Ecological Aquaculture: The Evolution of the Blue Revolution
Edited by Barry A. Costa-Pierce

Chapter 2
The *Ahupua'a* Aquaculture Ecosystems in Hawaii

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> '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 waterfowl'
>
> T. Bloxam, British naturalist on *H.M.S. Blonde*
> describing Waikiki in 1825 (Handy & Handy, 1972).

Introduction

Beveridge & Little (Chapter 1, this volume) describe what is known about the origins of aquaculture in traditional societies in China, Egypt, Europe and the Americas. Most of these examples are inland, freshwater developments associated with rivers or other water courses indigenous to large continental land masses. The ancient mariculture systems of Hawaii are unique in that they connect an isolated island society with sophisticated ocean harvesting and integrated sea farming activities to an entire watershed management/food production system (the *ahupua'a*).

Ancient Hawaiian mariculture systems are remarkable in terms of their diversity, distinctive management, and sheer extent of development, especially given the small size of Hawaii. Although the Hawaiian systems are relatively recent (only 1500–1800 years old) by Chinese and Egyptian standards, the evolution of ocean fishing to ranching and onwards to true ocean farming systems (mariculture) is notable. Evolution of such sophisticated farming systems may be a natural evolutionary part of societies whose population densities exceed the carrying capacity of natural ecosystems to support them. As a result, rapid evolution of new, innovative farming systems – such as ecological aquaculture and mariculture systems – occurred in Hawaii.

The social ecology of ancient Hawaii

> 'The shores of Hawaii are by no means so well stocked with fish as those of the Society Islands . . . The industry of the Hawaiians in a great degree makes up for

> the deficiency in fish, for they have numerous small lakes and ponds, frequently artificial, wherein they breed fish of various kinds and in tolerable abundance'
>
> (Ellis, 1826)

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 sociocultural 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 about 2 m high that is 11 m thick at the base. This wall contains an estimated 150 000 m^3 of rock and fill (Apple & 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 tremendous 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 natural resources, fishponds, communal and spiritual centers – were owned by the kings (*ali'i*). The kings would contract the bulk of the land and fishponds to subchiefs (*konahiki*), but keep sacred resources such as fishponds under their direct control. Couriers would transport from royal fishponds to the court plump fish in water-filled gourds or by hand (Rice, 1923).

Subchiefs were granted large, wedge-shaped areas (*ahupua'a*) of the Hawaiian islands that encompassed the watersheds of entire valleys, stretching from the mountains to the sea (Lind, 1938). *Ahupua'a* were generally not physically demarcated in Hawaii. No evidence of erect stones marking individual land holdings, such as in Tahiti, have been found (Handy & Handy, 1972). It appears that the *ahupua'a* were mainly political subdivisions granted by the kings to the subchiefs to assure subsistence supplies of food, firewood, timber, thatch, and ornamentation.

Handy & Handy (1972) have described a share-cropping arrangement between tenant families and the subchiefs that was 'comprehensive and reciprocal in its benefits.' Within an *ahupua'a*, sections of land (*'ili*) were granted to individual extended families (*'ohana*) for cultivation. These land divisions within the *ahupua'a* carried individual titles. 'It was said that in every community there were individuals who were well versed in the local lore of land boundaries, rights, and history' (Handy & Handy, 1972).

All harvests from the fishponds were distributed in a politically institutionalized manner by the subchiefs to extended family groups and pond workers living in the *ahupua'a*. Kikuchi (1976) 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 inter- and intratribal conflicts.

Kamakau (1976) argues, however, that the presence of the fishponds did not indicate any contempt on the part of the subchiefs 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 against one 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 dramatic effects on all levels of 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 traditiona1 barter system to a monetary economy. Contact with foreigners brought new diseases, which led to the massive depopulation of Hawaii.

The Hawaiian land decision of 1848 decision (known as the Great *Mahele*) allowed the purchase of crown lands by Hawaiian commoners and by foreigners. In many areas the largest purchase of these lands was by foreigners. Some of these purchased thousands of acres for $0.25–$0.50 per acre (Kelly, 1980). The Great *Mahele* was a pivotal point not only in Hawaiian history but also in the history of the integrated mariculture farming ecosystems. Decline of the fishpond complexes and Hawaiian integrated aquaculture ecosystems 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 & Handy, 1972) or 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 an estimated 900 metric tons (mt) of fish/year (Costa-Pierce, 1987). Farber (1997) speculated there were as many as 488 ponds. According to the State of Hawaii, only 28 ponds were suitable for fish culture in 1977 (Madden & Paulsen, 1977). By 1985 only seven ponds were in commercial or subsistence use, producing an estimated 15 000–20 000 kg/year. However, accelerated community development efforts in the 1980–90s, especially on Molokai, which included studies, conferences, and formation of a fishpond task force, identified 31 ponds on Molokai alone that the Hawaiian community wanted to restore (Wyban, 1992; Farber, 1997).

