Aquaculture in Ancient Hawaii
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Aquaculture in Ancient Hawaii

Integrated farming systems included massive freshwater and seawater fish ponds

Barry A. Costa-Pierce

A combination of food-producing technologies is required to support a large human population where there is a limited amount of arable land. Today integrated farming systems—combining agriculture, aquaculture, animal husbandry, and waste treatment technologies—are in use in South and Southeast Asia and China, as well as in Eastern Europe and the Middle East.

In Hungary, for example, a ten-year cycle of land and water use is commonly practiced to convert marginal agricultural and waste lands into productive agricultural lands (Brown 1977, Muller 1978). For five years a combination of duck and common carp (*Cyprinus carpio*) farming in ponds produces about 4000 kg/ha/year of ducks and fish. During years six and seven, the ponds are drained and alfalfa is planted in the pond bottoms. Yields of alfalfa are approximately 8000kg/ha in the first year and 6000 kg/ha in the second. During years eight, nine, and ten, rice is planted, and harvests average 3000–3500 kg/ha/year. The ten-year cycle then begins anew with combined duck and fish farming.

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Seawater farming may have originated in Hawaii more than 1500 years ago

In the northern Delta region of Egypt, aquaculture is being used as a first stage of reclaiming over 50,000 ha of highly saline soils for agriculture, and up to 10,000 families are supported by the practice (Cross 1981). In spring, large ponds are constructed in unreclaimed saline soils, which may have salt concentrations as high as 200 parts per thousand (ppt). These ponds are flooded with water of 5–8 ppt for two weeks, then the water is drained. Flooding is then repeated. After the second batch of water is discarded, the ponds are filled to 30 cm depth and stocked with mullet fingerlings (*Lisa ramada, Lisa saliens,* and *Mugil cephalus*) caught from the sea. Farmers regulate the pond salinity by adding water during the season, and no feed or fertilizer is used. Fish are harvested from December to April and yields are 300–500 kg/ha/year.

Low salinity standing water in the ponds forces the higher salinity groundwater downwards through the soil profile, where it is collected in subsurface drains. Each spring the progress of soil desalination is checked by inserting twigs of *Eucalyptus* sp. into the pond soil. If the twigs die, the land is again used for aquaculture; if the twigs live, the farmers know the soil can support a crop of barley. This system reclaims soils over a three- to four-year period and has replaced the costly conventional ten-year reclamation schemes previously used by government engineers in the region.

Similarly, in Thailand, a single large farm may contain several thousand ducks, chickens, and pigs, as well as over a million fish, in a system incorporating anaerobic digestion, waste recycling, and water reuse (Figure 1).

Only recently have scientists begun to understand the fundamental value of integrating food production systems (Bardach 1982, Billard 1986, Ma 1985, Pullin and Shehadeh 1980, Shang and Costa-Pierce 1983). In some cases, however, integrated farming systems techniques have experienced failure due at least in part to socio-economic, cultural, and political factors. Therefore it is useful to consider historical examples of integrated farming systems and their socio-cultural contexts.

Some traditions of ancient aquaculture

Integrated farming systems, which included aquaculture, arose in ancient China, Egypt, and Hawaii, and perhaps also Europe and the southwestern United States. This innovation in food production, which developed in localized regions, may have resulted from extreme population pressure on the production capacities of natural and agricultural ecosystems. There is evidence of both local and widespread famine in ancient China, Europe, the Middle East, and Oceania. Mallory (1928) reported that China experienced famine in some province nearly every year for over a thousand years. In 1878 Cornelius Walford compiled a chronicle of 350 famines in Europe and the Middle East, going back as far as a famine in Rome in 436 B.C. (Ehrlich and Ehrlich 1972).

Originally, aquaculture seems to have evolved from fishing. Then it developed into integrated agriculture-aquaculture farming systems in the most advanced ancient agricultural societies (Ruddle 1980, 1982). For example, in the upper Mekong River watershed, in southwest China and Laos, ricefield fisheries may have co-evolved with wet rice cultivation and the fermentation of rice and fish surpluses (Ishige and Ruddle 1985). In these systems freshwater aquaculture was integrated into existing agricultural enterprises, creating a new type of agroecosystem.

China is often credited with the development of much of the art and science of modern aquaculture. Chinese fishing methods, fisheries management, and early aquaculture techniques have been documented as far back as 1122 B.C. (Radcliffe 1926). Intensive fishing pressure, due to the great population pressures in the coastal zone of ancient China likely helped initiate the early aquaculture development. Around 2000 B.C. the ruler Yu Wang issued a conservation edict prohibiting fishing during the spawning seasons (Wu 1985). During the Chou Dynasty (1122 to 249 B.C.), Fan Li started breeding and raising common carp in Wuxi, Jiangsu Province, in eastern China. In 473 B.C. he wrote a book entitled *Fish Breeding*, the first known document on aquaculture (Fan Li fifth century B.C.).

Ancient Chinese aquaculture employed only common carp until the Tang Dynasty (618 to 906 A.D.), when the Emperor Li banned the culture, fishing, sale, and consumption of this fish because its Chinese name was the same as that of the Emperor! Over time, aquaculture was begun using five other carp species—grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), mud carp (*Cirrhina molitorella*), and black carp (*Mylopharyngodon piceus*)—whose fingerlings could be easily caught in the Pearl and Yangtze rivers and reared together in ponds. Thus arose the classical Chinese fish polyculture that is widely practiced today (FAO 1983, Ruddle and Zhong 1987).

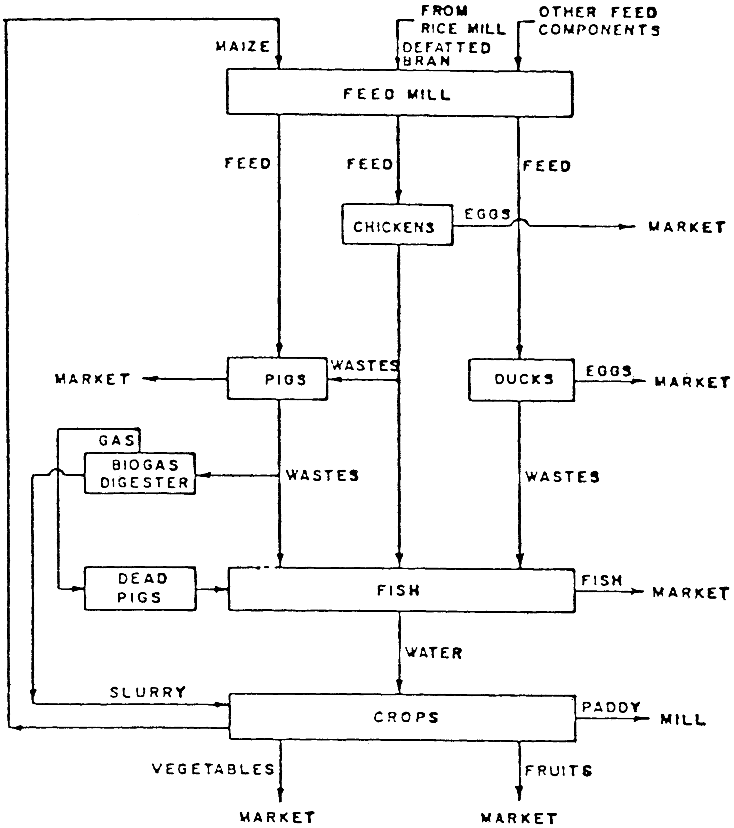

Figure 1. System schematic of Kirikan Farm, Thailand, a large-scale integrated biogas energy-agriculture-aquaculture facility, which illustrates the principles of resource conservation, waste recycling, and symbiotic, high-yielding food production subunits. Modified from Edwards (1980).

