains. McEldowney mapped four different mesic forest types, primarily of koa (Acacia koa) and māmane (Sophora chrysophylla), to the south and east of the cultivated kula and ulu lā'au lands. Additionally, an extensive band of ʻōhiʻa and ʻōhiʻa/koa rain forest was present upslope of the Hawaiian agricultural area, on the Kohala Mountains and stretching to the east above the Hamākua coast. Clark (1983b) speculated that strong sociocultural pressures existed among the Hawaiians to prevent expansion of settlement and cultivation into the forested uplands and to maintain the forest resources for later exploitation.

Kaʻū Field System. Kaʻū is another district of the island of Hawaiʻi that supported a major Hawaiian field system; it is also the least well known. Newman (1972) reported two Kaʻū sites with extensive agriculture, one west and one north of Punaluʻu. The earliest European explorers, such as Captain King in 1779, were impressed with the barrenness of the many lava flows in Kaʻū and mentioned the scattered fishing villages along the coast; however, King wrote nothing of the area's agriculture (Beaglehole 1967). A lithograph made by an artist who accompanied Captain Vancouver in 1792-94 depicted an orderly, well-developed field system upslope of the village of Makakupu in Kaʻū, near the present Wood Valley (reproduced in Kirch 1985a). Forty years after Cook, Ellis (1827) noted that Kaʻū was populous near Waiʻōhinu, Kaʻaluʻalu, and Kapāpala and observed that the population was scattered over the countryside where numerous taro (Colocasia esculenta) and sweet potato (Ipomoea batatas) fields were cultivated.

Waiʻōhinu was possibly the most important village of the district, because of its location on the only continuously flowing stream in Kaʻū (Kelly and Crozier 1972). Handy and Handy (1972) catalogued other important sites of habitation in Kaʻū; of these, Hīlea was perhaps the richest inland site for agriculture, supporting a number of crops, of which dryland taro was the most important. The true extent of the Hawaiian cultivation in these and other historical sites, as well as their possible connections to form an integrated Kaʻū field system similar to that of Kona and Waimea, is not understood, as the archaeology of these areas has not been thoroughly examined (Kirch 1985a). Newman (1972) speculated that a fifth field system may have been present in Puna, southwest of Kapoho, but much of this area was buried by the Kīlauea eruptions of 1955 and 1960, so the actual extent of past agriculture there may never be known.

Scattered Fields. While the bulk of the aboriginal Hawaiian population was supported by irrigated taro (Colocasia esculenta) cultivation in valleys or by the intensive farming of large field systems, scattered dryland fields in which shifting cultivation was practiced were also important in pre-contact Hawaiian agriculture. Dryland cultivation, particularly of taro and sweet potato (Ipomoea batatas), was undertaken on all the Islands, even those where taro irrigation was widespread, such as Kauaʻi and Oʻahu (Handy and Handy 1972; Kirch 1985a). Areas that seem completely unsuitable for agriculture today were apparently cultivated by Hawaiians, perhaps during
a pre-European contact population peak. Examples of seemingly non-arable sites are Kaho'olawe, which supported sweet potato and yam (Dioscorea spp.) cultivation (Myhre 1970), and Barbers Point, O'ahu, where archaeological remains suggest that between 1200 and 1870 A.D. Hawaiians were growing crops in mulched sinkhole pit gardens, behind windbreaks, and along margins of wetlands (Davis 1982).

On the island of Hawai'i, scattered fields interspersed with habitations were numerous along the lower windward slopes, where they were noted by many early European explorers and visitors. Captain King in 1778-79 noted that the slopes along the Hamakua coast seemed "fully cultivated" (Beaglehole 1967). Forty years later, the naturalist James Macrae (Macrae 1972) and William Ellis (1827) observed many Hawaiian "plantations" in a band 6 to 10 km (4-6 mi) wide along the coast. For 64 km (40 mi) northwest of Hilo, forests were seen only above this zone of cultivation and on the bottoms and steep sides of ravines (Macrae 1972). McEldowney (1983) presented historical evidence for a band of agricultural land that stretched between Waipi'o Valley and Hilo during the early historical period (until 1850). The zone contained actively cultivated fields, many fallow fields in which grasses and ferns grew, and groves of useful trees such as *hala* (Pandanus tectorius), *kukui* (Aleurites moluccana), mountain apple or *ōhi'a* 'ai (*Syzygium malaccense*), and breadfruit or 'ulu (*Artocarpus altilis*). This Hamakua coastal zone of habitation and cultivation was politically distinct from the nearby settlements of Waimea, from which it was separated by a dense rain forest crossed by foot-trails (McEldowney 1983).

While the Hilo area did not support a population as dense as that of leeward Hawai'i, during the early historical period Hawaiian settlements were found on Hilo Bay and in six villages along the Puna coast between Hilo and Cape Kumukahi, in areas with old lava flows and good soil development (McEldowney 1979). In marshy sites near streams and rivers of Hilo, wetland taro was cultivated (Handy and Handy 1972), supporting an estimated 400 people in the early 19th century (Ellis 1827). Many early visitors to windward Hawai'i who travelled between Hilo and Kilauea mentioned two zones of cultivation: one near the shore 6 to 8 km (4-5 mi) wide and another more than 24 km (15 mi) above Hilo Bay, separated from the lower zone by dense forest (Bloxam 1925; Macrae 1972). The upland agricultural zone, with its upper limit near 460 m (1,500 ft) elevation (near present-day Mountain View), was characterized by small plots of taro and banana (*Musa x paradisiaca*), and much unwooded land covered by grasses, ferns, native shrubs, and scattered trees. These uncultivated lands were probably areas allowed to go fallow in the Hawaiian shifting system of slash and burn cultivation, but they also provided food in times of famine from arrowroot or *pia* (*Tacca leontopetaloides*), *ri* (*Cordyline fruticosa*), and the native *ama'u* fern (*Sadleria* spp.). Above this upland agricultural zone was the lower forest, where resources were periodically exploited by Hawaiians, but permanent cultivation did not take place (McEldowney 1979).

