van der Leeuw (ed), What's New?

5 *Dynamics of production intensification in precontact Hawaii*

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Introduction

There were three main technological advances resulting in production intensification in precontact Hawaii: (a) walled fishponds, (b) terraced pondfields with their irrigation systems and (c) systematic dry-land field cultivation organized by vegetation zones. The Hawaiian walled fishpond stands as a technological achievement unmatched elsewhere in island Oceania. The genius of Hawaiians in cultivating fish was their utilization of the herbivore link in the food chain. The selected species of herbivorous fish, primarily grey mullet (*Mugil cephalus* or *'ama'ama*) and milk fish (*Chanos chanos* or *awa*), short circuit two steps in the natural food-chain by feeding directly on minute algae, diatoms growing on the larger algae and on the bottom of the pond, and organic detritus. Thus, Hawaiians raised the natural food chain efficiency of protein production by 100 times.

A second technological invention by Hawaiian Polynesians was the development of their extended stone-faced, terraced pondfields (*lo'i*) and their accompanying irrigation systems (*'auwai*) for the intensive cultivation of wetland taro (*Colocasia esculenta* or *kalo*). The terraces were irrigated with water brought in ditches from springs and streams high in the valleys, allowing extensive areas of the valleys to be cultivated. The irrigation ditches and pondfields were engineered to allow the cool water to circulate among the taro plants and from terrace to terrace, avoiding stagnation and overheating by the sun, which would rot the taro corms. At the same time, the flow of the water was controlled to prevent erosion of ditches and terraces, an engineering feat of no mean proportions.

An acre of irrigated pondfields produced as much as five times the amount of taro as an acre of dryland cultivation. Over a period of several years, irrigated pondfields could be as much as 10 or 15 times more productive than unirrigated taro gardens, as dryland gardens need to lie fallow for greater

lengths of time than irrigated gardens. In addition, walled pondfields not only produce taro, but were also used to raise an additional source of food, freshwater fish: primarily the Hawaiian goby (*Chonophorus stamineus* or *'o'opu nakea*), and certain kinds of shrimp (*'opae*).

The third form of subsistence intensification involved the systematic cultivation of dryland crops in their appropriate vegetation zones as exemplified by the Kona Garden System, which was utilized in areas that lacked perennial streams. In this chapter, I postulate, first, that these three innovations were achieved in response to the demands of a rapidly increasing population in the late precontact period (primarily the 16th and 17th centuries) and, secondly, that the technological developments resulted in changes in the sociopolitical structure, producing a hierarchical class structure also unmatched in Polynesia.

Fishponds and pondfields

The cultivation of fish took place in Hawaiian agricultural pondfields as well as in specialized fresh- and brackish-water fishponds. Traditionally, certain kinds of freshwater and freshwater-tolerant fish that usually lived in salt water were often raised in pondfields along with taro. These salt water fish were caught along the shoreline and released into the taro gardens. The freshwater fish usually found their way from the streams into the taro gardens through the irrigation ditches.

Additionally, some inland fishponds were freshwater ponds fed by springs, streams and/or ditches carrying stream water enriched by its course through the taro terraces. Many of these inland ponds were created by stream water draining into lowland areas with the freshwater stream life, such as the goby, making its home in the ponds.

In contrast, walled, brackish-water fishponds were usually constructed on the reef along the shore, many of them having walls 1200 and 2500 m or more in length, and one or more sluice gates. Others were created by connecting two headlands of a bay or lagoon with a stone wall. Fresh water provided by springs or streams reduced the salinity of the ponds and produced a favourable environment for algal growth. The development of walled, brackish-water fishponds was a marked technological advancement towards increasing the amount of protein food available for human consumption.

A natural food chain can be expected to produce a ratio of 10:1 in terms of the conversion of one link by another (MacGinitie 1935, 1949). Thus, 10 000 kg of algae make 1000 kg of tiny crustaceans, which in turn make 100 kg of small fish. These 100 kg of small fish then produce ten kg of large fish, which when eaten by humans make one kg of human flesh. Alternatively, Hiatt (1947, pp. 278, 256–60) proposed that 'these proportions are different in Hawaiian ponds' because of the rich growth of algae in the ponds and the choice of the herbivorous fish species being raised. These fish have a diet

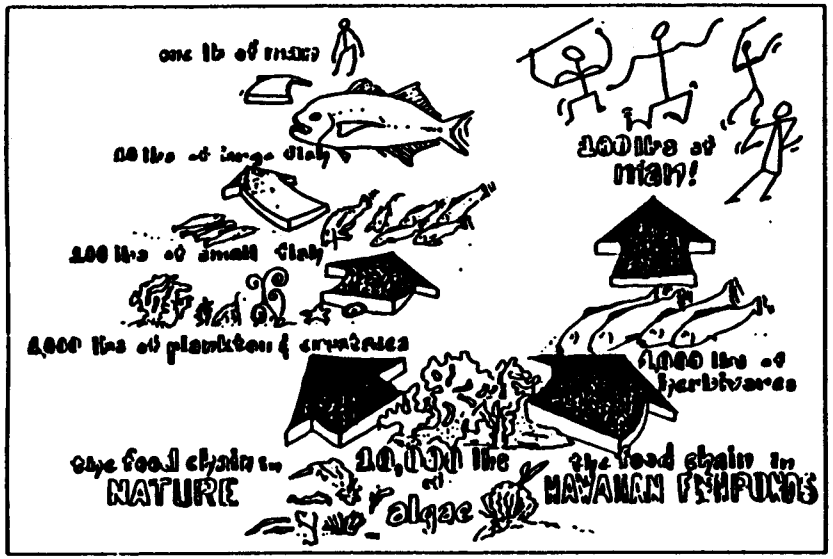


Figure 5.1 Diagram comparing the natural food chain with the Hawaiian fishpond food chain utilizing the herbivore link. By selective development of the herbivore link, the food chain in Hawaiian fishponds was 100 times more efficient to man than unimproved nature.

consisting primarily of diatoms, algae, and organic substances such as vegetable debris and detritus, and other minute algae growing on the bottom of the pond or sometimes even on the larger algae.

Due to these factors, according to Hiatt (ibid.), the results in the Hawaiian ponds 'are closer to the following: 10 000 pounds of algae and detritus make 1000 pounds of herbivorous fish; 1000 pounds of herbivorous fish make about 100 pounds of carnivorous fish, or man' (ibid.). Thus, herbivorous fish produced in Hawaiian fishponds provided man with protein 100 times more efficiently than the natural food chain (Fig. 5.1).