It is not clear whether aquaculture originated in China or was introduced from elsewhere before 2000 B.C. Common carp are not native to China but came from the rivers of Central Asia that drain into the Black and Caspian Seas (Schäperclaus 1962). Okada (1960) proposes that the Romans or their predecessors introduced the fish into ancient China and Europe. Thus the origins of aquaculture might lie somewhere in ancient Europe, and aquaculture may have been transplanted into China by ancient trade and migration.

Once established in China, however, fish culture techniques spread rapidly from the Chinese mainland into Japan, but aquaculture in Japan remained unimportant until recently (Drews 1951). Chinese aquaculture techniques also spread into India around 1127 A.D. (Bimacher and Tripathi 1966, Jhingran 1969). More recently (about 1910), Chinese immigrants introduced aquaculture into Thailand (Smith 1925) and integrated farming techniques into Malaysia, Singapore, and Indonesia (Terra 1958).

The sophistication of aquaculture in ancient China has been well documented; however, parallel developments occurred in ancient Egypt. Although no written treatise is known that describes ancient Egyptian aquaculture techniques, well-preserved, magnificently detailed bas reliefs illustrate a highly developed technology of farming the Nile tilapia (*Oreochromis niloticus*) (Chimits 1957).

In a scene on the Tomb of Thebaine (Davis and Gardner 1954), for instance, an Egyptian of importance is sitting in his garden and fishing a drainable, artificial fish tank for Nile tilapia, using a double line with two hooks (Figure 2). His wife is seated

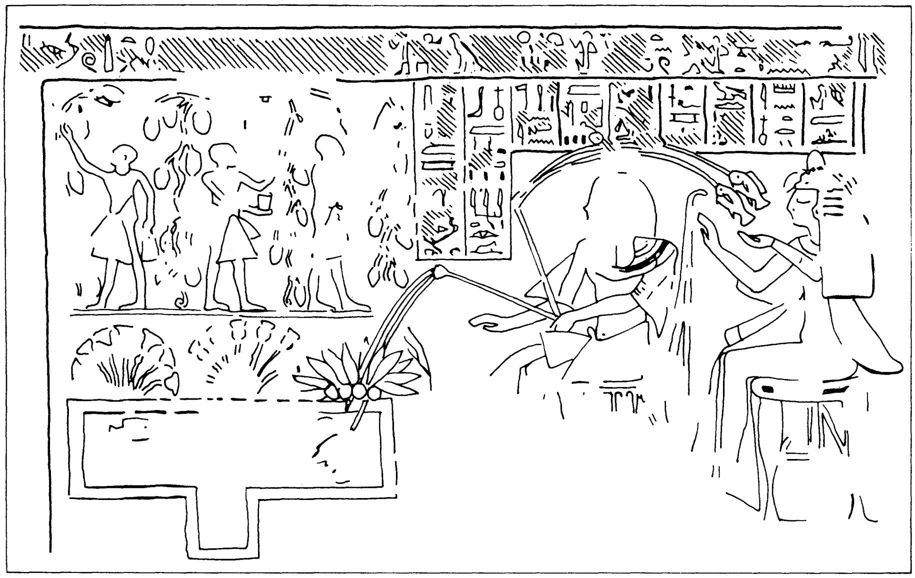

Figure 2. Bas relief on the Tomb of Thebaine, Nile Delta, Egypt, circa 2000 B.C. Note the central drainage canal, floating plants, and juxtaposition of tank to fruit trees. These components are widely used in modern aquaculture to harvest fish, provide shelter for small fish, and reuse wastewaters in agriculture, respectively. Redrawn from author's photographs and Chimits (1957).

just behind him to unhook the catch. The tank has a clearly defined central drainage canal and shallow sides with floating plants as shelter for the fish. In the background are servants picking fruit from trees that are irrigated by water from the fish pond. This illustration indicates that fish culture in artificial ponds was used in conjunction with agriculture before 2000 B.C. in Egypt, and the system provides a remarkable parallel to ancient Chinese integrated farming systems.

With a system of canals and gates, ancient Egyptians managed large inland lakes for fish production. Isaiah's prophesy (19 Is 10) was failure "for all that make sluices or ponds for fish," referring to the ancient Egyptians (Fryer and Iles 1972). These techniques are described further:

> Lake Moeris, which is in a very dry region, is fed by an artificial canal coming from the Nile; the water flows into the lake for six months, and back from the lake into the Nile for another six months. With the water flowing back into the Nile, the lake brought to the Royal Treasury, through its fisheries, one talent [35 kg] a day. While flowing back into the lake, the output was only 20 mines [11 kg].
>
> —*Herodotus,* Book II written circa 450 B.C. (Chimits 1957, p. 214).

In addition to the Chinese and Egyptian examples of ancient aquaculture, fish culture or fish "storage" may have been practiced in ancient Poland (Bogucki and Grygiel 1983) and in the US Southwest (Figure 3) (McCown and McCown 1982). But more careful studies are needed to document true aquaculture at these sites.

The ancient aquaculture and integrated farming systems of Hawaii exhibit a very remarkable sophistication in terms of their diversity, distinctive management, and sheer extent of development, especially given the small size of Hawaii. Although the Hawaiian systems are only 1500–1800 years old (a comparatively recent development by Chinese and Egyptian standards) mariculture—seawater farming—may have originated in Hawaii.

Socio-cultural system of ancient Hawaii

> The whole distance to the village of Whyeete is taken up with innumerable artificial fishponds extending a mile inland from shore, in these the fish taken by nets in the sea are put, and though most of the ponds are fresh water, yet the fish seem to thrive and fatten.... The ponds are several hundred in number and are the resort of ducks and other water fowl.
>
> —T. Bloxam, British naturalist on *H. M. S.* Blonde, describing Waikiki in 1825 (Handy and Handy 1972, p. 482).

The ancient Hawaiian fishponds were part of a large, integrated, and complex Hawaiian subsistence and barter economy that included agriculture, aquaculture, and animal rearing. The political aspects of this socio-cultural system contributed greatly to the development of the expansive aquaculture-agriculture network.

Hierarchical political control and redistribution of food was essential to the smooth functioning of the ancient integrated farming systems, because construction and management of the huge fishpond complexes required sizeable labor forces. Massive ponds such as the Kaloko pond in Kona, Hawaii, have a 229-m-long wall measuring about 2 m high and 11 m thick at the base. This wall contains an estimated 150,000 m^3 of rock and fill (Apple and Kikuchi 1975). The Kuapa pond at Maunalua, Oahu, was reportedly built over several years by thousands of people who formed long human chains to transport rocks from the Ko'olau Mountains. Efforts of this magnitude obviously required great social organization.