Puna was thought by Captain King in 1779 to be very sparsely populated (Beaglehole 1967). However, in 1823, Ellis (1827) reported relatively large populations in communities such as Kaimu, Keheha, Kamā'ilī, Kea'au, and 'Ola'a, where people were cultivating taro, sweet potatoes, bananas, and sugar cane (*Saccharum officinarum*). Ellis commented on the groves of coconuts (*Cocos nucifera*) and kou trees (*Cordia subcordata*) at Kaimu and estimated the population at 725 with a total of 2,000 people in the vicinity. Coastal hala forest and "fern-covered plains" of Puna were modified and planted with taro; tree fern (*Cibotium* spp.) forests of the uplands were also used for taro cultivation after the ferns were uprooted (Handy and Handy 1972).
Cultivated lands of the Ka'ū District were either part of a field system or were scattered fields, drier but otherwise similar to those of Puna. Much of the Ka'ū and South Kona coast was too dry for agriculture but supported numerous small fishing villages (Ellis 1827; Beaglehole 1967).

Vegetation Replacement, Deforestation, and Erosion

Deforestation and erosion were the natural results of Hawaiian agriculture. There can be no doubt that Hawaiians greatly altered the lowland vegetation of the Hawaiian Islands, particularly during the period of expansion in population and intensification of agriculture between 1100 and 1650 A.D. (Kirch 1985a). Environmental changes associated with deforestation (apart from the simple loss of species) include increase in solar radiation; decrease in soil moisture, permeability, and surface water retention; faster run-off; lower water table and altered micro-climates; and drought (Newman 1969).

The forests of the irrigated valleys and windward slopes were often replaced completely by the taro ponds, gardens, habitations, and introduced tree species of the Hawaiians. Replacement was accomplished early in the sequence of Hawaiian cultural development by manually clearing the trees and burning vegetation. European botanists and naturalists who visited Hawai'i in the first few decades after Captain Cook's voyage to the Islands described the windward lowlands as a cultivated region several miles wide (Douglas 1914; Menzies 1920; Beaglehole 1967; Macrae 1972). Often such explorers encountered native plants only at the extreme heads of cultivated valleys or on ridges overlooking them. Erosion sometimes followed the clearing of valley slopes and nearby ridges for cultivation, and downslope effects on land fertility, water quality, run-off, and marine environments have been noted (Spriggs 1985). The capability of the land to grow crops, and undoubtedly the size of the human population, also influenced deforestation patterns and progress.

Ni'ihau and Kaua'i. In 1778, the island of Ni'ihau was described by David Samwell as a "low land entirely bare of trees" (Handy and Handy 1972). That this view was something of an oversimplification based on a short and limited visit is indicated by the several native tree and shrub species that St. John (1959) was able to collect on valley walls and cliffs of eastern Ni'ihau during two trips there in 1947 and 1949. These woody plants, as well as those collected on Ni'ihau by earlier botanists, are species adapted to dry forests and include wiliwili (Erythrina sandwicensis) and kulu'i (Nototrichium sandwicense). One seemingly anomalous plant collected from Ni'ihau in the 1860s is Delissea niihauenensis, thought by St. John (1959) to indicate the past occurrence of a moist forest in the uplands. However, Ni'ihau probably never had a rain forest, because of dry climatic conditions due to its position in the lee of Kaua'i (St. John 1982). Even though native woody plants did persist into the 20th century, it seems likely that the original dry and mesic forests of Ni'ihau were largely destroyed by Hawaiian land practices before the arrival of continental man.

The adjacent and much larger island of Kaua'i has fared far better than Ni'ihau and still retains a significant cover of native vegetation at higher elevations. Nonetheless, Hawaiian cultivation left its mark on that island, particularly in the densely populated, well-watered stream valleys of the northern and eastern sides. The valleys of the Nā Pali coast are archaeologically rich and display the remains of extensive irrigation systems (Kirch 1985a). Although undeveloped since their abandonment by Hawaiians, these valleys currently support native vegetation only at their extreme heads.
and on steep cliffs and ridges (Corn et al. 1979), indicating the replacement of natural vegetation by Hawaiian land practices. Of course, the presence of domestic cattle (Bos taurus) and feral goats (Capra hircus) after European arrival undoubtedly played a role in the displacement of native plants. The impacts of Hawaiian agriculture on many other lowland slopes and valleys of Kaua'i are difficult to assess, as most wet areas below 460 m (1,500 ft) elevation have been used for sugar plantations or cattle grazing after European contact (Armstrong 1983).