Grey mullet was the most popular fish raised in Hawaiian walled seashore fishponds. Its ability to consume diatoms and other minute algae directly is facilitated by an 'elaborate, pharyngeal sieving mechanism' which allows the fish 'to select a sufficient quantity of minute plant types and organic detritus for its sustenance'. Larger plant fragments and mud are rejected or filtered out, 'permitting only the diatoms and other minute algae to enter the oesophagus' (Hiatt 1947, p. 256).

Whether or not the raising of mullet by Hawaiians was influenced by knowledge of their 'pharyngeal sieving mechanism' will probably never be known. However, patient observation by Hawaiian fishermen of the habits of herbivorous fish (what and where they ate) was undoubtedly part of the

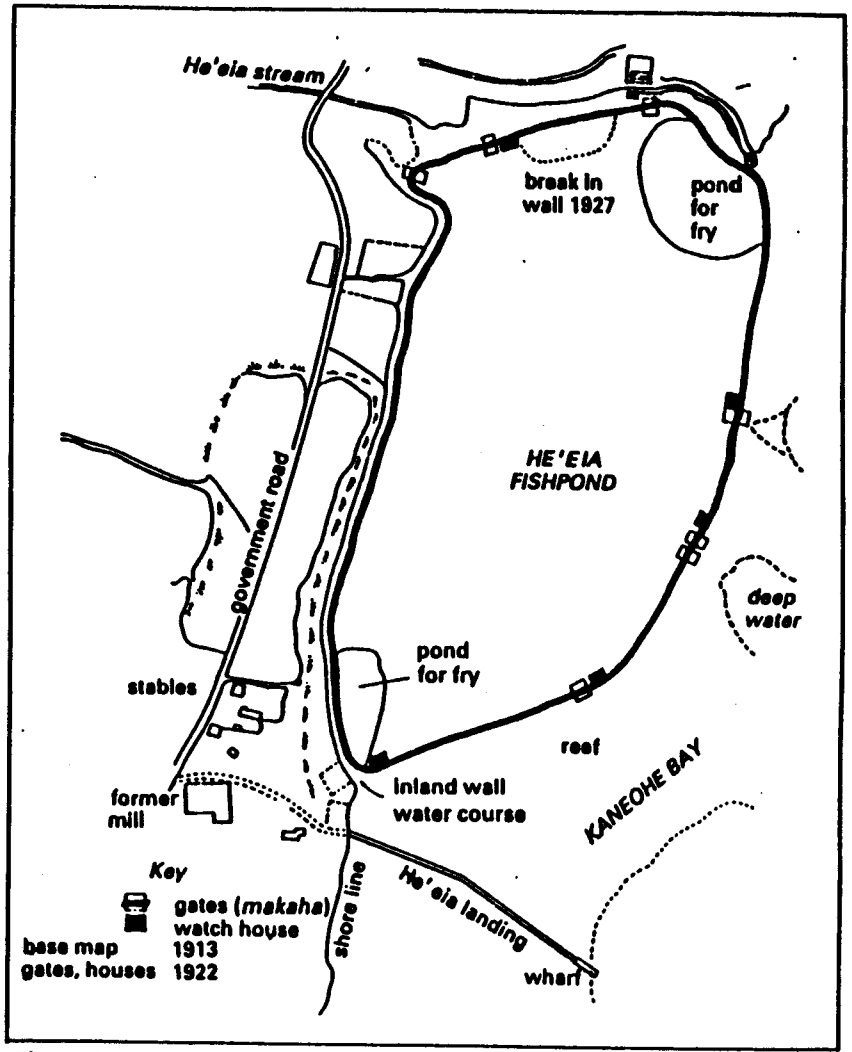


Figure 5.2 Drawing of He'eia fishpond and surrounding area based on a map by Monsarrat drawn in 1913. Holding-ponds for fry are shown at the SE and NW ends of the pond.

great fund of knowledge held by Hawaiians about the sea and the plants and animals which inhabit it. Certainly, the Hawaiians recognized the value of walled fishponds and built them wherever conditions permitted.

The Hawaiian fishpond was primarily a grazing area in which the fishpond keeper cultivated algae for his fish, much in the way a cattle rancher cultivates grass for his cattle. Thus, pond conditions were kept optimum for the cultivation of algae. This included designing the ponds with depths of only two or three feet, so that sunshine could penetrate the water, providing energy for the growth of algae.

Since the types of algae that mullet consume grow best in brackish water, Hawaiian walled fishponds were often located (a) on the shoreline near the mouth of a stream, (b) where fresh water escapes in springs along the shore, or frequently (c) in the sea. With ample supplies of fresh and salt water, such locations ensured a continuous replenishment of oxygen for fish and plants. Another effective strategy involved the construction of multiple sluice gates. As fishponds were located next to the mouth of a stream, by opening a sluice gate a pondkeeper took advantage of the highly nutritious water that had passed through the inland terraced pondfields and been returned to the stream. In this way, such a walled fishpond became an integral part of the agricultural/aquacultural system of the valley (Fig. 5.2).

Furthermore, Hiatt (1947, p. 279) pointed out that the concentration of mullet or other herbivores in the ponds depended ultimately upon the amount of available algae, which in turn directly depended on the total environment, the microbenthos that the pond-builders created. In other words, the pond's physical features produced its available food supply. Correctly constructed, a pond eventually became autarchic, self-perpetuating.

Hawaiian historian Samuel M. Kamakau (1976, p. 48) described the making of a fishpond wall and the construction of a system of sluice gates to control the flow of water into and out of the pond. After only 'five or six months fish would begin to be seen in the *loko kuapa* (walled pond)' (ibid.). A correctly built pond provided a highly favourable setting for algal growth, thus enhancing the natural resources of the sea. Herbivorous fingerlings entered the pond through the narrow openings in the sluice gates and fed on the algae within the walls of the pond. The openings in the sluice gates also allowed fresh sea water with its nutrients and dissolved oxygen into the pond for the fish and algae. The ponds protected the herbivores from carnivorous predators outside the walls. In time, the fingerlings grew too fat to escape through the same narrow sluice gate openings which they had used to enter the pond. Correctly managed and maintained, a pond could continue this cycle of efficient protein production indefinitely. Proper management called for periodic cleaning of the pond, breaking up the bottom layer of algae to encourage new growth, and opening the sluice gates on the incoming tide. As the fresh oxygen and nutrients flowed into the pond through openings in the sluice gates, the larger fish flocked into the sluices, where they could easily be harvested with small hand-nets (Beckley 1887).