Ancient Hawaii had highly stratified chiefdoms with a well-defined class structure separating chiefs, advisors, stewards, and commoners. This organization was similar to that of the chiefdoms found in Tonga, Samoa, and the Society Islands (Sahlins 1958). Prior to 1848, all Hawaiian land—its resources, fishponds, and communal and spiritual centers—were owned by the kings (*ali'i*). The kings would contract the bulk of the land and fishponds to lesser chiefs (*konohiki*) but keep sacred and special resources, such as fishponds that produced especially tasty fish, under their direct control. Couriers would transport, from these royal ponds to the court, plump fish in water-filled gourds or by hand (Rice 1923) (Figure 4).

Konohiki were granted large, wedge-shaped areas (*ahupua'a*) of the Hawaiian islands that encompassed entire valleys and stretched from the mountains to the sea (Lind 1938)

Figure 3. Aerial view of fish ponds, possibly built by the Palm Springs or Cahuilla Native Americans, along the shore of ancient Lake Le Conte, now west of the Salton Sea in Southern California. Numerous circular and rectangular ponds can be seen along the former lake shoreline. It is not yet known if true aquaculture or simple fish trapping occurred in this region, but growing archeological evidence exists that a highly sophisticated agricultural/fisheries society trapped migrating fish from the ancient lake, cultured them in small ponds, and reproduced them for distribution elsewhere. Photo: Frank Colver with permission from B. H. McCown, Archaeological Survey Association of Southern California, Redlands, CA.

(Figure 5). These *ahupua'a* were generally not demarcated in Hawaii; no evidence of erect stones marking individual land holdings, such as in Tahiti, have been found (Handy and Handy 1972). It appears that the *ahupua'a* were mainly political subdivisions granted by the *ali'i* to *konohiki* to assure subsistence supplies of food, firewood, timber, thatch, and ornamentation.

Handy and Handy (1972) have described a share-cropping arrangement between tenant families and the *konohiki* that was "comprehensive and reciprocal in its benefits." Within an *ahupua'a* were sections of land (*'ili*) granted to individual extended families (*'ohana*) for cultivation. These temporary or permanent land divisions within the *ahupua'a* were clearly marked and carried individual titles. "It was said that in every com-

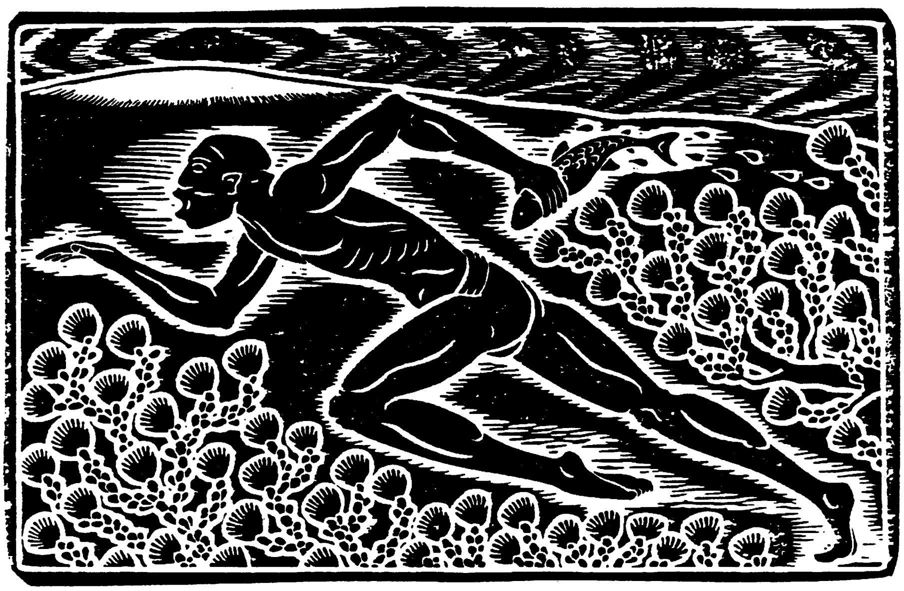

Figure 4. "Makoa," an illustration of the Hawaiian fish couriers who carried fresh fish over long distances from royal ponds to the travelling court of ancient Hawaiian kings. Print: Dietrich Varez, Volcano, HI.

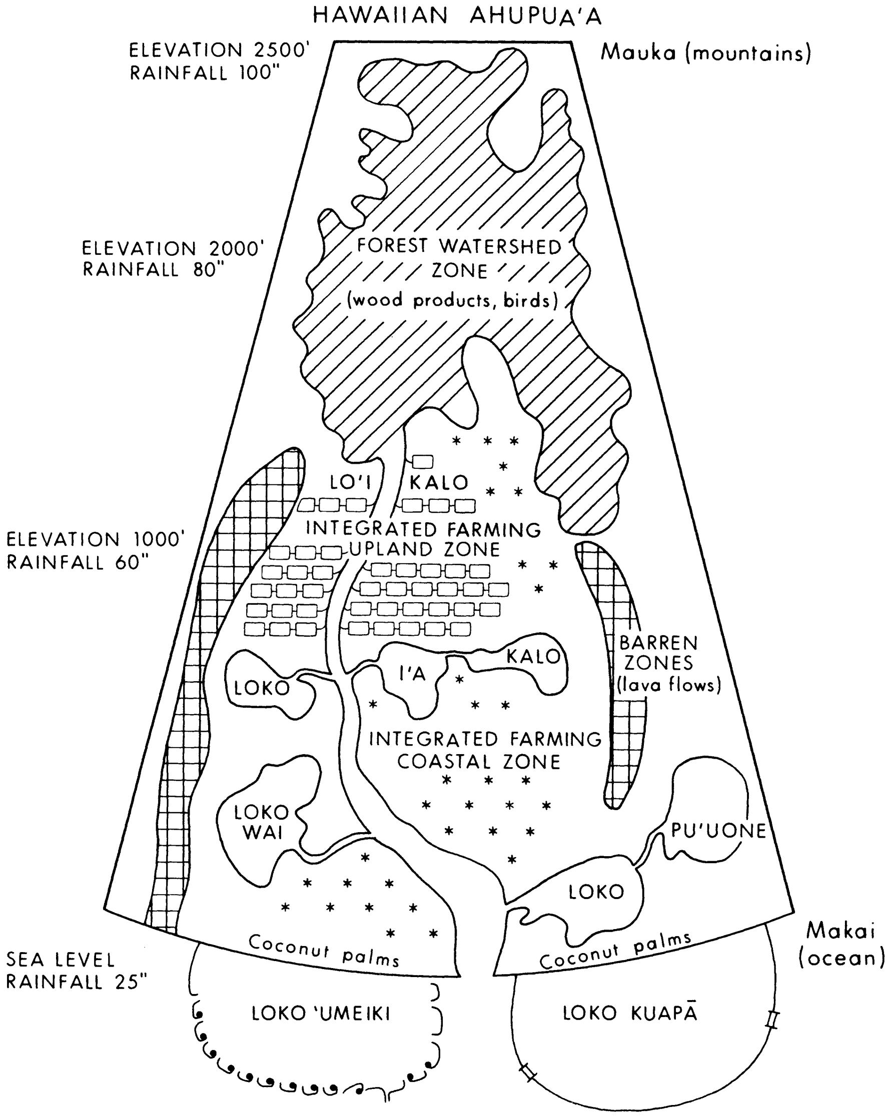

Figure 5. An idealized Hawaiian *ahupua'a* showing topographical placement of freshwater, brackish-water, and oceanic integrated farming systems. Stars indicate placement of settlements. The systems were very diverse and were adapted to the wide range of environments present, but typical valley systems of this type would be approximately 10 km from mountains to ocean and 10–20 km along the shoreline.

munity there were individuals who were well versed in the local lore of land boundaries, rights, and history" (Handy and Handy 1972, p. 49).