**O'ahu.** In a trip to Nu'uanu Valley, O'ahu, in 1825, Macrae (1972) estimated that he had walked 8 km (5 mi) through taro (Colocasia esculenta) fields and other crops before he reached the "woods." Even then, the first trees he mentioned were Polynesian introductions such as kukui (Aleurites moluccana) and mountain apple (Syzygium malaccense), and it was only after Macrae continued inland that he began to see native trees such as koa (Acacia koa), kōpiko (Psychotria sp.), ʻōhiʻa (Metrosideros polymorpha), and "lobelia" (probably a species of Clermontia). Meyen (1981) gave a similar description of his trip to Nu'uanu Valley and ascent to the pali (cliff) edge in 1831. It was only in the upper reaches of Nu'uanu, which had only a few huts and small cultivated fields, that Meyen saw the native ʻōhiʻa. The density of the native vegetation and the variety of plant life impressed the young naturalist, and he listed dozens of native ferns, mosses, herbs, Cyrtandra species, and members of the family Lobeliaceae, which he observed and collected near the head of the Valley.

Apparently, Nu'uanu was fairly typical of southeastern O'ahu valleys, for Macrae (1972) commented that Mānoa Valley was also cultivated to its upper reaches. MacCaughey (1917) listed a few native plants that still occurred on the Mānoa Valley floor in the early 20th century and speculated that the lower talus slopes had been covered with native trees in Hawaiian times. In 1831 Meyen (1981) climbed to 245 m (800 ft) elevation above Punchbowl Crater before he began to record native plants. Kukui was prominent in his description of the vegetation, along with koa, tree ferns (Cibotium spp.), olonā (Touchardia latifolia), and Clermontia.

Archaeological evidence of erosion has been gathered from several sites on O'ahu. Severe upslope erosion is indicated in Mākaha Valley, where irrigation systems were buried under material washed downstream (Yen et al. 1972). Degradation and erosion due to clearing and agriculture may have been responsible for the repeated flooding of Kamoʻolāliʻi Stream in upland Kāneʻohe during the period of Hawaiian habitation (Rosendahl 1976). The two most extreme examples of erosion during the prehistoric Hawaiian period are Kahana Valley, where an entire bay has been filled in by sediments from cleared lands upslope, and Kawainui Marsh, which was formerly on the coast (Kirch 1985a). Erosion from upslope forest clearing and swidden agriculture on adjacent slopes led to sedimentation and infilling of the Kawainui basin, which was first a bay, then a lagoon and fishpond, and later a marsh (Kelly and Clark 1980; Spriggs 1985). Some have speculated that erosion was encouraged by the Hawaiians to increase fertility of lowland agricultural areas.

**Maui, Lānaʻi, and Molokaʻi.** Although Maui is the second largest of the Hawaiian Islands, little archaeological work has been carried out there (Kirch 1985a). Many stream valleys and well-watered slopes of West Maui are known to have been settled early (Kirch 1974) and eventually supported large populations and intensive irrigation cultivation (Handy and Handy 1972; Kirch 1985a). Thus, vegetation in lowland sites of West Maui was probably replaced early during the Hawaiian period.
A similar replacement of natural vegetation by wetland cultivation of taro (Colocasia esculenta) probably also occurred in the lower valleys and slopes of windward East Maui, although the history and archaeology of this area are not well understood (Kirch 1985a). Archaeological investigations of leeward East Maui, however, indicate a large concentration of habitations and dryland cultivation between 400 and 700 m (1,310-2,300 ft) elevation in the district of Kahikinui. This complex of sites probably represents a field system similar to those of leeward Hawai‘i Island and was apparently developed in the late prehistoric period as an expansion into a harsher, more marginal region (Chapman and Kirch 1979; Kirch 1985a). The Kahikinui area is part of the south slope of Haleakalā, where vegetation was recently surveyed by Medeiros et al. (1986). This study located many remnants of a rich dry-forest flora. A large Hawaiian population clearing land, setting fires, and gathering firewood in and near dry forests and shrublands could have severely impacted the native vegetation and contributed to its decline and present fragmentation. Likewise, a postulated agricultural area upslope of the coast between Kihei and Mākena (Kirch 1985a) could have greatly disturbed natural dryland vegetation there, a remnant of which was described by Medeiros et al. (1984, 1986) on a very rocky substrate unsuitable for agriculture.

Even the high slopes of Haleakalā were visited by ancient Hawaiians, who used a shelter cave at 3,050 m (10,000 ft) elevation as early as the 9th century (Kirch 1974). Hawaiians were probably travelling to this area near the East Maui summit to gather adz material and to exploit the now-endangered 'ua‘u or dark-rumped petrel (Pterodroma phaeopygia) for food (Kirch 1985a).

In Hālawa Valley on Moloka‘i, evidence exists for erosion and slope instability resulting from shifting agriculture after clearing the koa (Acacia koa) and ʻōhiʻa (Metrosideros polymorpha) forest during an intensification of cultivation around 1200 A.D. (Kirch and Kelly 1975). Erosion of the upper valley and slopes over hundreds of years resulted in flooding, stream siltation, and lower valley infilling, producing land later cultivated during periods of agricultural intensification (Spriggs 1985).