Pond walls were constructed with consideration for the flow of ocean currents along the reef, and at times the walls produced an interconnected lacework effect as the leeward wall of one pond became the windward wall of the next. Ponds along the southern coast of Moloka'i are an example of this type of construction (Summers 1964, 1971).

Time-frame for Hawaiian walled fishponds

What do the traditions tell us as to when these great walled fishponds were built? To begin with, Kamakau (1976, pp. 47–8) points out that building fishponds in the Hawaiian islands was an ancient art. While the names of some of the chiefs who oversaw the construction of fishponds are known, Kamakau indicated that 'the majority of their builders is not known'. He also surmises that 'one can see that they were built as "government" projects by chiefs (*hana aupuni 'iae na li'i*), for it was a very big task to build one, [and] commoners could not have done it [singly, or without co-ordination]' (ibid.). Chiefs had the power to command a labour force large enough to transport the tons of rock required and to construct such great walls. In addition, Kamakau (1961, p. 42) identified the building of Mau'one fishpond on the island of Maui with a meeting between the high chiefs of Maui and Hawaii, Kiha-a-Pi'ilani and Keawe-a-'Umi, respectively. It was constructed on the order of Kiha-a-Pi'ilani at a time when Ka-kukihewa was the high chief of the island of O'ahu.

Fornander (1919, pp. 312–13) estimated the birth dates of these three ruling chiefs, using a 30-year generation count and rounding out the results as follows:

Kiha-a-Pi'ilani: 12 generations from Pinao (1824) = 1460
Keawe-a-'Umi: 11 generations from Kalakaua (1836) = 1500
Ka-kuhihewa: 11 generations from Kapi'olani (1834) = 1500

Kamakau's (1961, pp. 22–5) history of the life of Kiha-a-Pi'ilani indicates that this chief's early years were fraught with poverty and the need to hide his whereabouts and identity to protect himself from his elder brother. It was not until later life that he became the recognized ruler of the Island of Maui. Thus, his reign may have been delayed and he may not have been high chief of Maui until after the beginning of the 16th century, according to Fornander's estimate of the length of a generation for Hawaiian genealogies.

Considerable study of the problem of judging the length of time that should be allowed for a generation in chiefs' genealogies was undertaken by the anthropologist Stokes (1933), who concluded that 20 years would result in better estimates for the length of an Hawaiian generation on genealogies that list ruling chiefs. His 20-year estimate takes into consideration many of the customs involved in producing Hawaiian ruling chiefs. Using Stokes' formula, the birth dates of the three reigning chiefs mentioned above would

have been AD 1584, 1616, and 1614 respectively, or the late 16th and early 17th centuries.

Other chiefs were said to have been responsible for building specific fishponds. A female chief, Kalai-manuia, is said to have ordered three fishponds – Kapa'akea, Opu, and Pa'aiau – to be built on the island of O'ahu (McAllister 1933, p. 103, Fornander 1969, p. 269). Her son, Ka'ihikapu-a-Manuia, is said to have been responsible for building two very large ponds with surface areas of 135 and 105 ha (McAllister 1933, p. 93). One of these had a wall measuring nearly 1400 m long, 1–2.5 m wide and 1 m high (McAllister 1933, p. 103, Fornander 1969, p. 270). Fornander (1919, p. 313) places these two ruling chiefs at 11 and 12 generations back from Kapi'olani (born 1834), and their births around the turn of the 16th century and late in the 15th century. Stokes' 20-year generation count would place them approximately one hundred years later.

One tradition concerns a power struggle between Kamalalawalu, a ruling chief of the island of Maui, and the chiefs of the Kona District on the island of Hawaii. The Maui chief sent spies to Kona. When they reported their discoveries, they mentioned the 'walled-in ponds' of Kaloko and Honokohau (Kamakau 1961, p. 56). This tradition does not deal with the building of the fishponds, but merely reveals that they were already in place. Both these ponds were walled embayments. Fornander (1919, pp. 313–14) places Kamalalawalu 11 generations before Kalakaua, or in the early 16th century (AD 1510). By Stokes' (1933) estimate, Kamalalawalu would be placed in the early 17th century (AD 1616).

To summarize the dating of the six chiefs mentioned in connection with Hawaiian fishponds, their birth dates span the 15th and early 16th centuries (by Fornander's 30-year count), or in the late 16th and early 17th centuries (by Stokes' 20-year count):

Ruling Chief	*30-Year Count*	*20-Year Count*
Kiha-a-Pi'ilani	AD 1460	AD 1580
Keawe-a-'Umi	AD 1500	AD 1620
Ka-kuhihewa	AD 1500	AD 1610
Kalai-manuia	AD 1470	AD 1590
Ka'ihikapu-a-Manuia	AD 1500	AD 1610
Kamalalawalu	AD 1510	AD 1620

Regardless of the differences in dates between the results of the two methods of calculating the births of these ruling Hawaiian chiefs, both place them well within the later period of Hawaiian precontact history. At that time the major condition that generated the need for fishponds was a large population with sustained growth. This also enabled their innovation by providing a large workforce capable of constructing massive fishpond walls.

In addition, by this time a class of very powerful chiefs had developed in Hawaiian society. They managed the use of the land and other resources in their districts, or, in some cases, on entire islands. The co-ordination of labour by the chiefs enabled the walled fishponds to be constructed. This, in turn, supported the power of those chiefs and their claims to a substantial portion of the surpluses generated.

Stone-faced, terraced pondfields

An archaeological survey team has recently found and recorded a large complex of stone-faced, terraced, agricultural pondfields, built and used by Hawaiians in past centuries for cultivating wetland taro (*Colocasia esculenta* or *kalo*). The complex, which was found to extend over an area of approximately 4 ha, was irrigated by ditches (*'auwai*) that formerly brought water from spring-fed streams originating at the foot of the nearly vertical mountains of the Ko'olaupoko District on O'ahu. The retaining walls of the terraces measure between 30 cm and 2 m in height, with a mean width of the terraces approximately 5 m and variations up to about 15 m, depending on the slope of the land. Remains of an irrigation ditch and probable water-flow controls were also found in the area (Allen-Wheeler 1985; Fig. 5.3). Other similar areas have been recorded in the past, but few are extant today, most having been destroyed by urbanization. One stone-faced irrigation ditch was reported to be about 3 km long (McAllister 1933, p. 113).