Hawaiian integrated aquaculture ecosystems

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

The diversity, extent, and number of fishponds in Hawaii before contact with Europeans is impressive. The various fishponds spanned the natural salinity range of water. The four types of fishponds (Fig. 2.1) 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*)

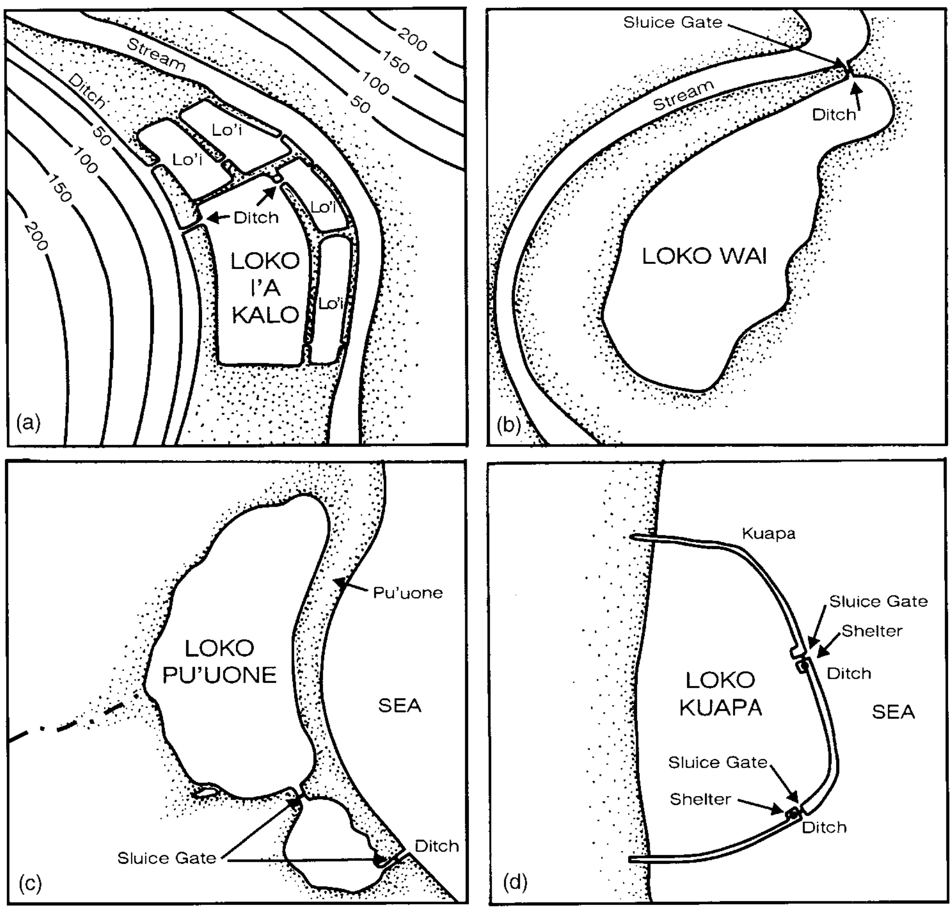

Fig. 2.1 Four types of Hawaiian integrated aquaculture ecosystems developed in historical times: (a) *lo'i* were for the paddy culture of taro (*Colocasia esculenta*); and *loko i'a kalo* were taro patches modified to include aquaculture. These upland ponds are depicted in a valley with elevation contours indicated; (b) *loko wai* were artificial (and modified natural) freshwater lakes excavated for aquaculture; (c) *loko pu'uone* were brackishwater lakes separated from the sea by a *pu'uone* (a 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 ocean shore usually on top of a reef flat with volcanic rock and/or coral rock to form a wall (*kuapa*). Controlled harvests were accomplished using a canal, net, and grate system. Modified from Kikuchi (1976).

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

Freshwater taro fishpond ecosystems

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 integrated freshwater fishpond ecosystems probably arose originally from shallow ponds (*lo'i*) created by the diversion of stream runoff for the irrigation of wetland taro agriculture. Over time the Hawaiians added aquaculture to the design of these ponds.