All harvests from the fishponds were distributed in a politically institutionalized manner by the *konohiki* to the *'ohana* and pond workers living in the *ahupua'a*. Kikuchi (1976) has suggested that the fishponds were symbols of the chiefly right to conspicuous consumption and the exclusive ownership of the land and its resources, and that the fishponds were the subject of frequent intertribal and intratribal conflict.

Kamakau (1976) argues, however, that the presence of the fishponds did not indicate any contempt on the part of the *konohiki* for the local populace. He stated, "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 fruit of their efforts?" Indeed, a native Hawaiian, David Malo, wrote of a Big Island chief who was killed because of his cruel efforts to exploit his people when he ". . . made the people of Ka'u sweat and groan . . .[with] the building of heavy stone walls about several fishponds. . ." (Malo 1951).

Contact with Europeans, which began in 1778, had a variety of dramatic effects on Hawaiian society. It destroyed the ancient religion and the chief's supernatural right to control all the land, its resources, and its people. The economy changed from the traditional barter system to a money economy. Contact with foreigners also brought new diseases, which led to the massive depopulation of Hawaii.

The Hawaiian land decision of 1848 allowed the purchase of land by Hawaiian commoners and by foreigners. In many areas the largest purchase of government lands was by foreigners; some foreigners purchased thousands of acres for \$.25–\$.50 per acre (Kelly 1980). This land decision (locally known as the Great Mahele) was a pivotal point not only in Hawaiian history but also in the history of the integrated farming systems. Decline of the fishpond complexes and Hawaiian integrated farming systems was rapid after the Great Mahele.

Once the harvests from the lands and fishponds became economic entities with prices, their distribution tended no longer to follow either an institutionalized pattern of sharing (Handy and Handy 1972) or of exploitation of the commoners by the chiefs (Kikuchi 1973), as before the Great Mahele. With the general demise of native Hawaiian society, the majority of Hawaiian integrated farming systems fell into disuse and disrepair.

When Captain James Cook reached Hawaii in 1778, at least 360 fishponds existed. They produced some 900,000 kg fish/yr (Table 1). According to the State of Hawaii only 28 ponds were suitable for fish culture in 1977 (Madden and Paulsen 1977); by 1985 only seven ponds were in commercial or subsistence use. These ponds produced 15,000–20,000 kg/yr, a mere one to two percent of the earlier production.

Integrated farming systems

Four basic types of fishponds and one fish "trap" were known in ancient Hawaii and were integrated to various degrees with taro (*Colocasia esculenta*) agriculture. Ponds were fed with cut grass, mussels, clams, seaweeds, and taro leaf from adjacent agricultural or natural ecosystems (Titcomb 1952, Wilder 1923). In contrast to modern integrated systems, Hawaiian fishponds did not receive fertilization from animal or human wastes or kitchen refuse; the chiefs prohibited such waste use (Kikuchi 1976).

The diversity, extent, and number of fishponds in Hawaii before contact with Europeans is impressive. The various fishponds (Figure 6) spanned the natural salinity range of water. The four types of fishponds (Figure 7) developed within the *ahupua'a* were:

- freshwater taro fishponds (*loko i'a kalo*)
- other freshwater ponds (*loko wai*)
- brackish water ponds (*loko pu'uone*)
- seawater ponds (*loko kuapa*)

An additional type of pond (really a fish trap) was known as *loko 'umeiki* (Summers 1964).

Table 1. Estimated yields of Hawaiian aquaculture ponds before 1900.

Island	Number of ponds	Area in hectares*	Minimum yield† (kg)	Percent total
Oahu	175	1306	438,816	49
Hawaii	59	440	147,840	16
Molokai	56	418	140,448	16
Kauai	42	313	105,168	12
Maui	26	194	65,184	7
Lanai	1	7	2,352	<1
Niihau	1	7	2,352	<1
Total	360	2685	902,160	100

* Using an average of 7.46 ha per fishpond (Kikuchi 1973).
† Using an average of 336 kg/ha/yr (Cobb 1902).

Freshwater taro fishponds. The taro fishponds (*loko i'a kalo*) were developed in the uplands to cultivate taro and simultaneously grow a limited range of euryhaline and freshwater fish, such as mullet (*Mugil cephalus; ama 'ama*), silver perch (*Kuhlia sandwicensis; aholehole*), and Hawaiian gobies (*Eleotris sandwicensis* and *E. fusca; 'o'opu*). Freshwater prawn (*Macrobrachium* sp.; *opae*) and green algae (*Spirogyra* sp. and *Cladophora* sp.; *limu kalawai*) were also grown. These fishponds probably arose originally from shallow ponds (*lo'i*), which were created by the diversion of stream runoff for the irrigation of taro, and over time the Hawaiians added aquaculture to the design of these ponds.

Surplus fish from abundant sea harvests of milkfish (*Chanos chanos*), mullet, and silver perch were put in shallow ponds located close to the sea. Fish also directly entered the taro patch-fishponds from the sea through the newly created artificial estuary. It is likely that the originators of the stocking practice observed that fish held in these ponds not only survived the harsh transition in salinity from seawater to freshwater but also grew well. They also probably noticed that their taro grew more luxuriantly and had fewer pests, owing to the continual grazing and pruning activities of certain types of fish. Taro was planted in mounds to leave channels for swimming fish to feed on the insects and ripe leaf stems of the taro (Kamakau 1976).