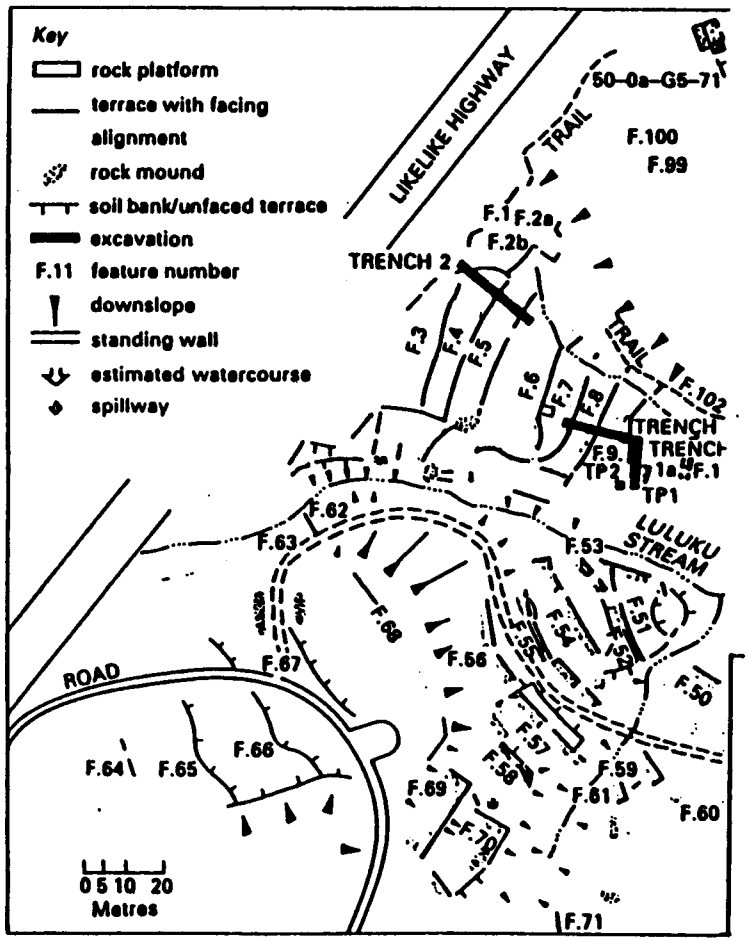
Usually water was fed into an irrigation ditch from a stream (Nakuina 1894). A loose-rock dam built across the stream allowed water to flow between and over the top of the rocks to provide for farmers living downstream. The dam functioned to raise the water level just high enough at that point to permit water to flow into the ditch leading to the terraces. In this way the amount and speed of the water could be controlled. If too much water was found to be flowing into the ditch, a few stones could be removed from the dam, thus lowering the water level and reducing the volume of water entering the ditch. The speed of the flow of water into the pondfields was controlled by the length and slope of the ditch. By varying the length and grade of the ditch, its builders were able to maintain a constant and low-level gradient over variegated terrain. The flow through the pondfields was controlled by the height of the terraces.

In building the pondfields, farmers stomped the earth down with their feet to make the terraces as impermeable as possible. As the irrigation water flowed through the terraces, some was taken up by transpiration, some by evaporation, and a little soaked down into the ground, replenishing the supply of groundwater in downstream springs. The remaining water flowed through the terraces and was returned to the stream at a lower elevation. Having added nutritional value from the flora and fauna in the pondfields, the remaining irrigation water was often used to fertilize fishponds that were built along the shore near stream outlets.

Captain George Vancouver visited O'ahu in 1792 and wrote about the taro gardens in the Waikiki–Kapahulu–Mo'ili'ili–Manoa complex that he observed:

Our guides led us to the northward through the village [Waikiki], to an exceedingly well-made causeway, about twelve feet broad, with a ditch on each side.

This opened to our view a spacious plain . . . the major part appeared divided into fields of irregular shape and figure, which were separated from each other by low stone walls, and were in a very high state of cultivation. These several portions of land were planted with the eddo, or taro root, in different stages of inundation, none being perfectly dry, and some from three to six or seven inches under water. The causeway



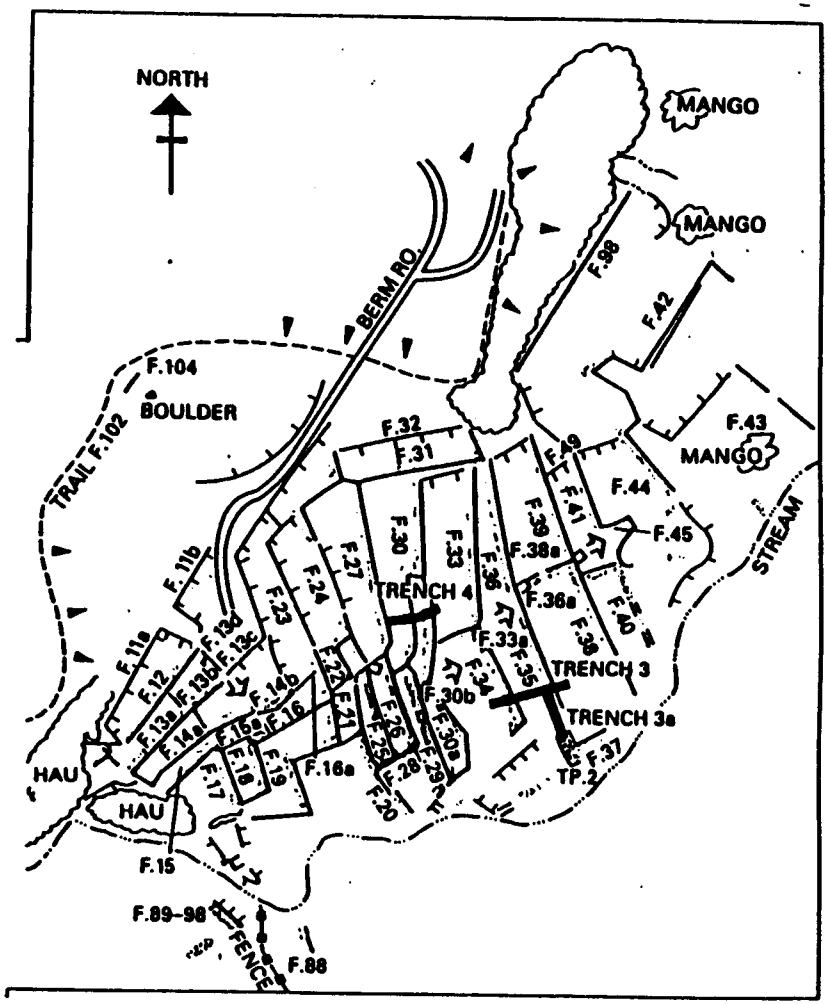


Figure 5.3 The extensive agricultural pondfields of Luluku, Kane'ohe and O'ahu (from Allen-Wheeler 1985).