In addition, surplus fish from abundant sea harvests of milkfish (*Chanos chanos*), mullet and silver perch were put in shallow freshwater taro ponds located close to the sea. Fish also directly entered the taro patch-fishponds by migrating from the sea up the newly created artificial estuary. It is likely that the originators of the stocking practice observed that fish put temporarily in these freshwater ponds near the ocean not only survived the harsh transition in salinity from salt to fresh 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 herbivorous and benthic-feeding fish such as milkfish and mullet. 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 pond ecosystems

The second type of freshwater ponds, *loko wai*, 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 anjernesis*) and migrants from the sea that move into freshwater (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.

Brackishwater pond ecosystems

Brackishwater ponds, *loko pu'uone*, 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 (Fig. 2.1). A sand bar, coastal reef, or two adjacent edges of land masses 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 saltwater produced a brackishwater environment that was very productive and very diverse in fish species that could acclimate to both fresh- and saltwater. Two types of *loko pu'uone* have been described, a commoner's *pu'uone* and a king's *pu'uone* (Handy & Handy, 1972), classified by their ownership and the effort and elaboration used in their construction.

Nearshore mariculture ecosystems

The fourth type of fishpond, the seawater ponds, *loko kuapa*, were the ultimate aquaculture achievement of the native Hawaiians and a valuable contribution to native engineering and the evolution of 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 to 1920 m, with the greatest frequency of lengths between 366 and 610 m, 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 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 (Fig. 2.2). Large numbers of these ponds were also developed in the Kaneohe Bay, Waikiki,

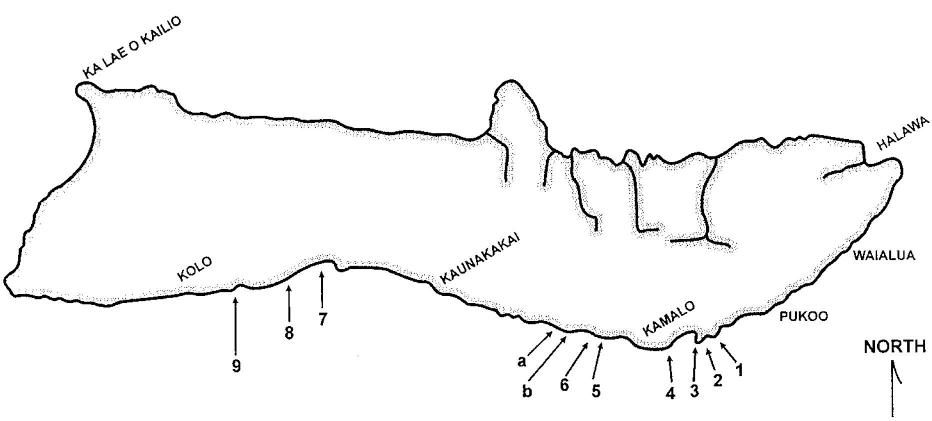

Fig. 2.2 A map of the Hawaiian island of Molokai with its long, shoal, southern coastline. Darkened areas indicate the areas of some 28 marine fishponds (*loko kuapa*), Two brackish water ponds (*loko pu'uone*) are indicated by letters. Numbers refer to the location of fish traps (*loko 'umeiki*). Modified from Cobb (1902).

and Pearl Harbor areas of Oahu (Fig. 2.3). In some of the Molokai ponds coralline algae, which secrete a natural cement, were used to strengthen the walls. Women and children gathered coralline 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 (Fig. 2.4).

