Draft

Dynamics of Production Intensification in Pre-contact Hawai'i.

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Introduction

There were three main technological advances resulting in production intensification in pre-contact Hawai'i: walled fishponds, terraced pondfields with their irrigation systems, and 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 selection of the herbivore link in the food chain. The selected herbivorous fish, primarily Mugil cephalus (grey mullet, or 'ama'ama) and Chanos chanos (milk fish, 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 achievement 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 wet-land Colocasia esculentas (taro, 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 that 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 5 times the amount of taro as an acre of dry-land 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 dry-land gardens need to lie fallow for greater lengths of time than irrigated gardens. In addition, walled pondfields not only produced taro, but were also used to grow fresh-water fish, primarily Chonophorus stamineus (the Hawaiian goby, or 'o'opu nakea), and certain kinds of shrimp ('opae).

A third achievement was the systematic cultivation of dry-land crops in their appropriate vegetation zones as exemplified by the Kona Garden System, utilized in areas that lacked perennial streams.

The author postulates that these three developments were achieved in response to the demands of a rapidly increasing population in the late pre-contact period (primarily the 16th and 17th centuries) and resulted in changes in the socio-political

structure, producing a hierarchical class structure also unmatched in Polynesia.

Fishponds

The cultivation of fish took place in Hawaiian agricultural pondfields as well as in specialized fresh- and brackish-water fishponds. Traditionally, certain kinds of small fresh-water and fresh-water-tolerant fish that usually live 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 fresh-water fish usually found their way from the streams into the taro gardens through the irrigation ditches.

Some fishponds were located inland and were fresh-water ponds. These ponds were also 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 fresh-water stream life, such as the goby, making its home in the ponds.

Walled, brackish-water fishponds were usually constructed on the reef along the shore, many of them having walls 1200 and 1500 meters 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 favorable environment for algae growth. The development of walled, brackish-water fishponds was a marked technological advancement toward increasing the amount of protein food available.

Walled Fishponds

MacGinitie's (1935) natural food chain postulates that 10,000 pounds of algae make 1,000 pounds of tiny crustaceans, which in turn make 100 pounds of small fish. These 100 pounds of small fish then produce 10 pounds of large fish, which in turn make one human pound.

Hiatt (1947:278, 256-260) 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 consisting primarily of diatoms, other algae and organic substances that are vegetable debris, detritus and other minute algae growing on the bottom of the pond, or on the larger algae.

Due to these factors, according to Hiatt (ibid.), the weight ratios in Hawaiian ponds 'are closer to the following: 10,000 pounds of algae and detritus make 1,000 pounds of herbivorous fish, 1,000 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.

Mugil cephalus (grey mullet, or 'ama'ama) 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 1947:256).

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, were undoubtedly part of the great fund of knowledge held by Hawaiians about the sea and the plants and animals that 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 the algae.

The types of algae that mullet consume grow best in brackish water. Hawaiian walled fishponds were often located on the shoreline near the mouth of a stream, or where fresh water escapes in springs along the shore and often in the sea. With ample supplies of fresh and salt water, such locations ensured a continuous replenishment of oxygen for fish and plants.

Fishpond walls were built with one or more sluice gates. With fishponds located next to the mouth of a stream, the pondkeeper, by opening a sluice gate, took advantage of the highly nutritious water that had coursed through the inland 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.

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

Hawaiian historian Samuel M. Kamakau (1976:48) 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,' he said, 'fish would begin to be seen in the loko kuapa (walled pond.)' A correctly built pond provided a highly favorable setting for algae growth, thus

enhancing the natural resources of the sea. Herbivorous fingerlings entered the pond through narrow openings in the sluice gates and fed on the algae within the walls of the pond. The openings in the sluice gate also allowed fresh sea water with its nutrients and diluted oxygen into the pond for the fish and algae. The ponds protected the herbivores from carnivorous predatores outside the walls. In time the fingerlings grew fat, too large to escape through the same narrow sluice-gate openings that 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 of 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 necklace 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?

Kamakau (1976:47-48) 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, '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 coordination. Chiefs had the power to command a labor force large enough to transport the tons of rock required and to construct such great walls.

Kamakau (1961:42) identified the building of Mau'oni fishpond on the Island of Maui with a meeting between the high chiefs of Maui and Hawai'i, 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-kuhihewa was the high chief of the Island of O'ahu.

Abraham Fornander (1919:312-313) estimated the birth dates of these three ruling chiefs, using his 30-year generation count and rounding out the results as follows:

Kiha-a-Pi'ilani, 12 generations from Pinao b.1824 = A.D. 1480
Keawe-a-'Umi, 11 generations from Kalakaua b.1836 = A.D. 1540
Ka-kuhihewa, 11 generations from Kapi'olani b.1834 = A.D. 1540

Kamakau's (1961:22-25) 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 well 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 done by anthropologist John G. F. Stokes (1933), who concluded that 20 years would result in better estimates for the length of a Hawaiian generation on geneaologies 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 A.D. 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 to be built on the Island of O'ahu (Fornander 1969(2):269). Her son, Ka'ihikapu-a-Manuia, is said to have been responsible for building two very large ponds, 135 and 105 hectares (McAllister 1933:93). One of these had a wall nearly 1,400 meters long, 1 to 2 1/2 meters wide and 1 meter high (Fornander 1969(2):270; McAllister, ibid.)