led us near a mile from the beach, at the end of which was the water we were in quest of. In this excursion we found the land in a high state of cultivation, mostly under immediate crops of taro, and abounding with a variety of water fowl, chiefly of the duck kind . . . The plains . . . from the labour bestowed in their cultivation, seem to afford the principal proportion of the different vegetable productions in which inhabitants depend for their subsistence . . . At Woahoo [O'ahu],

> nature seems only to have acted a common part in her dispensations of vegetable food for the service of man; and to have almost confined them to the taro plant, the raising of which is attested with much care, ingenuity, and manual labour. (Vancouver 1798, pp. 163–4)

The naturalist Archibald Menzies, who was with Vancouver, also wrote about these large plantations:

> We pursued a pleasing path back into the plantations which was 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 and a species of Draecena without the aid of much cultivation, and the whole watered in a most ingenious manner by dividing the general stream into little aquaducts leading in various directions so as to supply the most distant fields at pleasure, and the soil seems to repay the labour and industry of these people by the luxuriancy of its productions. (Menzies 1920, pp. 23–4)

In 1815, the explorer Kotzebue added to these descriptions by writing about the gardens and the artificial ponds that were scattered throughout the area:

> The luxuriant taro-fields, which might be properly called taro-lakes, attracted my attention. Each of these consisted of about one hundred and sixty square feet, forms a regular square, and walled round with stones, like our basins. This field or tank contained two feet of water, in whose slimy bottom the taro was planted, as it only grows in moist places. Each had two sluices, one to receive, and the other to let out, the water into the next field, whence it was carried farther. The fields became gradually lower, and the same water, which was taken from a high spring or brook, was capable of watering a whole plantation. When the taro is planted, the water is lowered to half a foot, and the slip of a gathered plant stuck into the slime, where it immediately takes root, and is reaped after three months. The taro requires much room, having strong roots; it strikes forth long stalks and great leaves, which appear to swim on the water. In the spaces between the fields, which were between three and six feet broad, are pleasant shady walks, planted on both sides with sugar-cane or bananas. They also use the taro-fields as fish-ponds. In the same manner as they keep the river-fish here, they keep the fish in the sea, where they sometimes use the outer coral-reefs, and form from them to the shore a wall of coral stones, thus making fish-preserves in the sea. Such a preserve requires much labour, but by no means so much art as the taro-fields, which serve for both purposes. I have seen whole mountains covered with these fields, through which the water flowed gradually down, each sluice forming a cascade, and falling between sugar-canes and banana-trees into the next tank. Sugar plantations, taro-fields, and far-scattered plantations succeeded each other on our road . . .' (Kotzebue 1821, p. 102).

On the question of the productivity of wet-land taro versus dry-land taro, some missionaries recorded their experiences and observations in 1847 and 1848. In answer to the questions, what 'number of souls that could be fed by one square acre of land, of average quality in the district, if cultivated for kalo? How many crops of kalo in succession can be raised from the same plot of land, and how many years the land requires to lie fallow, before it recovers itself?', Revds Coan and Lyman wrote from Hilo, Hawaii, where mostly dryland taro was cultivated:

> Ans. — Perhaps four, if carefully cultivated. Several successive crops can be grown, if the soil is well dressed or manured. If not, it should lie fallow every other year [Coan].
>
> Two, perhaps. This is more than I have been able to feed from the land belonging to the boarding school under my charge. The land may not be so good as the district will average. Our cultivation is much better than that of the natives generally; they, themselves, being judges.
>
> We usually raise two crops of kalo from the same plot. The natives in this vicinity more commonly raise but one crop. The land requires to lie fallow from two to five years, in general, the longer the better [Lyman]. (Wyllie 1848, p. 82)

On O'ahu, the soil was much more productive, and wetland taro-growing was made possible because of the type of soil and the large amount of water available. Revd. Armstrong suggested that there would be 'food enough for ten persons' (Wyllie 1848, p. 82) on an acre of average taro land in Honolulu, that is, subsistence for ten persons.

> With proper management, kalo [taro] land needs no rest. So the natives tell me. Let the water be kept constantly upon it and the weeds cleared out and that is all that is needed. The kalo plants, however, must be changed every crop. It requires about a year to bring a crop of kalo to maturity [Armstrong]. (Wyllie 1848, p. 82)

Writing from his experiences on the well-watered windward side of O'ahu, Pali Ko'olau, or Ko'olau Poko, Revd. Parker wrote:

> An acre of kalo land would furnish food for from twenty to thirty persons, if properly taken care of. It will produce crops for a great many years in succession, without lying fallow any time. (Wyllie 1848, p. 82)

Revd. Bishop, writing from 'Ewa District on O'ahu, suggested that 15–20 people could be fed from an acre of taro:

> Good kalo land, irrigated by water, improves by cultivation. It only requires time enough between crops to rot the weeds, which serve as manure. (Wyllie 1848, p. 82)

Revd. Emerson lived and worked in Waialua District on O'ahu where several large rivers and numerous springs watered the land. He wrote:

> Twenty persons, I think can be fed on an acre of good kalo land. The land can generally be cultivated perpetually, if it has two or three months between each crop, in which to decompose the weeds which might grow during the time the kalo was ripening. Some land does not require to rest so much as three months, as it does not become weedy. I have a large kalo patch that has not been left to rest one month at a time for fifteen years, and yet it produces as largely as fifteen years since. I presume the same patch was cultivated centuries before I knew it. It requires one year for kalo to come to maturity. (Wyllie 1848, p. 82)

Revd. Johnson of Hanalei, Kaua'i, a noted wetland taro-producing valley, suggested that 25 persons subsist on an acre of good taro land (ibid.). Hawaiian historian David Malo (1951, p. 206) explained how a taro garden could keep a large number of people in vegetable food continuously:

> Some farmers did not plant a great deal at a time. They would plant a little, and after waiting a few months, they planted more land. So they continued to plant a little at a time during the months suitable for planting. The food did not all ripen at once, and by this plan the supply was kept up for a long time and they had no lack of food.

Undoubtedly, Hawaiians knew well the productive advantages of growing wetland taro and placed the greater effort in this area very early, when required to increase food production capabilities for the rapidly increasing number of people. By the time of Captain Cook's visits in 1778 and 1779, every large river valley in the islands contained many pondfields, and each was systematically irrigated by means of ditches delivering water to the fields spread throughout the valley.