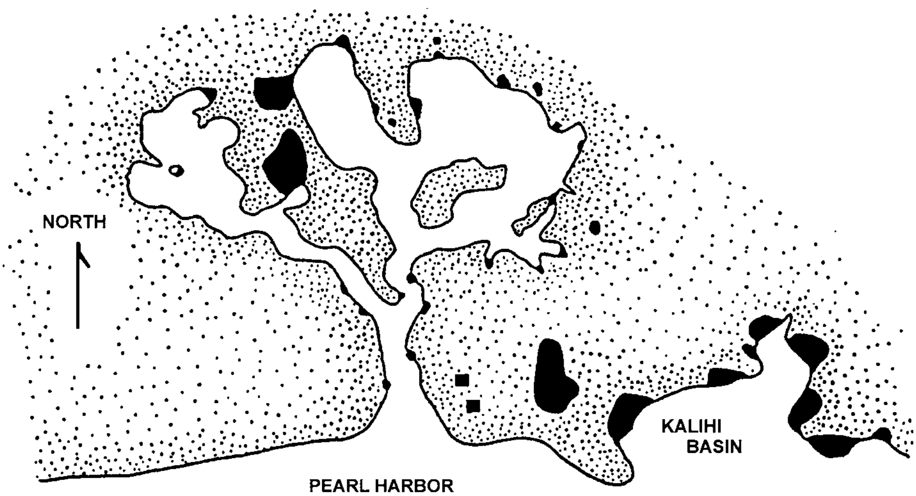

Fig. 2.3 A map of the Pearl Harbor and Kalihi Basin areas of the island of Oahu, Hawaii. Darkened areas depict the locations of more than 30 *loko wai*, *loko pu'uone* and *loko kuapa*. Modified from McAllister (1933).

Loko kuapa had an additional feature that can only be described as an ancient ecological 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 (Fig. 2.5). 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. As a result, only water and very small fish could pass freely in and out of the pond. The pond was therefore automatically stocked by normal recruitment of juvenile fish from the sea.

The grates were fixed in the canal, and large fish trying to migrate to the sea to spawn 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 sea spawners (catadromous). During spring moons in Hawaii, they return from their freshwater and brackishwater habitats to spawn in coastal seawater. Salmon, being anadromous fish, have an exactly opposite life cycle. During the migration periods the keepers of the fishpond (*kia'i*) would joyously watch hundreds of fish swim into