Fornander (1919:313) places these two ruling chiefs at eleven and twelve generations back from Kapi'olani (b. 1834), and their births around the turn of the 16th century. Stokes' 20-year generation count would place them approximately a 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 Hawai'i. The Maui chief sent spies to Kona. When they reported their discoveries, they mentioned the 'walled-in ponds' of Kaloko and Honokohau (Kamakau 1969:56). This tradition does not deal with the building of the fishponds, but merely reveals that they were already in place. Both of these ponds were walled in embayments.

Fornander (1919:313-314) places Kamalalawalu eleven generations before Kalakaua, or in the early 16th century (A.D. 1510). By Stokes' (1933) estimate, Kamalalawalu would be placed in the early 17th century (A.D. 1616).

To summarize the dating of the six chiefs mentioned in connection with fishponds, their birthdates span the 15th and early 16th

centuries (by Fornander's 30-year count), or the late 16th and early 17th centuries (by Stokes' 20-year count).

Ruling Chief	30-year count	20-year count
Kiha-a-Pi'ilani	1480	1584
Keawe-a-'Umi	1540	1616
Ka-kuhihewa	1540	1616
Kalai-manuia	1474	1594
Ka'ihikapu-a-Manuia	1504	1614
Kamalalawalu	1510	1616

Regardless of the differences in dates between the results of the two methods of calculating the births of these ruling Hawaiian chiefs, both methods place them well within the latter period of Hawaiian pre-contact history. The major conditions that generated as well as enabled the development of fishponds at that time was a population that was large and continuing to increase. It continued to provide pressure for additional food resources as well as provide a large work force capable of constructing massive fishpond walls.

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 on entire islands. The coordination of labor by the chiefs enabled the walled fishponds to be constructed, thereby contributing to the power of those chiefs and their claims to a substantial portion of the surpluses generated.

Stone-faced, terraced pondfields.

An archaeological survey team recently found and recorded a large complex of stone-faced, terraced pondfields, built and used by Hawaiians in past centuries for cultivating wet-land taro (Colocasia esculenta, or kalo). The complex was found to extend over an area of approximately four hectares and 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 about 30 centimeters and 2 meters in height, with a mean width of the terraces approximately 5 meters, and variations up to about 15 meters, depending on the slope of the ground. Remains of irrigation ditches, some with water-flow controls, were found throughout the area (Allen-Wheeler Ms.).

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 recorded by archaeologist J. Gilbert McAllister (1933:113) was reported to be about 3 kilometers long.

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 water 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 constructed to carry water to the terraces. In this way the amount and speed of the water could be controlled. If too much water were found to be flowing into the ditch, a few stones could be removed from the dam, thus lowering the water level and reducing the amount of water flowing into 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 varigated terrain. The flow through the pondfields was controlled by the heights between 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 water. 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 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 wild 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 attended with much care, ingenuity, and manual labour (Vancouver 1798(1):163-164).

Naturaliat Archibald Menziea, who waa with Vancouver, alao wrote about theae large plantationa:

> We puraued a pleaaing path back into the plantation, which waa nearly level and very extenaive, and laid out with great neatneaa into little fielda planted with taro, yama, aweet potatoea and the cloth plant. Theae in many caaea, were divided by little banka on which grew the augar cane and a apecies of Draecena without the aid of much cultivation, and the whole watered in a moat ingenious manner by dividing the general atream into little aquaducts leading in various directions ao as to supply the moat diatant fielda at pleaaure, and the aoil aeema to repay the labour and induatry of theae people by the luxuriancy of its productiona (Menzies 1926:23-24).

In 1815, explorer Kotzebue added to these discriptions 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 are 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 1821:102).

On the question of the productivity of wet-land taro vs. 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' (Wyllie 1848:82)? Revs. Coan and Lyman wrote from Hilo, Hawai'i, where mostly dry-land taro was cultivated by them:

> 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 1848:82).

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

> With proper management, kalo [taro] land need 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 1848:82).

Writing from his experience on the well-watered windward side of O'ahu, Pali Ko'olau, or Ko'olau Poko, Rev. 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. [Parker.] (Wyllie 1848:82).

Rev. Bishop, writing from 'Ewa district on O'ahu, suggested that 15 to 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. [Bishop.]' (Wyllie 1848:82).

Rev. Emerson lived and worked in Waialua District where several large rivers and numerous springs watered the land. Emerson 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. [Emerson.] (Wyllie 1848:82).