Time-frame for extensive terraced pondfields

Traditions on the island of O'ahu provide the names of a dynasty of ruling chiefs beginning with Ma'ilikukahi, who was estimated to have been born about AD 1360, according to Fornander's 30-year generation count, or AD 1514 according to Stokes' 20-year count. Ma'ilikukahi occupies a prominent place in O'ahu legends for his wise, firm, judicious government (Fornander 1969, p. 89). It is said that he caused the island to be surveyed thoroughly and the boundaries between the different divisions and lands to be marked out

definitely and permanently, thus avoiding future disputes between neighbouring landholders (ibid.).

Ma'ilikukahi is said to have enacted a code of laws in which theft from the people by chiefs was forbidden. His son, Kalona'iki, followed in his father's footsteps, as did his grandson, Piliwale. Piliwale was succeeded by his daughter, Kukaniloko, referred to in legends as a great and powerful chiefess who kept the country peaceful and orderly (Fornander 1969, pp. 88–91).

Another son of Ma'ilikukahi was Kalona-nui, who in turn had a son called Kalamakua, born about AD 1414 on the 30-year count, or around AD 1554 on the 20-year count. Kalamakua is said to have been responsible for developing large taro gardens in what was once a vast area of wet-taro cultivation on O'ahu: the Waikiki–Kapahulu–Mo'ili'ili–Manoa area. The extensive pondfields were irrigated by water drawn from the Manoa and Palolo Valley streams and large springs in the area. A map drawn in 1881 provides a graphic placement of these gardens, the irrigation system and some 30 fishponds at their lower end (Bishop 1881).

O'ahu Chiefs	*30-Year Count*	*20-Year Count*
Ma'ilikukahi	AD 1360	AD 1514
Kalona'iki and Kalona-nui	AD 1390	AD 1534
Piliwale and Kalamakua	AD 1420	AD 1554
Kukaniloko	AD 1450	AD 1574

Other chiefs mentioned in O'ahu traditions were associated with organizing activities in more systematic ways than those in times previous to them. One such high chief was Kakuhihewa, who was said to have built

> a government house for himself forty fathoms long, and fifteen fathoms wide, which was named Pamoa. The main purpose of this house was for debating land divisions, claiming ancestors, genealogy registration, practice with war club, spear thrusting, astrology, designing, astronomy, konane, instruction in royal ancestral songs, royal songs, running, cliff leaping, bowling, sliding, boxing . . . (McAllister 1933, p. 186, quoting S. M. Kamakau)

Kakuhihewa's birth date estimates are AD 1540 and 1634 by the 30-year and 20-year counts respectively.

Perhaps the tradition remembered for another great chief of O'ahu who came along a little later (AD 1660 or 1714) can be interpreted as evidence for the productive successes of earlier chiefs. Kuali'i was famous for the *kolowalu* law: 'If a man says, "I am hungry for food" feed [him] with food, lest he hungers and claims his rights by swearing the kolowalu law by his mouth, whereby that food becomes free, so that the owner thereof must observe the law faithfully' (Fornander 1917, p. 432). Kuali'i became the acknowledged high chief (*moi*) of O'ahu (Fornander 1969, p. 281) and lived to a very advanced age (ibid., p. 283).

Thus, the most prominent chiefs associated with organizing the lives of the people of O'ahu, identifying the land boundaries and creating intensive wetland taro terraces, are estimated to have been born between the latter half of the 14th and the early part of the 18th centuries

Systematic dryland cultivation in vegetation zones

Agricultural intensification also took place in Hawaiian dryland cultivation as exemplified by the Kona agricultural system (Newman MS, Kelly 1983). Cultivation of the soil in Kona, Hawaii, in Hawaiian times was characterized by a variety of unirrigated root and tree crops grown for subsistence, each farmer having gardens in one or more vegetation zones. Each crop was cultivated in the zone in which it grew best. Descriptions of Kona by early visitors support this view. Crops were matched with their most compatible vegetation zones, trees had adequate spreading space, and double cropping was utilized where appropriate. Captain Charles Wilkes of the American Exploring Expedition, which visited Hawaii in 1840, placed the zone of planted breadfruit trees two miles back from the coast:

> a mile back from the shore, the surface is covered with herbage, which maintains cattle, etc.; and two miles in the interior there is sufficient moisture to keep up a constant verdure.
>
> Here, in a belt a mile wide, the breadfruit is met with in abundance, and above this the taro is cultivated with success. (Wilkes 1845, p. 95)

Revd William Ellis described the area behind Kailua town in Kona above the breadfruit and mountain apple trees as seen by Revds Thurston, Goodrich, and Harwood:

> The path now lay through a beautiful part of the country, quite a garden compared with that through which they had passed on first leaving the town. It was generally divided into small fields, about fifteen rods square fenced with low stone walls, built with fragments of lava gathered from the surface of the enclosures. These fields were planted with bananas, sweet potatoes, mountain taro, paper mulberry plants, melons, and sugar-cane, which flourished luxuriantly in every direction.
>
> Having travelled about three or four miles through this delightful region, and passed several valuable pools of fresh water, they arrived at the thick woods, which extended several miles up the sides of the lofty mountain that rises immediately behind Kairua. (Ellis 1963, pp. 31–2)

The written description is borne out in a drawing done by one of the daughters of Revd and Mrs Asa Thurston (Fig. 5.4).