Other freshwater ponds. The second type of freshwater ponds, *loko wai* (Figure 7), were inland ponds or lakes typically excavated by hand from a natural depression, lake, or pool and supplied with water diverted by ditches from streams, rivers, or by natural groundwater springs or aquifers. Native species of freshwater prawn and Hawaiian gobies (*Eleotris sandwicensis, E. fusca*, and *Gnatholepis anjer-*

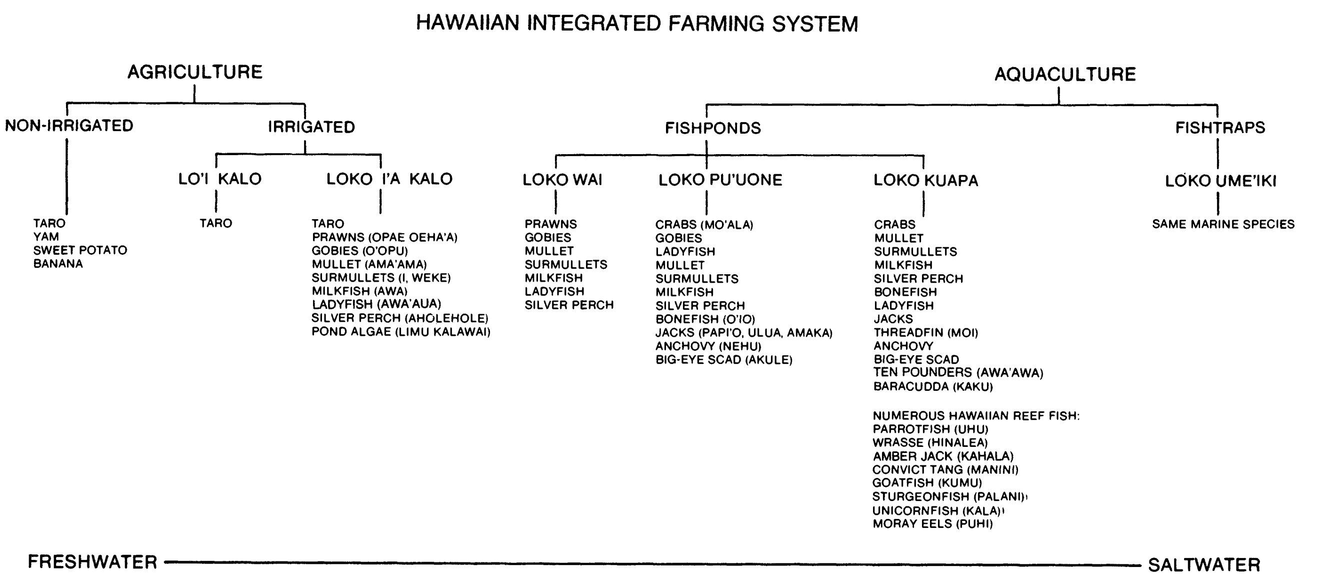

Figure 6. The Hawaiian integrated farming system spanned the normal salinity range of water and comprised a continuum from agriculture to aquaculture. An impressive number of species were harvested from seawater fishponds and traps; the ponds enclosed a reef-flat environment and all its species. Modified from Kikuchi (1976).

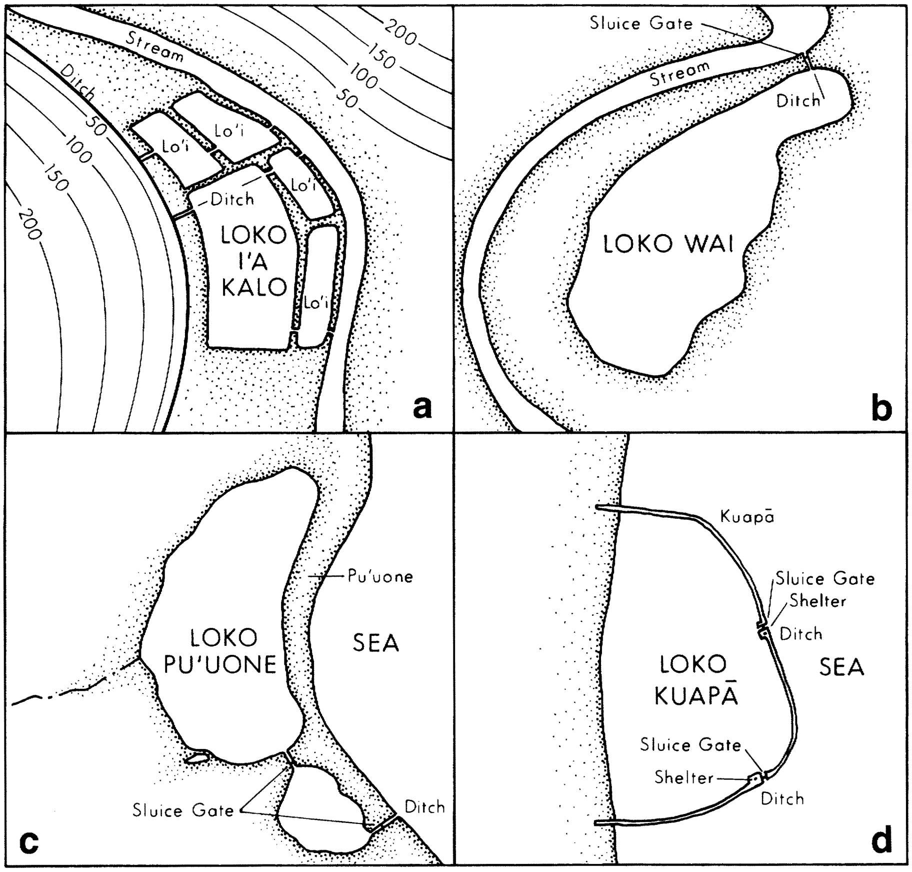

Figure 7. Four main types of ancient Hawaiian integrated farming systems: (**a**) *lo'i* were for the paddy culture of taro (*Colocasia esculenta,* and *loko i'a kalo* were taro patches modified to include aquaculture; these upland ponds are depicted in a valley with elevation contours indicated; (**b**) *loko wai* were artificial and natural freshwater lakes excavated for or modified for aquaculture respectively; (c) *loko pu'uone* were brackish-water lakes separated from the sea by a *pu'uone* or spit of land reinforced by mud, silt, and refuse and connected to the sea by a ditch that had grates to trap and hold large fish; (**d**) *loko kuapa* were ponds built along the shoreline usually on top of a reef flat with volcanic rock and/or coral to form a wall (*kuapa*). Controlled harvests were accomplished using a canal, net, and grate system. Modified from Kikuchi (1976).

nesis) and migrants from the sea that move into fresh water (mullet, milkfish, and silver perch) were stocked, grown, and harvested from these ponds. Milkfish were particularly abundant in these ponds, having been procured in shallow shoreline areas and carried long distances in large gourds filled with water (Beckley 1883). These ponds were harvested by woven reed nets (*hala*) placed across a channel to capture the fish during their seaward spawning migrations, oftentimes during full moons in the spring.

Brackish-water ponds. Brackish-water ponds, the third type of fishpond, were coastal ponds excavated by hand from a natural body of water stranded by eustatic sea-level changes (Kikuchi 1976), or formed by piling mud, sand, and coral to form earth embankments parallel to the coast (Figure 7). A sand bar, coastal reef, or two adjacent edges of land mass isolated these ponds from the open sea. These *loko pu'uone* were connected to the ocean by a canal constructed so that seawater would enter the fishpond on a rising tide. *Loko pu'uone* usually had some freshwater inputs, either from springs, streams entering the pond, submarine groundwater discharges, or water percolating from adjacent aquifers. The combination of fresh and salt water produced a brackish-water environment that was very productive and very diverse in the species that could acclimate from both fresh and salt water. Two types of *loko pu'uone* have been described, a planter's *pu'uone* and an *ali'i pu'uone* (Handy and Handy 1972), classified by their ownership and the effort and elaboration used in their construction.