Rev. Johnson of Hanalei, Kaua'i, a noted wet-land taro producing valley, suggests that 25 persons subsist on an acre of good taro land (ibid.).

Hawaiian historian David Malo (1951:206) 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 wet-land taro and placed the greater effort in this area very early, when required to increase food production capabilities for the rapidly increasing numbers of people. By the time of Capt. Cook's visits in 1778 and 1779, every large river valley in the islands contained many pondfields, systematically irrigated with ditches delivering water to the fields spread throughout the valleys.

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 A.D. 1360, according to Fornander's 30-year generation count, or A.D. 1514, according to Stokes' 20-year count. Ma'ilikukahi occupies a prominent place in O'ahu legends for his wise, firm, and judicious government (Fornander 1969(2):89). It is said that he caused the island to be thoroughly surveyed, and the boundaries between the different divisions and lands to be definitely and permanently marked out,

thus avoiding future disputes between neighboring 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 1959(2):88-91).

Another son of Ma'ilikukahi was Kalona-nui. Kalona-nui had a son, Kalamakua, who was born about A.D. 1414 on the 30-year generation count, or around A.D. 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 thirty fishponds at their lower end (Bishop 1881).

O'ahu chiefs	30-year count	20-year count
Ma'ilikukahi	A.D. 1360	A.D.1514
Kalona'iki & Kalona-nui	1390	1534
Piliwale & Kalamakua	1420	1554
Kukaniloko	1450	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 1933:186, quoting S.M. Kamakau).

Kakuhihewa's birthdate estimates are: A.D. 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 (A.D. 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(4):432). Kuali'i became the acknowledged high chief (mo'i) of O'ahu (Fornander

1969(2):281), and lived to a very advanced age (ibid.:283).

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

Systematic dry-land cultivation in vegetation zones.

Agricultural intensification also took place in Hawaiian dry-land cultivation as exemplified by the Kona agricultural system (Newman Ms.; Kelly 1983). Cultivation of the soil in Kona, Hawai'i, 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. Capt. 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 bread-fruit is met with in abundance, and above this the taro is cultivated with success (Wilkes 1845(4): 95).

Rev. William Ellis described the area behind Kailua town in Kona, above the breadfruit and mountain apple trees as seen by Revs. 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 1963:31-32).

The written description is borne out in a drawing done by one of the daughters of Rev. and Mrs. Asa Thurston.

Time frame for systematic dry-land cultivation.

The systematic organization of this dry-land 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 having lived in an earlier period 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 labor. Abraham Fornander wrote about 'Umi's activities in Kona:

> During his reign Umi-a-Liloa set the laborers 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 laborer 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 1917(4):228-231).

Of 'Umi as a cultivator, Fornander had this to say:

> 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(4):230).

Division of labor, a universal device 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 the end of the 16th and early 17th centuries (born about 1576 by the 20-year count).

Over-all Time Frame for Intensification of Production in Hawai'i

The names of specific chiefs identified in Hawaiian traditions with the building of fishponds are those of some of the highest ruling chiefs known. It might therefore be theorized that during this latter time of large population and powerful chiefs, all (or at least most) 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, rather, that once the practicality of the Hawaiian walled fishpond, or the wet-land, or dry-land cultivation techniques had been established, the building of large walled fishponds, extensive irrigated taro gardens and systematic dry-land 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 may have been motivated by chiefs desiring to increase their status.

Alternatively, those fishponds identified with remembered chiefs were simply those 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 dry-land gardens were overshadowed by remembered traditions of powerful chiefs in the later period. The recently discovered O'ahu terraces were found to have been built on smaller terraces that date as early as the 12th century A. D.

Assigning the building of some great works, such as walled fishponds and large religious structures, to '<u>menehune</u>,' 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.

On the other hand, some traditions provide details of the construction technology and the role of the masses of 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 in order to prevent disaster, if indeed the rocks were 'flowing.'

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 incarrying stones towards building this Heiau [Pu'ukohola]. His description of the thousands of people encamped on the neighboring hillsides, and taking their turns

> at the work, of their oganisation and feeding, their time of work and relaxation, the number of chiefs that attended, and who, as the old man said, caused the ground to tremble beneath their feet (Fornander 1969(2):328 footnote).

Kamehameha was involved in constructing this temple as a step toward bringing the island of Hawai'i 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,' more so than the presence of thousands of people working tirelessly to build a monument to the power of their chiefs.

Pre-contact Hawaiian Population Profile.

When Hawaiian historian Samuel M. 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 1,600 'half casts' by 1866 (Schmitt 1968:42,74). 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 Hawai'i 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 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 <u>'anae</u> to an <u>'iwilei</u>, (yard); the <u>ulua</u> to a meter or a <u>muku</u> (four and a half feet); and <u>aholehole</u> until its head was as hard as coral (<u>ko'a ka lae</u>); and the <u>'o'opu</u> until their scales were like the <u>uhu</u>? 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 1967:47).