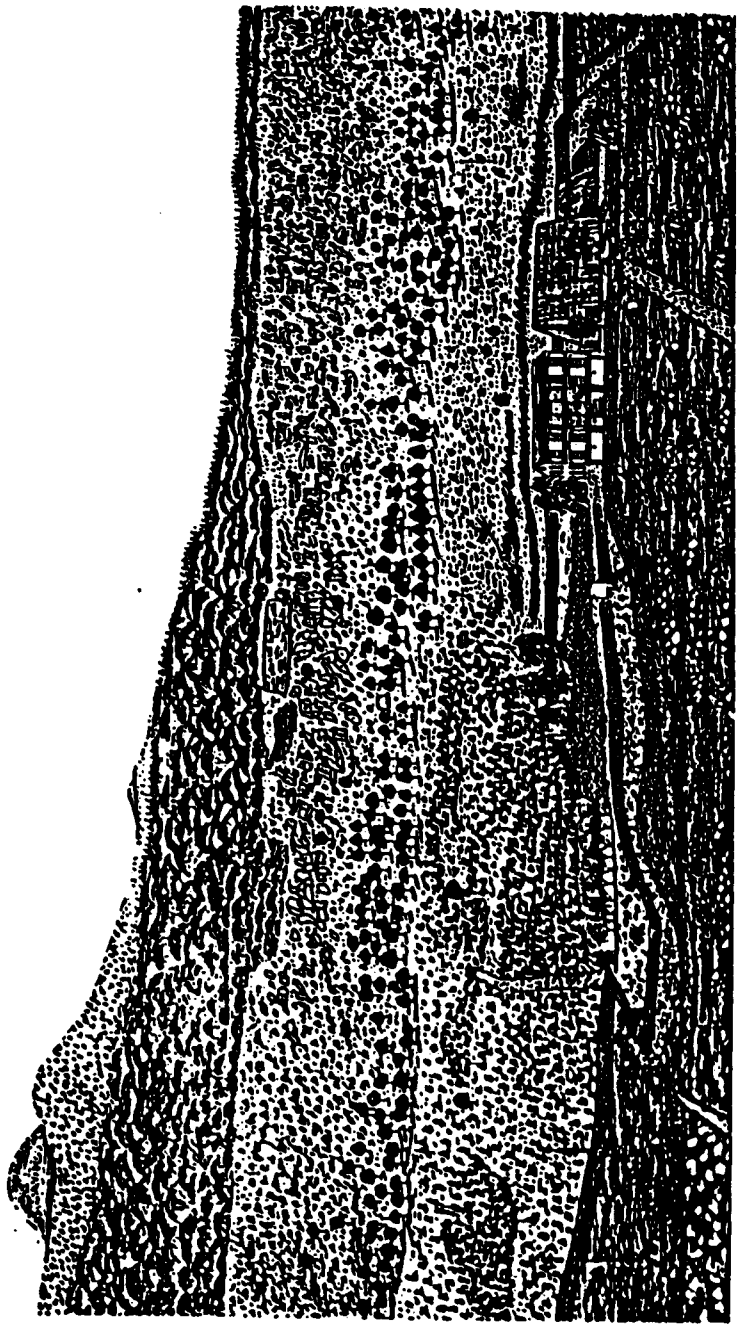


Figure 5.4 Engraving of a drawing by 'Miss Thurston' done in c.1840 of the country behind Kailua Village, North Kona, Hawaii island showing the breadfruit tree forest and the dryfield taro cultivation above the forest. Engraving by Kapoboni, Lahainaluna School, Maui (from Andrews Collection, Bishop Museum Library).

Time-frame for systematic dryland cultivation

The systematic organization of this dryland agriculture may have been developed during the time of 'Umi-a-Liloa, who came to live in Kailua, Kona in the latter part of his life after he had lived in Waipi'o Valley, where there was an extensive system of pondfield terraces and irrigation ditches. Taro production of Waipi'o was distributed widely in areas where taro was not able to be grown. 'Umi-a-Liloa was famous for farming and fishing and for organizing the division of labour. Fornander wrote about 'Umi's activities in Kona:

> During his reign Umi-a-Liloa set the labourers in order and separated (*ho'oka'awale*) those who held positions in the government. He separated the chiefs, the priesthood, the astrologers and the skillful in the land. He separated the cultivators (*ka po'e mahi'ai*) and the fishermen (*ka po'e lawai'a*), and the canoe hewers. He set apart the warriors, the spear-warders, and every department with proficiency, and every labourer in their respective lines of work. So with the governors (*kia'aina*), district superintendents (*'ai 'okana*), division overseers (*'ai ahupua'a*) and section wardens (*'ai 'ili'aina*), they were all set in order. (Fornander 1919, pp. 228–31).

Traditions that describe 'Umi as a master cultivator and fisherman, and his supporting chiefs also as experts in these occupations were recorded by Fornander:

> Umi-a-Liloa had two principal occupations which he undertook to do with his own hands: they were farming and fishing. He built large taro patches in Waipio, and he tilled the soil in all places where he resided, and when in Kona that was his great occupation; he was noted as the husbandman king . . . All the chiefs of his government were noted in cultivating the land and in fishing, and other important works which would make them independent. (Fornander 1917, p. 230).

Division of labour, a device often used to increase production, necessitates centralization of authority. It is probable that 'Umi's efforts not only enhanced food resources for the rapidly increasing population during his reign, but also elevated the status of the chief in the process. 'Umi-a-Liloa is believed to have lived in the latter half of the 15th century (born 1446 by the 30-year count), or at the end of the 16th century and early part of the 17th century (born about 1576 by the 20-year count).

Time-frame for intensification of production

The names of specific chiefs identified in Hawaiian traditions with the building of fishponds are those of some of the highest ruling chiefs known. We might therefore assume that during this latter period of large population and powerful chiefs, all (or at least most) large walled fishponds were built. This does not allow, however, for any lengthy period of time for the development of the technology for intensifying food production. It assumes, instead, that once the practicality of the Hawaiian walled fishpond, or the wetland, or dryland cultivation techniques was established, the building of large, walled fishponds, extensive irrigated taro gardens, and systematic dryland gardens spread relatively rapidly throughout the islands. Such a rapid acceptance and widespread use of these new technologies could only have been motivated by need. Some of the impetus may have come from chiefs wanting to increase their status. For the people to be willing to put as much effort into the construction of the terraces and fishpond walls as was required, however, would seem to indicate that there was a real need on their part for the increased production which these works provided.

It could also be said that those fishponds identified with remembered chiefs were built most recently. Others had their origins obscured over time, or their creators' traditions overshadowed by those of later-ruling chiefs. Similarly, the beginning of building and cultivating in extensive terraced pondfields and systematic dryland gardens was overshadowed by remembered traditions of powerful chiefs in the later period. The recently discovered O'ahu terraces were found to have been built on earlier terraces which date to the 12th century AD and perhaps earlier.

Assigning the building of some great works, such as walled fishponds and large religious structures, to *menehune*, a mythical diminutive people of the distant past, could be viewed as an attempt to deny credit to commoners, the people who actually did the work of constructing the walls of the ponds or the massive stone work of the religious structures (*heiau*). This view is supported because the suggested derivation of the Hawaiian term *menehune* is the Tahitian term *manahune*, meaning 'commoner' (Luomala 1951).

On the other hand, some traditions provide details of the construction technology and the rôle of the commoners. The people formed a long line between the source of the rocks and the construction site. The rocks then 'flowed' down the line, passed by hand from person to person, to the site where they were placed in the wall. Legend has it that a dropped stone became defiled and must not be picked up. The practicality of such a rule is clearly evident because it prevented a complete breakdown of the flowing 'river' of rocks.