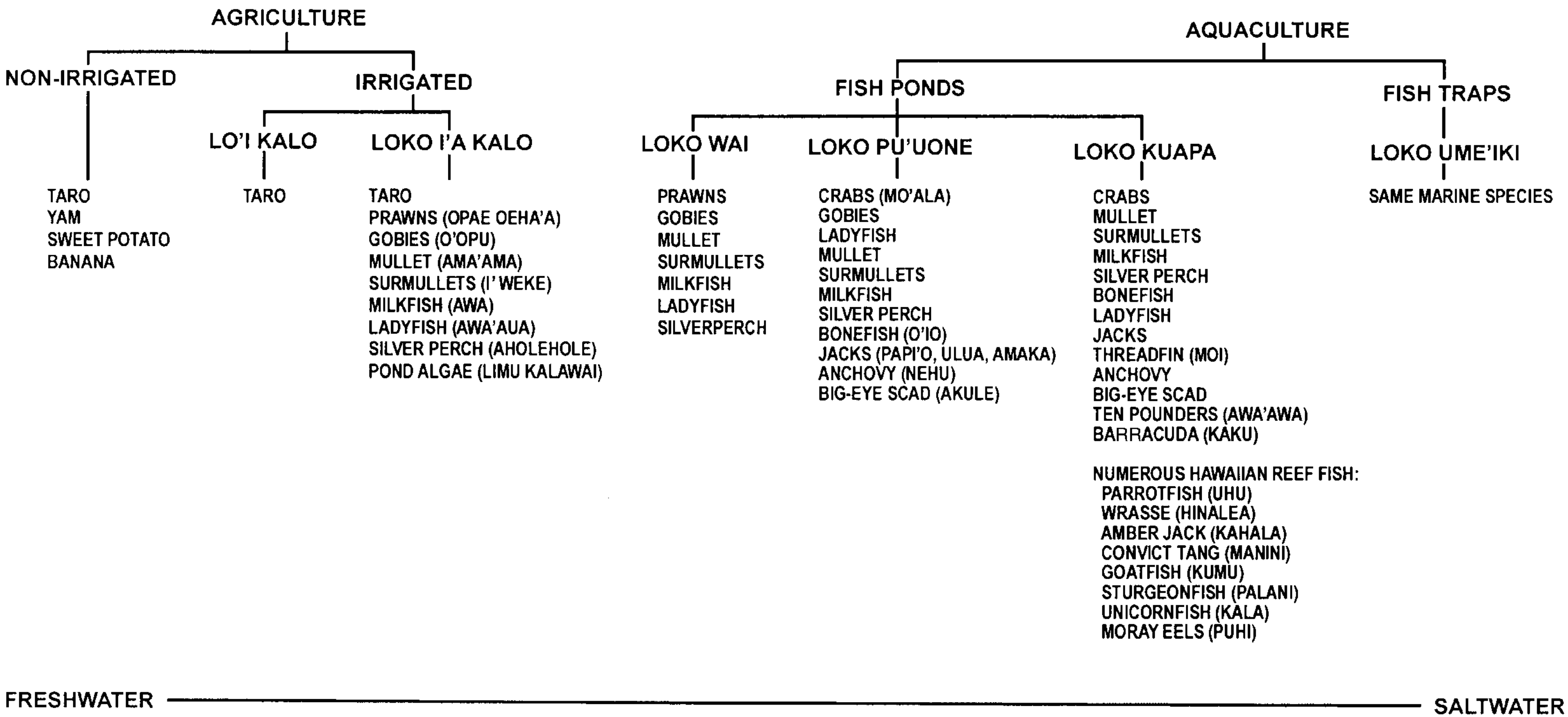

Fig. 2.4 The Hawaiian integrated aquaculture ecosystem spanned the entire normal salinity range of water, and comprised a continuum from agriculture to aquaculture. An impressive number of species were harvested from seawater fishponds and traps; the ponds enclosed a reef-flat environment and all of the reef-flat species. Modified from Kikuchi (1976).

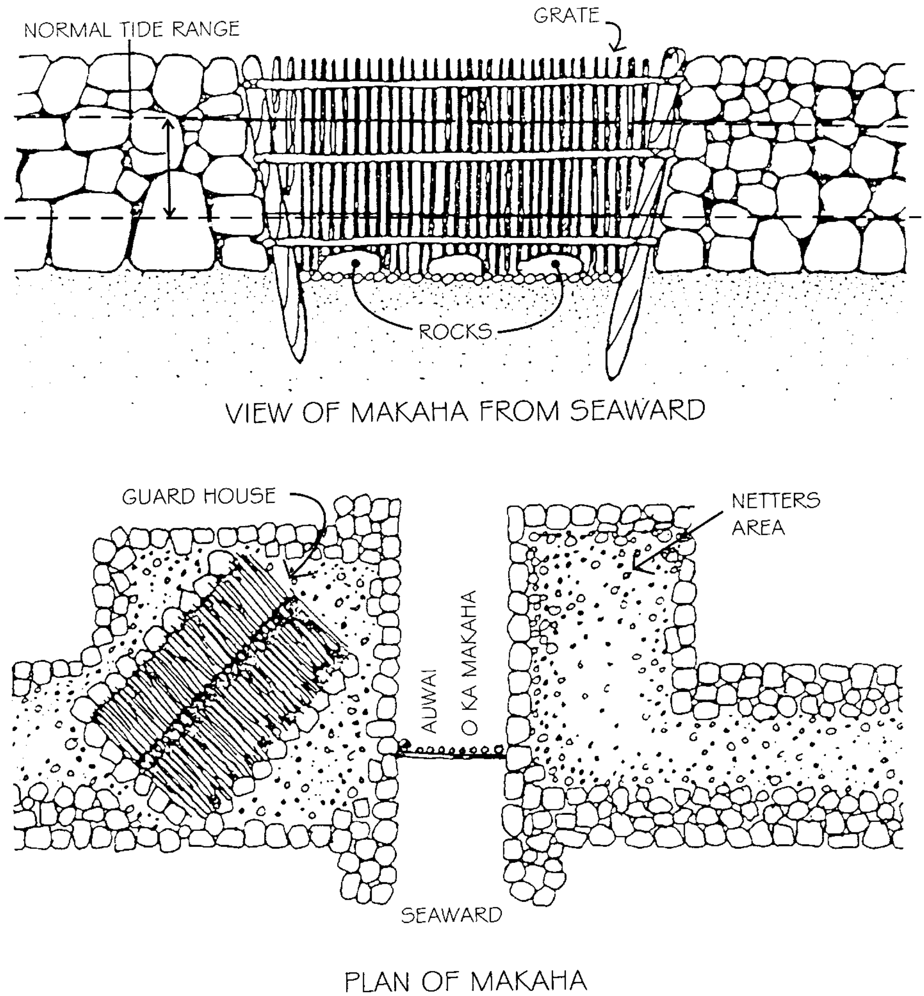

Fig. 2.5 Details of the sluice grate (*makaha*) that was permanently fixed in a canal (*auwai o ka makaha*) that connected the marine fishponds to the open sea. Nets were set on the pond side of the canal to capture fish gathering in the canal attempting to migrate to the sea. A single, immovable grate was used in the ancient design but was modified in recent times to have two grates on the ocean and pond sides of the canal. Modified from Apple & Kikuchi (1975).

the canal in a futile attempt to reach the sea. Nets set on the pond side of the *makaha* close off the migratory route.