In 1976, an attempt was made to develop a pre-contact population profile for the Hawaiian Islands. A series of assumptions about an initial population, a year 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 (Kirch 1979:183-185; Rosendahl 1972). 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 pre-contact times.

Capt. 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 Hawai'i. King figured that there were 80 houses in each village, totaling 320 houses 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 2,100 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 2,400 people for three miles of coastline, or 800 people per linear mile of coast.

As King did not believe that people could live on the rough 'a'a lava flows which covered parts of the island, he deducted one-fourth of the population per linear mile. This left an estimate of 600 people per mile (1.6 kilometers). King's estimate of 250 linear miles (approximately 400 kilometers) of coastline multiplied by 600 people per linear mile (375 people per kilometer) gave him a population estimate of 150,000 for the Island of Hawai'i.

King's figure has been criticized as being much too generous, particularly his grand-total figure of 400,000, for all the islands. We know today that Hawai'i Island has over 250 linear miles of coastline and over 4000 square miles (over 1,544 square kilometers) of land. We now know that many villages were built on 'a'a lava flows. And we know also that areas that today are uninhabited and unproductive were once fertile lands supporting numerous villages. King's population for Hawai'i Island, therefore, does not seem overly generous today. We know also that there were 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 mile as did the larger islands such as Hawai'i and O'ahu.

Indeed, O'ahu, a relatively large island, had several large lagoon areas (Ke'ehi Lagoon, Honolulu Harbor, Pearl Harbor, Moanalua, Maunalua, and Kane'ohe Bay) that provided extensive inshore fishing resources not available on Hawai'i 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 Hawai'i Island, its fishing resources and extensive river valleys where Hawaiians cultivated taro in pondfield terraces may

have increased its carrying caplacity to rival that of Hawai'i Island. Archaeologist J. Gilbert McAllister (1933:28) obtained information about 97 fishponds on O'ahu, which again says something about the size of the population, as well as the resources available to support it.

The Schmitt and Zane (Ms.) population profiles for the Hawaiian Islands before 1778, suggested a crude birth rate of 45 per thousand per annum, based on other similar Oceanic societies, and a death rate of 38.7 per thousand per annum, based on known or assumed data, leaving a constant growth rate of 6.3 per thousand per annum, or 0.63% per annum. An arbitrary figure of 300,000 (100,000 less than Capt. James King's estimate in 1779) was selected for the size of the population in 1778 (Schmitt & Zane Ms.). Thus, with the further assumption that the first immigrants came to Hawai'i in A.D. 500, that there were 100 of them, and that there were an average of 25 in-migrants annually for 1,000 years, it was concluded that the population had doubled approximately every 110 years.

	A.D.	Population
Period of La'ila'i (peace)	500	100
primarily cooperative, &	600	190
egalitarian; leadership	700	350
provided by senior	800	650
members of families.	900	1,200
	1000	2,300
	1100	4,300
	1200	8,000
Period of transition;	1300	15,000
adjustment; division of	1400	28,000
labor and land	1500	53,000
Period of Great Chiefs;	1600	98,000
dynasties; genealogies	1700	184,000
connect chiefs with gods.	1778	300,000

The Schmitt and Zane population profile produces a typical 'J' curve and contradicted the popular myth of a stagmant, feudal society with a long-established oppressive chief class that lived well off the miseries of the commoners. Instead, the 'J' curve reveals a relatively small population increasing in numbers slowly for at least the first 700 or 800 years, during which constant contact was maintained with the cultural heartland of central Polynesia. It is postulated that during this period, which we have called the 'La'ila'i Period' of Hawaiian prehistory, the basic activities of the Hawaiian people welded into a code of social values that are strongly family oriented in nature, and many of which are still practiced today among the Hawaiian population. La'ila'i, a woman, was the first human being in the Hawaiian Kumulipo genealogy (Beckwith 1940:276-277).

In the later period, perhaps the last two centuries before contact, catastrophic changes took place within Hawaiian society, setting it on a path tangential to the La'ila'i Period. It is

postulated that the necessity of this shift was triggered initially by the need for greater increases in food production than had been required in the previous period. Concomitant with the development of the Great Chiefs in Hawai'i was the discontinuance of contact with central Polynesia.

The period between La'ila'i and Great Chiefs is theorized as transitional, involving efforts to correct some problems as things began to get out of hand. Thus, dividing the land into permanent divisions to avoid rivalries between adjacent chiefdoms would have been one of the adjustments that occurred during this period. To provide a rationale for elders assuming far-reaching leadership roles, such as a dynasty of chiefs who achieved control over an entire island, could have led to their extending their genealogies to obtain greater power, or to make what power they had more secure than it was, perhaps due to rival chiefs.

Discussion

There seems to be little question that two of the cited food producing technologies were used to intensify food production: the walled fishpond and 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 labor power in these technologies.