Seawater ponds. The fourth type of fishpond, the seawater ponds or *loko kuapa* (Figure 7), was the ultimate aquaculture achievement of the native Hawaiians and a valuable contribution to native engineering and subsistence food production. Mariculture, or the farming of euryhaline and marine aquatic animals in seawater, appears to have reached a sophisticated level in ancient Hawaii. Summers (1964) states that *loko kuapa* are found nowhere else in Polynesia.

The main isolating feature of these ponds was a seawall (*kuapa*) constructed of coral or lava rock. Kikuchi (1973) noted that the lengths of 90 fishponds studied ranged from 46–1920 m, with the greatest frequency of lengths between 366–610 m, and containing an average of 955 m^3 of rocks and fill. Some of the stones used in the walls have been estimated to weigh as much as a half a ton.

On the island of Molokai, which has a protected, regular, shoal southern coastline, more *loko kuapa* were constructed per area of land than anywhere else in Hawaii (Figure 8). Large numbers of these ponds were also developed in the Kaneohe Bay, Waikiki, and Pearl Harbor areas of Oahu (Figure 9). In some of the Molokai ponds coralline algae, which secretes a natural cement, was used to strengthen the walls. Women and children gathered these algae from the sea for this purpose (Summers 1964). Ponds on Molokai were built on a reef flat, with the walls extending in a semicircle from the shoreline. The ponds thereby contained all of the marine aquatic biota of the original reef environment. At least 22 species of marine life flourished in these ponds.

Loko kuapa had an additional feature that can only be described as an ancient engineering marvel. Canals (*auwai*) were constructed into the walls of the ponds for the stocking, harvesting, and cleaning of the seawater ponds with minimal human effort. The canals connected the ponds directly to the sea and had, in the middle, a single, immovable grate (*makaha*) made of dense native woods (Figure 10). These grates were constructed by vertically lashing solid timbers (*'ohi'ia* or *lama*) to two or three cross beams with ferns, so that the individual timbers were separated by approximately 0.5–2.0-cm wide spaces. Thus only water and very small fish could pass freely in and out of the pond. The pond was therefore automatically stocked from the sea.

The grates were fixed in the canal and large fish trying to migrate to the sea were harvested by setting nets on the pond side of the grate or by hand capture (Kamakau 1976). Harvesting was attuned to the behavior of the fish. *Loko kuapa* were used to culture mainly two species of fish—milkfish and mullet. Both are technically sea spawners (catadromous). During certain seasons (frequently spring moons in Hawaii), they return from their freshwater and brackish-water habitats to spawn in coastal seawater. In contrast, salmon, being anadromous fish, have an exactly opposite life cycle. During the migration periods the keepers of the fish pond (*kia'i*) would joyously watch hundreds of fish swim into the canal in a futile attempt to reach the sea. Nets set on the pond side of the *makaha* would close off the migratory route.

Later in Hawaiian history, the canals were modified to have one or two vertically moveable *makaha* substituting for the set net and immovable *makaha* used earlier. With this modification, as the fish entered the canal and tried to migrate to the sea, the seaside *makaha* was lowered (or was permanently fixed) and the pondside *makaha* raised. The pondside *makaha* was then lowered, trapping the fish, which were simply netted out of the canal. The process was then repeated. Thus through the use of keen observational skills and knowledge of fish behavior, a method was devised of allowing the fish to harvest themselves.

> When the keeper of the pond wished to remove some fish, he would go to the makaha (grate) while the tide was coming. . . . The keeper would dip his foot into the water at the makaha and if the sea pressed in like a stream and felt warm, then he knew that the sluice would be full of fish. The fish would scent the fresh sea and long for it. I have seen them become like wild things. At a sluice where the fish had been treated like pet pigs, they would crowd to the makaha where the keepers felt of them with their hands and took whatever of them they wanted. . . .
>
> —S. M. Kamakau, 9 December 1869
> Translated from a Hawaiian Newspaper, *Ke Au 'Oko'a*
> (Kamakau 1976, p. 49)

Over time the *loko kuapa* would become filled with sediments, either washed in during heavy rains or accumulated from the settling of particles in the water. In some of the larger ponds on Molokai that tended to become silted, the grates and canals were operated to clean the ponds, in a clever example of practical maintenance. In these cases, more than one canal was constructed in an orderly pattern in the pond walls, with grates set across from each other into the direction of the prevailing longshore current.

On a rising tide the grate on the upstream end of the longshore current was opened. This washed the sediment accumulated at this upstream grate downstream toward the middle of the fishpond. On the next ebb tide this upstream grate was closed, and the downstream grate on the opposite side of the pond opened.

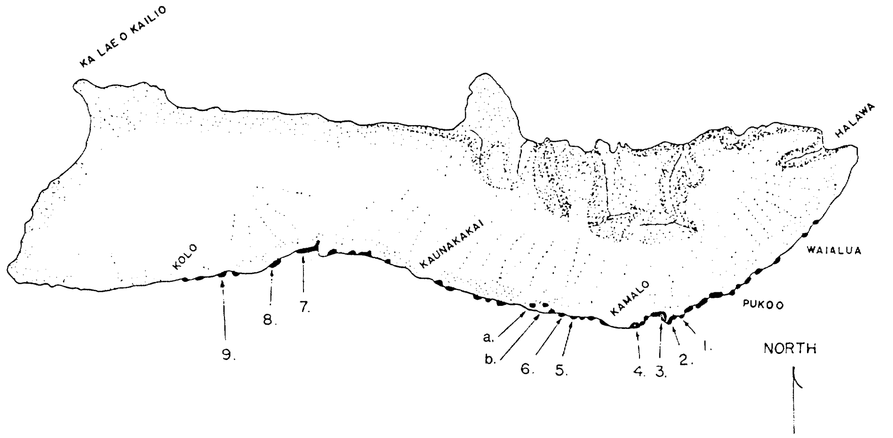

Figure 8. A map of the Hawaiian island of Molokai with its long, shoal southern coastline. Darkened areas indicate the areas of some 28 marine fishponds (*loko kuapa*). Two brackish water ponds (*loko pu'uone*) are indicated by letters. Numbers refer to the location of fish traps (*loko 'umeiki*). Modified from Cobb (1902).