Lāna‘i and western Moloka‘i were reported as treeless or "barren" by Captain Cook (Beaglehole 1967) and other European visitors. Menzies, on board Captain Vancouver’s ship in 1793, observed no trees or shrubs on the south side of Lāna‘i or the western end of Moloka‘i and described the vegetation of these regions as "thin withered grass" (Menzies 1920). Thirty years later, Ellis (1827) also portrayed Lāna‘i as "largely barren" but wrote that the people of Maui cut posts and rafters from the thickets of small trees found in gulches or ravines. It appears that these early accounts were not completely accurate: remnant dry and mesic forests exist today on Lāna‘i in the upper reaches of gulches as well as other isolated localities (Spence and Montgomery 1976; Ziegler 1989). Ziegler (1989) estimated that half of Lāna‘i could have supported dry forest or woodland before modification by Hawaiians and destruction by modern land use practices. While no native forests are extant on western Moloka‘i, several native tree species were considered by Rock (1913) to be relatively common on Mauna Loa (on Moloka‘i) in the early 1900s: keahi (Nesoluma polynesicum), alahe‘e (Canthium odoratum), ʻohe makai (Reynoldsia sandwicensis), kulu‘i (Nototrichium sandwicense), maua (Xylosma hawaiiense), and the endangered gardenia or nāʻu (Gardenia brighamii).

Kahoʻolawe. The low, arid island of Kahoʻolawe was likewise characterized by the early botanists and explorers as treeless with a vegetation cover of "coarse grass" and few shrubs, even before the advent of feral or domestic ungulates (Ellis 1827; Menzies...
During the mid to late 1800s, botanists who actually landed on the Island collected or observed a few native tree and shrub species but did not find extensive native plant communities (Myhre 1970). A few endemic *wiliwili* (*Erythrina sandwicensis*) trees still persisted on Kaho'olawe in the 1980s (Corn et al. 1980). Kaho'olawe was uninhabited or only sparsely inhabited when Europeans arrived in Hawai'i (Beaglehole 1967), but its eastern inland plateau apparently supported permanent settlements and dryland agriculture, particularly sweet potato (*Ipomoea batatas*) cultivation, during the period between the 15th and 17th centuries (Hommon 1980). Although severely impacted by introduced animals and later human manipulation, Kaho'olawe presents one of the clearest pictures of extreme environmental degradation during the pre-European Hawaiian occupation of the Island. Hommon (1980) speculated that an increasing human population and the excessive clearing and burning needed for intensified agriculture resulted in "island-wide degradation," severe erosion (evidenced by archaeological remains buried under massive colluvial deposits), and the eventual collapse of the island's culture.

Charcoal fragments from Kaho'olawe firepits and earth ovens (*imu*) were identified as native tree and shrub species characteristic of dry and mesic communities, none of which remain on the island today: 'aweoweo (*Chenopodium oahuense*), sandalwood (*Santalum* sp.), kulu'i (*Nototrichium sandwicense*), ko'oko'olau (*Bidens* sp.), alahe'e (*Cantthium odoratum*), and 'aiea (*Notocestrum* sp.) (Kirch 1985a). These findings indicate that much of the native woody vegetation of Kaho'olawe was exploited for firewood, although it is possible that some of the wood could have been salvaged from driftwood.

**Hawai'i.** John Ledyard, who visited the island of Hawai'i in 1779 on Captain Cook's last voyage, noted that the woods "surrounded this island at a uniform distance of four or five miles from the shore" (MacCaughey 1918). While Hawaiian agricultural practices probably impacted lowland vegetation on both wet and dry sides of the island, the native vegetation of the large field systems of leeward Hawai'i was particularly affected by use of the land to grow crops; the development of agriculture in North Kohala led to the total replacement of the original dry forest and scrub of the cultivated area (Rosendahl 1972; Kirch 1985a). From a Kohala bog near Hawaiian settlements, Juvik and Lawrence (1982) provided evidence from pollen to substantiate the modification of native vegetation during the Hawaiian period. Their pollen analysis indicated a decrease in trees (*Metrosideros* and *Cheirodendron*) and an increase in herbaceous species over the last 1,600 years. By contrast, analysis of a core from a more isolated bog near the Saddle Road revealed little change in the amount of *Metrosideros* pollen over a period of 2,400 years. In an analysis of pollen from upland bogs on several other islands, Selling (1948) noted a retreat of rain forest and replacement by drier vegetation types during a period corresponding with the time of Polynesian occupation.

In the upper Kona and Waimea field systems, replacement of native vegetation seems to have been less absolute. The upper reaches of these field systems were described as being small, cultivated patches among native trees (Menzies 1920; McEldowney 1983). In 1794, Archibald Menzies (1920) observed native 'ōhi'a (*Metrosideros polymorpha*) trees growing in the second zone of cultivation (*kalu'ulu*) at Kona, which was dominated by breadfruit or 'ulu (*Artocarpus altilis*). David Nelson, the botanist who accompanied Captain Cook in 1778-79, was able to rather casually collect a number of native plants along the coast at Kealakekua and in the lowland cultivated zone up to 365 m (1,200 ft) elevation, among them several species that are today extinct,
endangered, or extremely rare: *Scaevola coriacea, Achyranthes nelsonii, Solanum nelsoni, Neraudia cookii*, and *Kokia drynarioides* (St. John 1976, 1979). There is, however, evidence for erosion from strong winds after fields were abandoned in the Waimea area (Clark 1983b); wild cattle (*Bos taurus*) introduced later may also have played a role in degradation.