Evidence may be a little less convincing that the systematic planting of dry-land crops, such as the Kona Gerden 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 more radiocarbon dating is done in these productivity areas the time frame for the terraces and fishponds remains highly speculative. However, there is little question that the Hawaiians went through a period of great numerical population increase in the late pre-contact 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 more difficult to prove. Regardless, there is no question that Hawaiian society did produce Great Chiefs in its late pre-contact period, and they well may have taken advantage of conditions to improve their status and claim a large share of the increased productivity.

References Cited

Allen-Wheeler, Jane
Ms. Luluku: an Upland Agricultural System in Kane'ohe, Ko'olaupoko District, O'ahu. Second Preliminary Report on Archaeological Investigations. For Highways Division, Department of Transportation, State of Hawaii, June 1985. Department of Anthropology, Bernice P. Bishop Museum.

Beckley, Emma Metcalf
1887 'Hawaiian Fishing Implements and Methods of Fishing.' Bulletin, U.S. Fish Commission 6 for 1886. Article No. 78:245-256. Washington, D.C., U.S. Printing Office.

Beckwith, Martha
1940 Hawaiian Mythology. New Haven: Yale University Press.

Bishop, Serano E.
1881 Map of Waikiki, survey and map by S.E. Bishop in 1881. Hawaiian Govezrenment Survey. Scale 1:2400. Reg. Map 1398, Hawaii State Survey Office. Honolulu, Hawaii.

Fornander, Abraham
1919 Fornander Collection of Hawaiian Antiquities and Folk-Lore. With translations edited and illustrated with notes by Thomas G. Thrum. Memoirs of the Bernice P. Bishop Museum, Vol. 4,Part 2. Honolulu: Bishop Museum Press.

1969 An Account of the Polynesian Race: Its Origins and Migrations. Three volumes in one. Reprinted from earlier printings in the 1870s. Rutland, Vermont: Charles E. Tuttle Co.,Ltd.

Handy, E. S. Craighill and Elizabeth Green Handy
1972 Native Planters in Old Hawaii: The Life, Lore and Environment. With the collaboration of Mary Kawena Pukui. Bishop Museum Bulletin No. 233. Honolulu: Bishop Museum Press.

Hiatt, Robert W.
1947 'Food-Chains and the Food Cycle in Hawaiian Fish Ponds--Part I. The Food and Feeding Habits of Mullet (Mugil Cephalus), Milkfish (Chanos Chanos), and the Ten-pounder (Elops Machnata).' Pp. 250-261. 'Part II. Biotic Interaction.' Pp. 262-280. Transactions of the American Fisheries Society, published 1947.

Kamakau, Samuel M.
1961 Ruling Chiefs of Hawaii. Honolulu: Kamehameha Schools Press.

1976 The Works of the People of Old. Na Hana a ka Po'e Kahiko. Translated from the Newspaper Ke Au 'Oko'a by Mary Kawena Pukui. Bishop Museum Special Publication 61. Honolulu: Bishop Museum Press.

Kelly, Marion
1983 Na mala o Kona: Gardens of Kona, A History of Land Use in Kona, Hawai'i. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Kirch, Patrick V.
1979 Marine Exploitation in Prehistoric Hawai'i: archaeological investigations at Kalahuipua'a, Hawai'i Island. Pacific Anthropological Records No. 29. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Kotzebue, Otto von
1821 A Voyage of Discovery into the South Seas and Beering's Straits, for the purpose of exploring a North-west Passage...ship Nuick. 3 vols. London.

MacGinitie, G. E.
1935 'Ecological Aspects of a California Marine Estuary.' American Midl. Nat. Vol. 16, No. 5, pp. 629-765.

Malo, David
1951 Hawaiian Antiquities (Moolelo Hawaii). Translated from the Hawaiian by Dr. Nathaniel B. Emerson. Bernice P. Bishop Museum Special Publication No. 2, Second Edition. Honolulu: Bishop Museum Press.

McAllister, J. Gilbert
1933 Archaeology of Oahu. Bernice P. Bishop Museum Bulletin No. 104. Honolulu: Bishop Museum Press.

Menzies, Archibald
1920 Journal of Archibald Menzies kept during his three visits to the Sandwich, or Hawaiian Islands...when acting as surgeon and naturalist on board H.M.S. Discovery, edited by W. F. Wilson and entitled, 'Hawaii Nei 128 Years Ago.' Honolulu: W. F. Wilson.

Nakuina, Emma Metcalf B.
1894 'Ancient Hawaiian Water Rights and some of the customs pertaining to them.' Thrum's Hawaiian Almanac and Annual for the year 1894:79-84. Honolulu.

Newman, T. Stell
Ms. Aboriginal Hawaiian agriculture: the archaeological evidence. Typescript, Department of Anthropology, University of Hawaii. Honolulu.