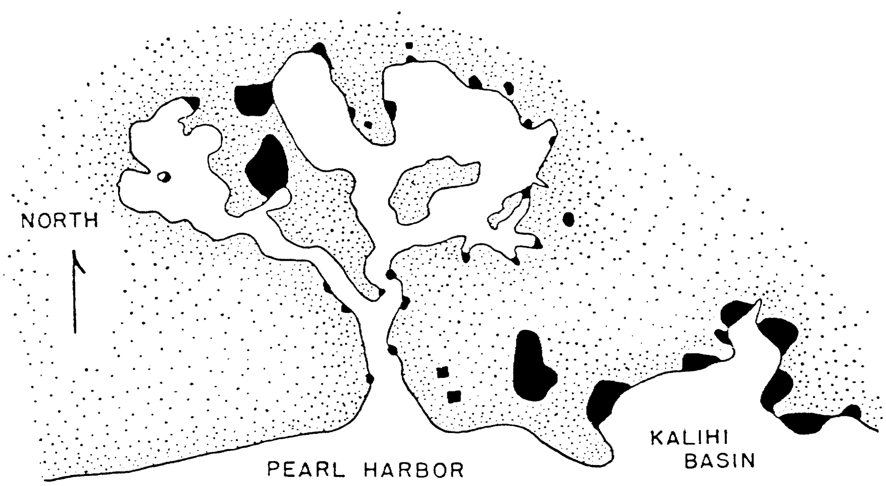

Figure 9. A map of the Pearl Harbor and Kalihi Basin areas of the island of Oahu, Hawaii. Darkened areas depict the locations of more than 30 *loko wai, loko pu'uone,* and *loko kuapa*. Modified from McAllister (1933).

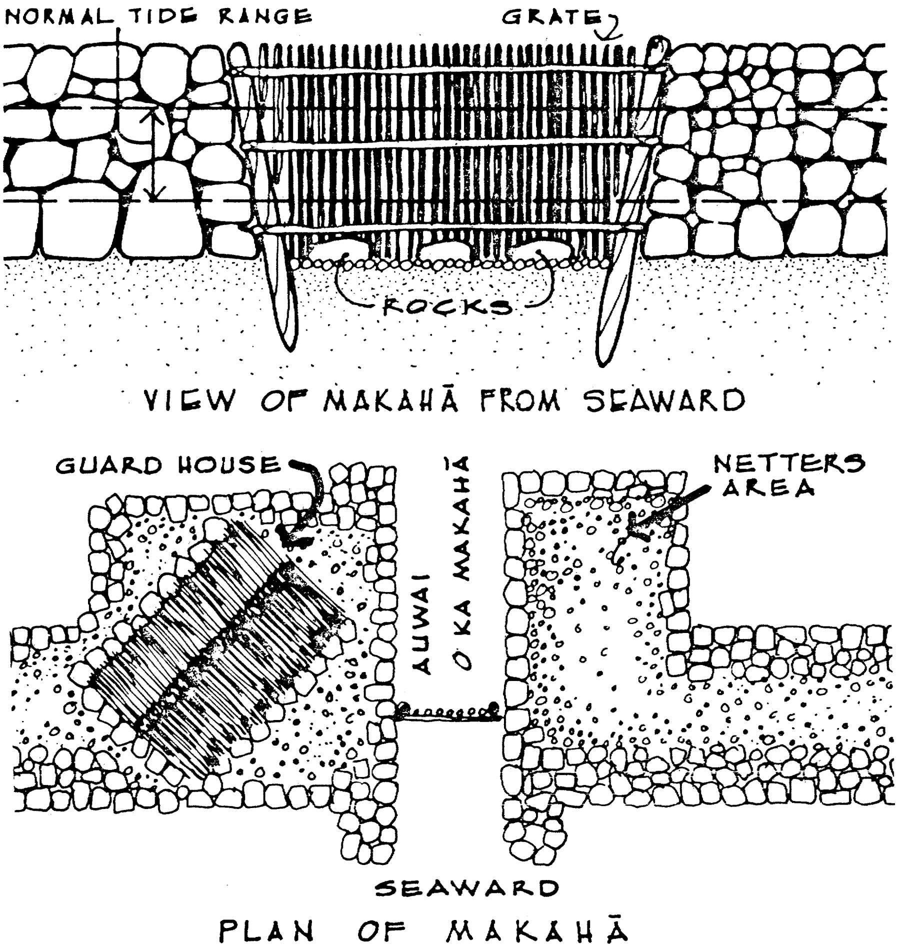

Figure 10. Details of the sluice grate (*makaha*) that was permanently fixed in a canal (*auwai o ka makaha*) connecting the pond to the open sea. Nets were set on the pond side of the canal to capture fish gathering in the canal attempting to migrate to the sea. Note that a single, immovable grate was used in the ancient design. Modified from Apple and Kikuchi (1975).

The ebb tide therefore tended to pull the accumulated sediment from the middle of the pond toward the downstream grate. By a regular program of following the tidal cycle and opening and closing the proper grates the ponds could be effectively cleaned of sediment. In addition, if a pond was silted up after a particularly heavy rain, weighted bamboo rakes (*kope 'ohe*) were towed behind outrigger canoes to facilitate movement of the accumulated sediment out of the fish ponds.

Cordover (1970) has discovered another type of seawater fishpond on Molokai with no grates. These ponds were stocked with fingerling mullet (*Mugil cephalus*) only once, and it was reported by Hawaiians that mullet spawned and grew there successfully. Hamre (1945) reported more of these types of ponds on Molokai prior to the 1946 tsunami. Although modern scientists have had great difficulty in spawning mullet in captivity (this has improved only recently), Phelps was assured by Hawaiian elders that mullet had indeed spawned regularly in these ponds. He states, "The Hawaiian knowledge of the natural history of fishes, in the old days, should not be underestimated" (Phelps 1937, p. 14).

Fish trap. The last type of fishpond used by the Hawaiians, *loko 'umeiki*, was actually a trap rather than a pond (Figure 11). Hawaiian fish traps are very similar to those in much of Oceania. Like *loko kuapa*, these traps were shoreline ponds with low, semicircular pond walls. However, unlike the *loko kuapa*, pond walls were partially or wholly submerged at high tide and contained numerous openings, or lanes, leading into or out of the trap. Most known *loko'umeiki* were located on the island of Molokai, possibly owing to the favorable orientation of the island with regard to longshore currents. However, it is claimed that Pearl Harbor, on Oahu, had three or four of these types of traps and that one fish trap may have existed on land.[1]

These lanes connecting the traps with the ocean were used to catch fish migrating down the coastline, which were attracted to the surge of water at the lane entrances (Figure 11). Fishermen simply laid a net facing the sea across the opening of the lane to capture inflowing fish on an incoming tide. When the tide reversed, fishermen faced their nets toward the traps, capturing fish as they swam out toward the sea. It was reported that the right to fish during different portions of the tidal cycle was divided among family groups.

> Such was the case of Mikiawa Pond at Ka'amola, Molokai. When the tide was coming in, the people of Keawanui could use the lanes. When the sea ebbed, the fish belong to Ka'amola.
>
> —Timoteo Keaweiwi, 1853
> *Foreign Native Testimony Book 16*
> State of Hawaii Archives
> Honolulu, Hawaii
> (Summers 1964, p. 56)

Implications

It is evident that the ancient Hawaiians supported a relatively high population density by managing an ecologically complex integrated farming system that connected agricultural watersheds to oceanic environments. These historical developments are remarkably similar in principle to integrated farming systems developed in ancient China and Egypt. Hawaiian society, like other ancient civilizations, was subject to droughts, climatic disruptions, natural disasters, and famines; it may have developed these integrated farming systems in response.