Even in areas with only scattered fields or shifting cultivation during the period before European contact, deforestation was widespread and often extreme. McEldowney (1979, 1983) catalogued the reports of early European visitors to windward Hawai‘i, in which a band of unforested land along the Hāmākua coast and open, disturbed vegetation above Hilo were described. McEldowney believed these grass- and fern-covered slopes to be fallow fields of long-term swiddening or shifting cultivation, which were periodically burned by the Hawaiians.

Deforestation and changes in vegetation resulting from the Hawaiians’ need for firewood have been recognized from several sites on Hawai‘i Island. Kelly (1983) speculated that any lowland forest remaining along the Kona coast of Hawai‘i would, by the 19th century, have been depleted by Hawaiians collecting firewood. She further theorized that the adaptation to the *imu* (earth oven) was an effort to conserve firewood and resulted in more "modest" needs of Hawaiians, compared with those people dependent on open fires. Based on current use in India, open fires might have required as much as two tons of firewood a year per family (Eckholm 1978). Identification of charcoal from firepits in or near the Waimea field system of Hawai‘i Island gave results similar to those from the island of Kaho‘olawe: all of the identified remains were of native tree and shrub species characteristic of dry or mesic forests (Murakami 1983). The most common type of charcoal recognized in Waimea belonged to the genus *Chenopodium* (probably *C. oahuense*), but other genera present were *Nothocestrum, Canthium, Nototrichium, Colubrina* or *Alphitonia, Diospyros, Sida*, and *Acacia*. The first four genera are the same as those found in Kaho‘olawe firepits (Kirch 1985a), indicating a similarity in the original vegetation of the two areas that can hardly be imagined today.

**Fire**

Fire was the primary tool used by Hawaiians to clear lands prior to cultivation (Kirch 1982). This was true in areas adjacent to irrigated valleys and windward slopes as well as in the great field systems of the island of Hawai‘i. Evidence for clearing and burning of vegetation has been found at many windward agricultural sites on several islands, such as Hālawa Valley, Moloka‘i (Kirch and Kelly 1975) and Kamo‘olali‘i Stream in upland Kāne‘ohe, O‘ahu (Rosendahl 1976). All three of the major Hawai‘i Island field systems that have been closely investigated were found to have burn layers dated to the Hawaiian period, which in the lowest level contained land snail remains and charcoal indicative of the former vegetation. This is physical evidence of the Hawaiian use of fire to convert "vast tracts of native xerophytic and mesophytic plant communities" to cultivated fields (Kirch 1982).

A study of the Waimea field system on Hawai‘i Island (Clark and Kirch 1983) included examination of fossil and subfossil land snails in a corridor from the coast to the upland field system (Christensen 1983). Abundant endemic land snail remains were found in a buried burn layer, while no native snails were found in the upper soil layers. The burn layer is interpreted to represent the interface between native forest vegetation and the cultivated fields and fired grasslands of the Hawaiian period of
occupation. As might be expected, the land snail species of the lower Kawaihae/Waimea corridor were dry forest species, while those found in the upland Waimea area included extinct taxa thought to be wet and mesic forest inhabitants.

Botanical evidence for the composition of the pre-burn native forest of Waimea was derived from charcoal found in a burn layer from the Hawaiian era (Murakami 1983); these buried charcoals were identified as native trees such as kaulia (Colubrina or Alphitonia), lama (Diospyros sandwicensis), koai'a (Acacia koaia), and shrubs such as 'aweoweo (Chenopodium sp.), 'ilima (Sida sp.), and 'akoko (Chamaesyce sp.). In an analysis of carbonized seeds of the Waimea burn layer, Allen (1983) identified several agricultural weed species and native shrubs that may have represented secondary succession on fallow or abandoned fields.

The leeward slopes of the Kohala Mountains that later became the Kohala field system were first occupied around 1300 A.D., and in the following 200 years the land was cleared and planted using slash and burn techniques (Rosendahl 1974). Peat cores from a Kohala bog at 1,100 m (3,600 ft) elevation were found to contain charcoal throughout the 1,600 years represented by the core, including the time of Polynesian occupation, when pollen shifted from that of native tree species to that of herbaceous plants (Juvik and Lawrence 1982). Carbonized plant material from the late prehistoric period of Lapakahi was almost completely composed of introduced agricultural species such as coconut (Cocos nucifera), yam (Dioscorea spp.), and sweet potato (Ipomoea batatas) (Griffin et al. 1971). The original dry forests and shrublands of leeward Kohala were probably similar in composition to those remnants described from upslope Kawaihae by McEldowney (1983).

The Kona field system had probably been occupied for more than 1,000 years when it was first seen by Europeans in 1778 (Kelly 1983). While forest burning and clearing for cultivation may have been relatively restricted during the first few hundred years of Hawaiian occupation, by the 16th and 17th centuries deforestation and cultivation had increased with the population to the level of intensity seen by the first European and American visitors of the 18th and early 19th centuries.

The more scattered fields of windward Hawai'i and other islands were carved out of the lowland forest by tree cutting and the use of fire. This shifting agriculture practiced on windward tablelands and less favorable leeward areas resulted in "even greater impacts upon the Hawaiian ecosystem" than did the irrigation agriculture of the valleys (Krch 1982). Handy and Handy (1972) described methods of planting taro (Colocasia esculenta) in the hala (Pandanus tectorius) forests of Puna, in which some hala trees were felled to admit light, and cut hala branches were laid over the mulched taro and then burned. The resultant ash provided fertilizer, a fact appreciated by both ancient and modern practitioners of slash and burn cultivation worldwide (Bartlett 1962). Another type of vegetation the Hawaiians burned before cultivating was the wet forest of young substrates that had a dense cover of the matted fern, uluhe (Dicranopteris spp.) (Handy and Handy 1972).