The extent of organization required to carry out a large construction project was described by a participant in the building of a large temple in the 1790s:

> The author a few years ago conversed with a centenarian Hawaiian at Kawaihaeuka who had assisted in carrying stones towards building this Heiau [*Pu'ukohola*]. His description of the thousands of people encamped on the neighbouring hillsides, and taking their turns at the work, of their organization and feeding, their time of work and relaxation, and number of chiefs that attended, and who, as the old man said, caused the ground to tremble beneath their feet. (Fornander 1969, p. 328 footnote)

Kamehameha was involved in constructing this temple as a step towards bringing the island of Hawaii under his control. The power of these chiefs was enhanced by the roar of guns and cannon that would indeed have 'caused the ground to tremble' (ibid., p. 328 footnote), more so than the presence of thousands of people working tirelessly to build a monument to the power of their chiefs.

Precontact Hawaiian population profile

When Kamakau wrote in the 1860s, the Hawaiian population had dropped from the original late 18th and early 19th century estimates that ranged from 242 000 to 400 000, to approximately 57 000 'native' Hawaiians and a little more than 1600 'half casts' by 1866 (Schmitt 1968, pp. 42, 74). With such a drastically reduced population Kamakau apparently felt compelled to prove, or at least assure his readers, that the Hawaiians were once a numerous people capable of having built such large structures as the great walled fishponds, of which there were so many still evident in his day.

Kamakau attributed the presence of large numbers of walled fishponds on O'ahu, Moloka'i and Kaua'i, and those less numerous on the Islands of Hawaii and Maui to a former large population that lived in peace:

> This shows how numerous the population must have been in the old days, and how they must have kept the peace, for how could they have worked together in unity and made all these walls if they had been frequently at war and in opposition one against another? If they did not eat the fruits of their efforts how could they have let the *awa* fish grow to a fathom in length; and *'anae* to an *'iwilei* (yard); the *ulula* to a metre or a *muku* (four and a half feet); and *aholehole* until its head was as hard as coral (*ko'a ka lae*); and the *'o'opu* until their scales were like the *uhu*? Peace in the kingdom was the reason that the walls could be built, the fish could grow big, and there were enough people to do this heavy work. (Kamakau 1961, p. 47)

In 1976 an attempt was made to develop a precontact population profile for the Hawaiian islands. A series of assumptions about an initial population, a year date for landfall, birth rate, death rate, growth rate, and a final

population upon contact were developed (Schmitt & Zane MS). Since then others have used the technique for developing their own theories about specific archaeological excavations, particularly those conducted in marginal areas (Rosendahl 1972, Kirch 1979, pp. 183–5). As the number of archaeological projects increases, evidence mounts to substantiate the presence of extensive agricultural terracing with irrigation systems and large, walled fishponds in precontact times.

Captain James King, second-in-command on the Cook expedition, made a population estimate of the Hawaiian islands based on his estimate of the inhabitants of the four Hawaiian villages (Ka'awaloa, Kealakekua, Napo'opo'o, and Ke'ei) which existed along the three miles of coastline nearest to their anchorage at Kealakekua Bay on the island of Hawaii. King (Schmitt 1968, pp. 19–20) reckoned that there were 80 houses in each village totalling 320 in all. To this he added a few straggling houses, bringing the total to 350. His estimate of six people to each house he thought was a 'moderate allowance' that gave a population of 2100 people in the four villages. To this he added 50 more families, or 300 people, who lived among the inland gardens, making a grand total of 2400 people for 4.8 km of coastline, or 500 people/km of coast.

As King did not believe that people could or did live on the rough *'a'a* lava flows which covered parts of the island, he deducted one-quarter of the population per linear kilometre. This left an estimate of 375 people/km. King's estimate of 400 km of coastline multiplied by this gave him a population estimate of 150 000 for the island of Hawaii (Schmitt 1968, p. 20).

King's figure has been criticized (Schmitt 1968, pp. 21–2) as being much too generous, particularly his grand-total figure of 400 000 for all the islands. In fact, Hawaii island has over 400 km of coastline and over 1544 km^2 of land. We now know that many villages were built on *'a'a* lava flows and that areas which are uninhabited and unproductive today were once fertile lands supporting numerous villages. Given current knowledge, King's population for Hawaii island, therefore, does not seem overly generous. Furthermore, one must account for the considerable inland populations in both Ka'u and South Kohala Districts.

The real problem with King's figures occurred when he mechanically applied his Kealakekua Bay estimates to some of the relatively barren smaller islands that had much less land area, little water and consequently not the resources to support the same rate of population per linear kilometre as did the larger islands such as Hawaii and O'ahu. Indeed O'ahu, a relatively large island, had several large lagoon areas (Ke'ehi Lagoon, Honolulu Harbour, Pearl Harbour, Moanalua, Maunalua, and Kane'ohe Bay), which provided extensive inshore fishing resources not available on Hawaii island. O'ahu also has about half of all the prime agricultural lands in the archipelago. Thus, although O'ahu has less than one-sixth the area of Hawaii island, its fishing resources and extensive river valleys where Hawaiians cultivated taro in pondfield terraces, may have increased its carrying capacity to rival that of

the farmer and fisher families continued to live as they had in the previous period, secure in their economic and social family-oriented interdependency.

Discussion

There seems to be little question that two of the cited food-producing technologies were used to intensify food production: (a) the walled fishpond and (b) the extensive terraced pondfield system with its irrigation system. In both cases, their productive advantages were known to Hawaiians and they were willing to invest great quantities of labour power in these technologies. In contrast, the evidence may be a little less convincing that the systematic planting of dryland crops, such as the Kona garden system, actually intensified the productivity of the land, but it does appear to be a strong effort to achieve higher productivity, whether or not the results paid off.

Until there are more radiocarbon dates, the time-frame for the terraces and fishponds remains highly speculative. There is little question, however, that the Hawaiians went through a period of great numerical population increase in the late precontact period and that they would have had to respond to the need for greater food production.

Any cause and effect relationship between the intensification of food production and the creation of great chiefs is difficult to prove. Nevertheless, there is no question that Hawaiian society did produce great chiefs in its late pre-contact period and that they may well have taken advantage of conditions to improve their status and claim a large share of the increased productivity. Through the changes in the late period the basic values developed in the early period continued to guide the society and are the core of beliefs and behaviour of many modern Hawaiians

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