The limited archeological and

[1]W. Kikuchi, 1985, personal communication. Department of Science, Kauai Community College, Lihue, Kauai, HI.

aquaculture research, as well as exploration in the Pacific Basin, allows no conclusions to be drawn either regarding the uniqueness of the Hawaiian integrated farming systems among the Pacific islands, as some have suggested (Kikuchi 1973, Summers 1964), or their possible relationships to Chinese or other Asian systems. The Hawaiians appear to be one of the originators of mariculture; there is no evidence of another ancient culture using oceanic resources in this manner.

Most of the previous work on early Hawaiian aquaculture focused on the marine fishponds. These studies concluded that the ponds were technologically primitive, ecologically inefficient, and unproductive in biomass per unit area when compared with Asian practices (Hiatt 1947a,b, Kikuchi 1973, 1976). But these earlier interpretations may be inappropriate in light of the total farming system, which spanned an extensive salinity range of water and encompassed entire valleys.

Direct comparison with Asian systems is unjustified, because the aquaculture systems are at opposite ends of the management spectrum. The Asian systems are semi-intensive, sustained by large inputs of labor, feed, and fertilizer supplements; whereas the Hawaiian systems were mostly sustained by natural productivity, and thus are called extensive. For an extensive system, the estimated yields by Cobb (1902) of 336 kg/ha/year would place the Hawaiian fishpond systems operated before contact with European culture on par with most extensive aquaculture systems in the world today. Indeed these yields are comparable to some of the smaller intensively managed modern Chinese lakes and reservoirs (Billard 1986).

Only recently have scientists systematically documented traditional technologies of agricultural and fishing societies. These studies of traditional crops, methods, and systems have produced so many advances in such a short time, many agricultural researchers now first consider traditional knowledge, however primitive it may appear, and use it as a foundation for further research (Richards 1985).

Until the 1970s, however, the poverty and underdeveloped status of fishing and agricultural societies were attributed to their "inefficient," "primitive," and "subsistence" technologies, without any consideration of sociocultural and economic concerns (Ruddle and Grandstaff 1978). Thus, the poverty of traditional fishermen was ascribed to a lack of modern fishing gear and methods. Recent scientific study, however, has shown that traditional fishermen have a wide knowledge of oceanography, fish biology and behavior, and conservation and management practices that preserved the biological integrity of fish stocks for generations before the advent of modern gear or methods (Johannes 1978, Johannes et al. 1983, RaiChoudhury 1980, Roy 1982, Ruddle and Johannes 1985). Perhaps these traditional fishing and agricultural societies should be termed ecologically advanced rather than technologically backward.

Extensive aquaculture systems, their sustainability, productivity, and roles in traditional food production networks have received little attention to date. These systems may have a much greater role in integrated rural development schemes worldwide than the high-yielding intensive aquaculture systems because they can be ecologically benign and integrated into fragile natural ecosystems with no pollution impact (Hirata 1983); they have lower capital costs, allowing entry by the poorest farmers in society; they require little management or foreign expertise; and they frequently have higher economic returns than intensive systems (Hirasawa 1985).

The vast majority of aquaculture production today comes from extensive and integrated farming systems in Asia (FAO 1984, Zweig 1985). The principles and management of these

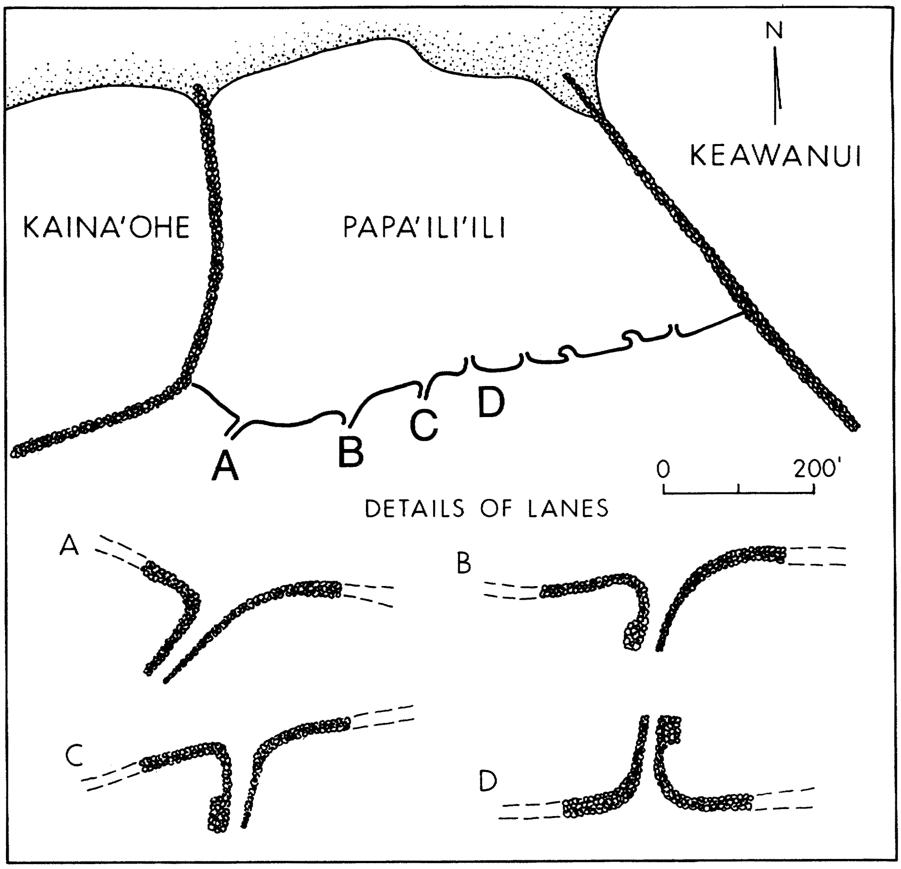

Figure 11. Plan of a fish trap (*loko'umeiki*) (*Papa'ili'ili*), from Molokai wedged between two marine fishponds (*loko kuapa*) (*Kaina'ohe* and *Keawanui*). Details of three pond outlet canals (A, B, C) and one pond inlet canal (D) are shown. Note the enlarged wall sections on canals B, C, and D accommodating fisherman. These areas indicate where nets were set to capture fish on rising (D) and falling (A, B, C) tides. Modified from Stokes (1909).

systems are quite similar to the ancient Hawaiian systems. Simple technology transfer from one traditional system to another may dramatically increase productivity and efficiency. For example, the modern version of the Hawaiian canal-grate system may have great potential for the thousands of hectares of extensive marine ponds along the coasts of India and Indonesia.

Transfer and improvement of knowledge in traditional food production systems may have greater value than any "technological fix" applied by modern machines and methods. While we do not know how to stimulate, manage, and sustain a natural food web in an extensive aquaculture system to repeatedly obtain high yields, we do know it is possible. With no supplemental feeds or fertilizers added, and management timed to the abundances of natural foods available, scientists have achieved experimental productivities from 11,000–25,500 kg/ha/year in Laguna de Bay, Philippines (SEAFDEC 1980).

Hawaiian integrated farming systems evolved and proliferated within a unique socio-cultural context. However, the traditional designs, ecosystem development concepts, and integrated aquatic resources management principles may be instructive to some modern societies with burgeoning populations desperate to increase food production and employment opportunities in traditional agricultural sectors.

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