Fire may have been repeatedly used to periodically clear the secondary growth on fallow fields. Many of the early European visitors to the island of Hawai'i described uncultivated but unforested lands of the lower slopes of Hamakua (Ellis 1827; Menzies 1920; Macrae 1972). These were probably fallow fields of the shifting agriculture regime. In 1824, Bloxam (1925) noted a region more than 24 km (15 mi) above Hilo that had been recently burned by Hawaiians. McEldowney (1979) speculated that firing may
have been done to encourage the growth of arrowroot or pia (*Tacca leontopetaloides*), morning glory (*Ipomoea* spp.), and other types of plants used as "famine foods" and pig feed.

Apart from the use of fire before and after the cultivation of food plants, Hawaiians used fire to stimulate the growth of desirable plants in the leeward lowlands, particularly pili grass (*Heteropogon contortus*). Pili, probably indigenous to the Hawaiian Islands (St. John 1973; Wagner et al., in press), was the preferred grass for thatching houses (Funk 1978) and was the primary material available in dry areas where alternate species such as ‘uki (*Machaerina* spp.), ti (*Cordyline fruticosa*), loulu palm (*Pritchardia* spp.), and hala were not found (Handy and Handy 1972). Some botanists have speculated that pili was a Polynesian introduction (Fosberg 1972); the grass is widespread in Polynesia and also occurs in India. Not surprisingly, pollen of this lowland grass has not been recovered from upland bogs (Selling 1948). Menzies (1920) in 1793 observed the Hawaiians burning a lowland grassland at Waimea, Kaua‘i, to encourage new growth to use for thatch. While he did not identify the “rank grass” burned, it was probably pili. This grass was treated almost like a crop in the Kona District and lent its name to the lower zone of the field system there (Kelly 1983) as well as in the Kawaihae/Waimea area (McEldowney 1983).

Pili is adapted to survive fires (as are recently introduced grasses from Africa and North America), and it benefits from annual burning, which destroys many woody species (Vogl 1969). Few other native grasses have significant cover in the lowlands of Hawai‘i; in most areas the natural lowland vegetation apparently lacked the fine fuels necessary for fire to carry with any great frequency. Most native Hawaiian plants are not adapted to survive frequent or intense fires, indicating that fire was not a significant ecological factor in pre-Polynesian plant communities (Mueller-Dombois 1981a). Exceptions are koa (*Acacia koa*), a few other species of the montane koa parkland ecosystem, and several lowland shrub species such as ‘ulei (*Osteomeles anthyllidifolia*) and ‘ali‘i (*Dodonaea viscosa*). In Hawai‘i, it is now generally recognized that most, if not all, of the "lowland grasslands were anthropogenic in origin" (Kirch 1982) and resulted from the periodic firing of the lowlands, which over time destroyed the native woody species. Areas capable of supporting forests, such as ‘Ewa, O‘ahu, which today are covered by savannas of alien kiawe (*Prosopis pallida*), were sparsely vegetated with grasses when first viewed by Europeans in the late 18th century. This is evidence that the original native forests had been destroyed by Hawaiian land practices (Davis 1982).

That Hawaiians used fire as a tool to modify their environment is not surprising, as pre-technological peoples all over the world have done so since the early Pleistocene (Stewart 1962); slash and burn agriculture is still practiced into the 20th century (Bartlett 1962). Use of fire in agriculture and vegetation alteration has been documented for other Polynesians such as the Maoris of New Zealand and for Melanesians (Davidson 1979). The North American Indians also manipulated their surroundings through the use of fire and may even have been partly responsible for the maintenance of the vast grasslands of the central plains of North America (Pyne 1982).

**Polynesian Introductions**

**Plants.** Hawaiian agriculture and concomitant deforestation and burning were physical disturbances to the land and original vegetation of the Islands. The Polynesians were also responsible for introducing nonnative plants and animals. Nagata (1985)
listed 32 plant species believed to have been brought to Hawai‘i during the Polynesian period. Most of these were either observed or collected by botanists and naturalists who were on board the European ships that visited Hawai‘i in the late 18th and early 19th centuries. Notable among the Polynesian introductions are food crop plants such as taro (Colocasia esculenta), bananas (Musa x paradisiaca), sugar cane (Saccharum officinarum), yams (Dioscorea spp.), and sweet potatoes (Ipomoea batatas). Taro, the staple food of Hawaiians, was represented in Hawai‘i by more than 300 named cultivars, more than have been recorded for any other part of the Pacific (Abbott 1977). The crop plants of the Hawaiians all have their origins in Asia except the sweet potato, which was a separate and possibly later introduction from South America (Yen 1974). Although the coconut palm (Cocos nucifera) has in the past been considered indigenous, it is now generally thought to have been intentionally introduced by Polynesians as an important fiber and food source. In addition to food plants, Hawaiians introduced many other useful plants: kukui (Aleurites moluccana) for its oily nuts that provided illumination; wauke (Broussonetia papyrifera) as a source of tapa cloth; ti (Cordyline fruticosa), useful for its leaves and roots; gourds (Lagenaria siceraria), essential in a culture lacking pottery; bamboo (Schizostachyum glaucifolium), the stems of which were fashioned into many different implements; and ‘ōlona (Curcuma longa), for its rhizomes, which yielded a dye. Some of the Polynesian introductions were apparently not strictly cultivated but were allowed to grow in a semi-wild state. Among these are plants such as ‘ape (Alocasia macrorrhiza) and noni (Morinda citrifolia), both used as sources of famine food.