Pukui, Mary Kawena and Samuel H. Elbert
1971 Hawaiian Dictionary: Hawaiian-English, English-Hawaiian. Honolulu: University of Hawaii Press.

Rosendahl, Paul H.
1972 Aboriginal Agricultural and Residence Patterns in Upland Lapakahi, Island of Hawaii. Unpublished Ph.D. dissertation, Department of Anthropology, University of Hawaii. Honolulu.

Schmitt, Robert C.
1968 Demographic Statistics of Hawaii, 1778-1965. Honolulu: University of Hawaii Press.

Schmitt, Robert C. and Lynn Y. S. Zane
Ms. How Many People Have Ever Lived in Hawaii? In Library, Department of Planning and Economic Development, State of Hawaii. See Also, Data Book for Hawaii State, 1984: Table 51.1, Department of Planning and Economic Development State of Hawaii. Honolulu.

Stokes, John F. G.
1933 'New Bases for Hawaiian Chronology.' Forty-First Annual Report of the Hawaiian Historical Society for the Year 1932. Honolulu: Hawaiian Historical Society.

Summers, Catherine C.
1964 Hawaiian Fishponds. Bernice P. Bishop Museum Special Publication No. 52. Honolulu: Bishop Museum Press.

1971 Molokai: A Site Survey. Pacific Anthropological Records No. 14. Department of Anthropology, Bernice P. Bishop Museum. Honolulu.

Vancouver, George
1798 A Voyage of Discovery to the North Pacific Ocean and round the kworld...in the Discovery...and... Chatham. 3 vols., and atlas of charts. London.

Wyllie, Robert C.
1848 Answers to Questions. Proposed by His Excellency, R.C.Wyllie, His Hawaiian Majesty's Minister of Foreign Relations, and addressed to all the Missionaries in the Hawaiian Islands, May, 1846. Honolulu, Hawaii.

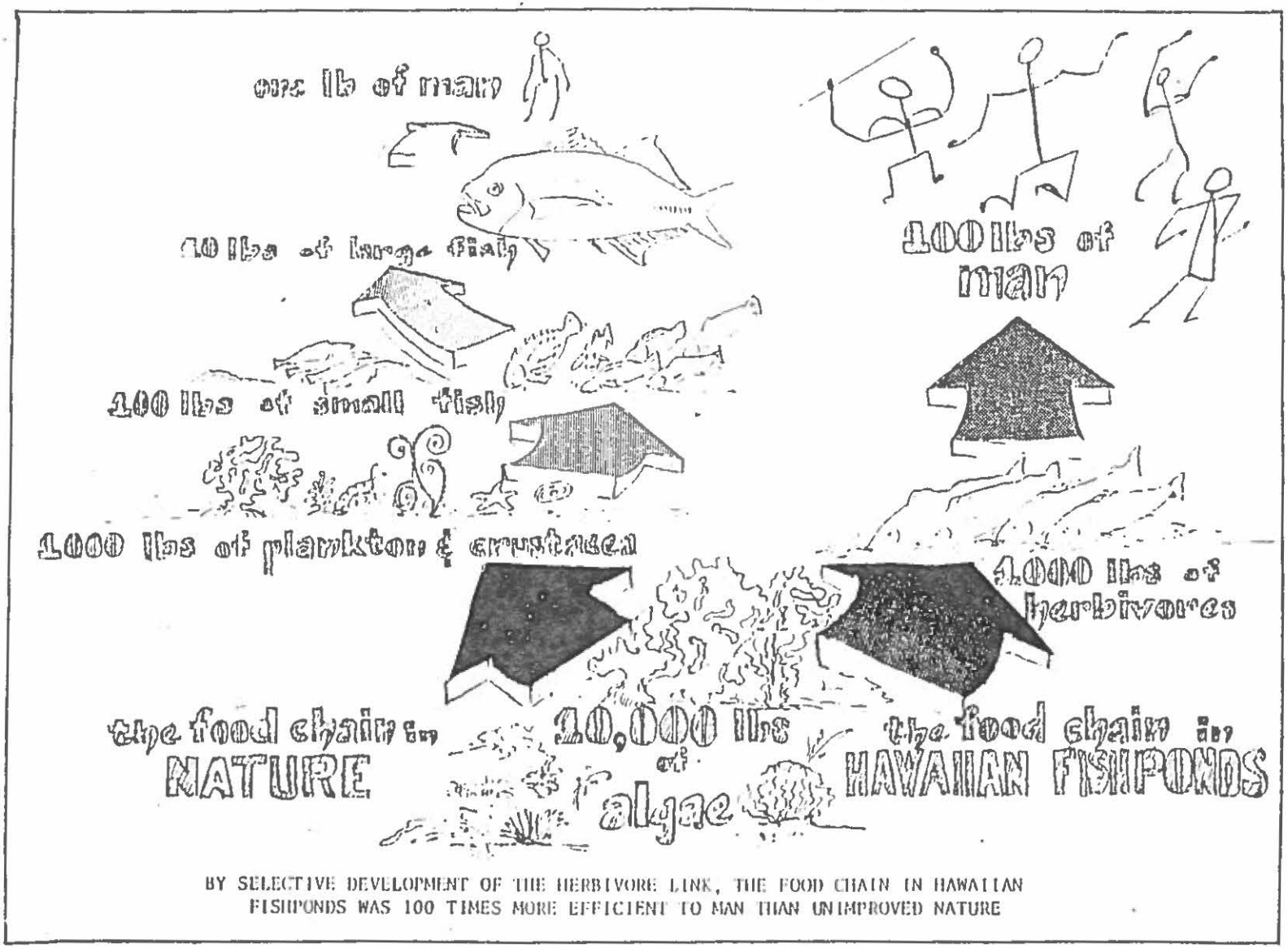

Figure 1. Drawing illustrating the efficiency of protein production by cultivating the herbivore link in the food chain. (Drawing by J. Kelly)

Figure 2. Aerial photograph of He'eia Fishpond, Kane'ohe Bay, O'ahu, Hawai'i. Note field broundaries in meadowland inland of the fishpond. This pond is 35.6 hectares in size.

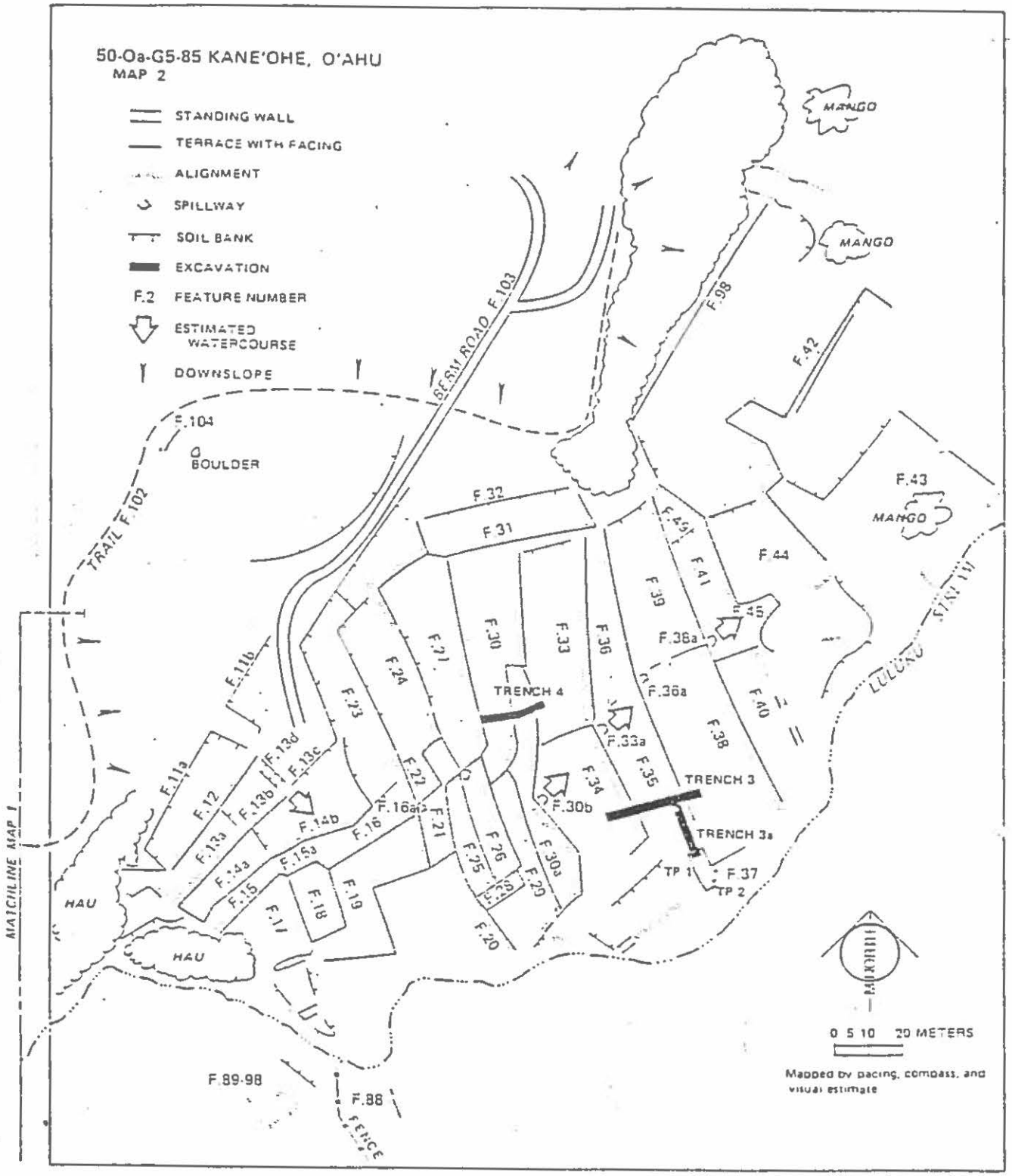

Figure 3. Preliminary survey map of portion of Luluku pondfields, terraced for growing wet-land taro in approximately 4,25 hectares (Fig. 4, Map 2 of Site 50-Oa-G5-85, Allen-Wheeler 1985).