A few weedy plants previously thought to be post-European contact introductions were recently found among the collections or notes of David Nelson, the botanist who accompanied Captain Cook in 1778-79 (St. John 1978). Among these weeds are yellow sorrel or ‘ihi (Oxalis corniculata), kāmoole (Ludwigia octivalvis), Urena lobata, hairy merremia (Merremia aegyptia), and indigo (Indigofera suffruticosa). Except for indigo, these plants are relatively non-invasive and were probably brought accidentally by Hawaiians, associated with their food plants, animals, or gear.

Almost all the plant species introduced by Polynesians may still be found growing wild in the lowlands, often in areas previously cultivated or disturbed by Hawaiian habitation. Some, like taro, persist only sparingly near the streams formerly used for irrigation. Only a few of the Polynesian introductions have become abundant in the lowlands; among these are kukui, mountain apple or ‘ōhi‘a ai (Syzygium malaccense), and ti. Today, mountain apple and ti may be found in the understories of otherwise native ‘ōhi‘a (Metrosideros polymorpha) and hala (Pandanus tectorius) forests, where they may have displaced native tree and shrub species. Many of the forests in which these early introductions predominate are probably successional after Hawaiian cultivation. Kukui may also be found in areas formerly cultivated (Wagner et al., in press), but it is also the primary tree on many windward lower valley slopes that seem too steep for agriculture. Of all the Polynesian introductions, kukui seems to have had the greatest capability for invasion in the lowlands, where it probably displaced forests of koa (Acacia koa) or mixed tree species (Fosberg 1972). Kukui has been found to escape from plantings and become invasive when introduced to other Pacific islands such as Christmas Island (T. Stokes, pers. comm. 1984).

Animals. Polynesians intentionally introduced food animals such as the pig (Sus scrofa), the dog (Canis familiaris), and the chicken (Gallus gallus). They also brought with them, probably inadvertently, the Polynesian rat (Rattus exulans), four species of geckos (Lepidodactylus lugubris, Gehyra mutilata,
Hemiphyllodactylus typus, and Hemidactylus garnoti), three types of skinks (Cryptobleparus, Lipinia, and Enoia), and land snails (Lemellaxis gracilis, Lamellidea oblonga) (McKeown 1978; Gagné and Christensen 1985).

The Polynesian pig was a domesticated form of the Eurasian wild boar, whose original range included most of Europe, the southern half of Asia, and many of the islands of Southeast Asia (Tisdell 1982). The Polynesian pig differed somewhat from today's feral descendents of domestic pigs in having a longer snout, underwool, and a straight tail (Stone, in press) and was apparently smaller than modern feral or domestic pigs. Captain Cook commented on the small size of Hawaiian pigs in 1779, estimating that the largest obtainable for his ships weighed only 23 to 27 kg (50-60 lb) (Giffin 1978).

It is thought that the Polynesian pig readily remained in domestication (Tomich 1986). Handy and Handy (1972) reported that only young pigs were allowed to run loose; older ones were kept in pens. David Douglas (1914) in 1834 told of a Hawaiian pig so tame that it came when called by its owner, who killed it and cooked it for his visitors. While early European visitors such as Cook (Beaglehole 1967), Ellis (1827), and Douglas (1914) all wrote of seeing domesticated pigs around the habitations of Hawaiians, botanists such as Macrae (1972) and Menzies (1920), who did considerable hiking in the Islands and wrote detailed journals, never mentioned seeing wild pigs in the native forests. Menzies described forests of the Kona slopes of Hawai‘i Island that were so dense and filled with ferns and undergrowth that he was unable to walk through them, suggesting an absence of feral pigs, which typically damage undergrowth and open up the forest floor.

Polynesian pigs may have adversely affected areas near Hawaiian settlements and lowland forests in which they were allowed to roam, but their importance as food to the Hawaiians and careful husbandry probably ensured that destructive population levels would not be achieved. A more significant factor in vegetation alteration was likely the use of fire by Hawaiians on lower forested slopes to encourage the growth of plants such as arrowroot (Tacca leontopetaloides) that were used for pig food (McEldowney 1979).

The dog was a favored food animal of the Hawaiians and was also sometimes treated as a pet (Handy and Handy 1972). No mention is made by early European explorers of these animals running wild. They appear to have been kept in close domestication (Hommon 1976), where they were fattened on poi and other foods and were killed in large numbers for special occasions.

The third food animal introduced by Hawaiians, the chicken (or moa) was apparently allowed to become wild and occurred near houses and also in the woods (Handy and Handy 1972). Berger (1972) speculated that this bird would have ranged from sea level to 2,130 m (7,000 ft) elevation. Living on a diet of seeds and fruits, chickens may have competed with some native ground-dwelling birds, but they are unlikely to have had a serious detrimental effect on native plants.

The Polynesian rat was originally a native of Southeast Asia but spread to many Pacific Islands with the people who colonized them (Atkinson 1985); thus, interactions of the Polynesian rat with Hawaiian vegetation likely began about 1,500 years ago. The rat was probably a "stowaway" on Polynesian voyaging canoes (Kirch 1985a). Primarily a lowland species, where it is common in fields and forests (Tomich 1986), in recent years the Polynesian rat has been collected in Maui rain forests above 2,050 m (6,500 ft) elevation (Stone et al. 1984). The full impact of this Polynesian
introduction may never be completely known, but Polynesian rats are especially likely to have negatively affected ground-dwelling birds of the lowlands (Kirch 1985a) and native invertebrates (Ramsay 1978; Gagné and Christensen 1985; F.G. Howarth, pers. comm.). The Polynesian rat may also have damaged native plants and altered community species composition through seed predation and girdling of soft-barked trees and shrubs, particularly during drought.

Remains of geckos, skinks, and nonnative land snails have been found during archaeological excavations of ancient Hawaiian sites of habitation (Davis 1982; Christensen 1983). Although lizards may have preyed on native insects of the lowlands, their true impact cannot easily be assessed (Gagné and Christensen 1985). The adventive land snails, which presumably were introduced with food propagules brought by the Polynesians (Kirch 1985a), are thought to have had little impact on native organisms (Gagné and Christensen 1985).

Use of Native Plants

The original Polynesian colonizers of Hawai‘i found few native food plants to sustain them in the coastal and lowland regions they first settled (Handy and Handy 1972). However, as their culture developed, the Hawaiians found many native plants to be useful for medicine, clothing, utensils, and building materials; and a few were found to be edible. Apart from seaweeds or limu, of which more than 70 species were regularly used for food (Krauss, n.d.), most other wild food plants were important mainly in times of famine. Chief among these were ferns, particularly the tree fern or hāpu‘u (Cibotium spp.) and ‘amā‘u (Sadleria spp.). The starchy cores of fern trunks were cooked and then eaten by humans or fed to pigs (Handy and Handy 1972; Krauss, n.d.). As these fern species are important components of many native plant communities, heavy use for food could have greatly changed lowland wet forests (Kirch 1985a). Other ferns, such as hō‘ōlo (Diplazium sandwichianum), kikawaiō (Christella cyatheoides), and pala (Marattia douglasii), were used for their edible fronds and rhizomes. The fruit of other native plants provided food, particularly shrubs such as ‘ōhelo (Vaccinium spp.), ‘akala (Rubus hawaiiensis), and ‘ūlei (Osteomeles anthyllidifolia), and trees such as lama (Diospyros sandwicensis) and loulu palm (Pritchardia spp.). The pulp of hala fruits (Pandanus tectorius) was also eaten (Handy and Handy 1972). Apart from the loulu, which is today scarce in the lowlands, these native plants are still rather common and were probably not severely impacted by Hawaiian use for food.

A number of native plants known to have been used for medicine by the Hawaiians are listed by Handy and Handy (1972) and MacBride (1975). Many medicines were made from portions of plants such as leaves, fruit, or sap and could be collected without destruction of the target plant. Quantities of medicinal plants required were probably small. Many other native plants were good sources of fiber for the production of tapa cloth, baskets, mats, and cordage (Funk 1978). Most native fiber plants remain relatively common in existing native lowland and mid-elevation forests, including māmaki (Pipturus albidus), used to make tapa; olonā (Touchardia latifolia), ōpuhe (Urera spp.), and ‘akia (Wikstroemia spp.), which were sources of cordage; and ‘ie‘ie (Freycinetia arborea), an important material for baskets and fish traps. Apparently some of these native fiber plants were maintained and partially cultivated in small forest plots (McEldowney 1979). Native plants were also used as dye sources; for example, the fruit of the nā‘ū (Gardenia remyi) and the bark of hōlei (Ochrosia spp.), both uncommon trees, were used to produce a yellow dye
Koki'o (Kokia drynarioides), an endangered tree of leeward Hawai'i Island, may have been depleted by Hawaiians who collected its bark to produce a dye for fish nets (Rock 1913).

Building was also a consumptive use of native plants. Undoubtedly, the lowland forests near Hawaiian habitations were heavily used for house frames. Trees regularly used as timber included 'ōhi'a (Metrosideros polymorpha), lama, naio (Myoporum sandwicense), and kōlea (Myrsine spp.) (Handy and Handy 1972). Canoe construction required the logging of large trees, particularly koa (Acacia koa). In 1793, the naturalist Archibald Menzies (1920) described the felling of koa for canoes in Mauna Loa forests approximately 16 km (10 mi) upslope from Kealakekua Bay on Hawai'i Island. Menzies noted that the lower woods along his path had been considerably "thinned" of large koa trees by this Hawaiian practice. Many other Hawaiian woody plants were used for various utensils such as bowls (koa), spears (alahe'e, Canthium odoratum; kauila, Alphitonia ponderosa and Colubrina oppositifolia), and fishing gear (hau, Hibiscus tiliaceus; wiliwili, Erythrina sandwicensis). For the most part, common woody plants were used for everyday objects; one exception is the endangered uhiuhi (Caesalpinia kavaiense), which possesses hard wood favored for use as hōlua sled runners (Handy and Handy 1972).