Figure 4. Drawing by Persis Goodale Thurston, ca. 1840, showing the Thurston residence in the right foreground, the kula grass lands behind it; above the kula is the breadfruit forest, and the food gardens between the breadfruit trees and the dense, upland forest. Engraving by

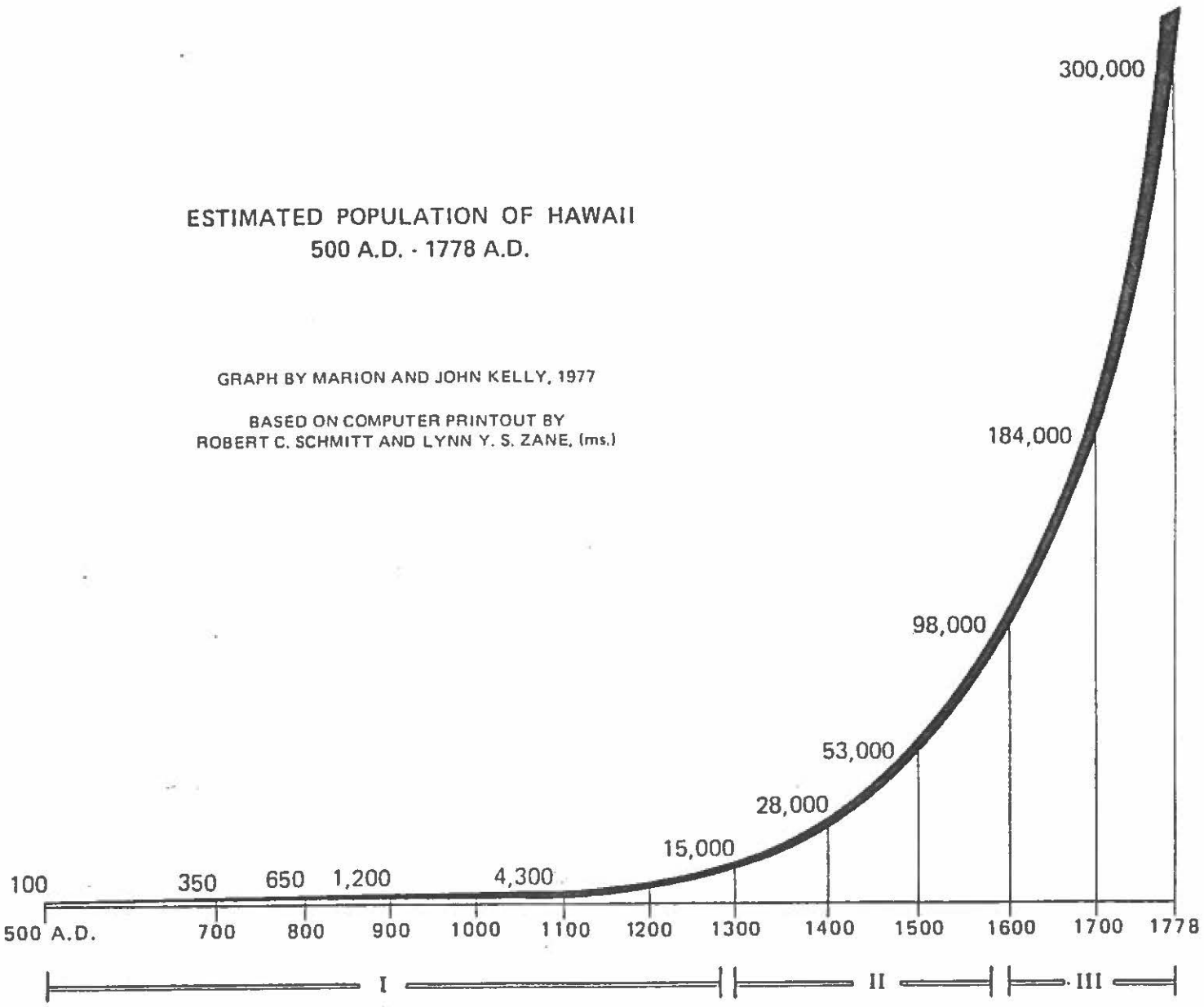

Figure 5. Estimated population of Hawai'i, 500 A.D. - 1778 A.D.; graph based on computer printout by Schmitt & Zane (Ms.).

Captions for illustrations (M. Kelly)

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