Later in Hawaiian history, the canals were modified to have one or two vertically movable *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 pond side *makaha* was raised and fish crowded into the harvest canal. The pond side *makaha* was then lowered, trapping the fish, which were simply netted out or hand harvested from 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)

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 pond 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.

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 fishponds.

Cordover (1970) 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 (1937) 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).

Nearshore fish traps

The last type of fishpond used by the Hawaiians, *loko 'umeiki*, was actually a trap rather than a pond (Fig. 2.5). 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.

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 (Fig. 2.6). Fishermen simply set nets facing the sea across the opening of the lane to capture fish swimming into the trap 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.

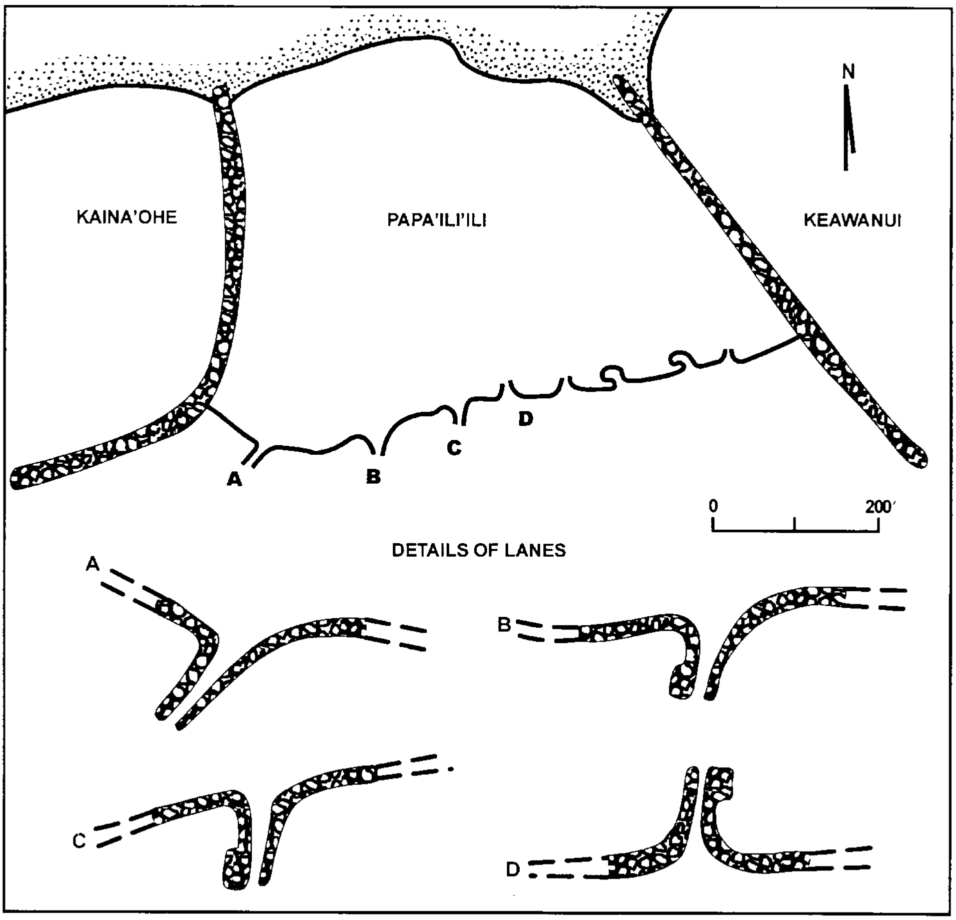

Fig. 2.6 Plan of a fish trap (*loko'umeiki*) called *Papa'ili'ili* on the island of Molokai wedged between two marine fishponds (*loko kuapa*) (called *Kaina'ohe* and *Keawanui*). Details of three pond outlet canals (A,B,C) and one pond inlet canal (D) are shown. Note the enlarged wall sections on canals B, C, and D accommodating fishers. These areas indicate where nets were set to capture fish on rising (D) and falling (A,B,C) tides. Modified from Stokes (1909).

'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)

The context of the Hawaiian innovations in the evolution of mariculture ecosystems

It is evident that the ancient Hawaiians supported a high population density by managing an ecologically complex integrated farming system that connected agricultural watershed ecosystems to nearshore mariculture/fisheries ecosystems – the *ahupua'a* aquaculture ecosystem (Fig. 2.7). These historical developments are

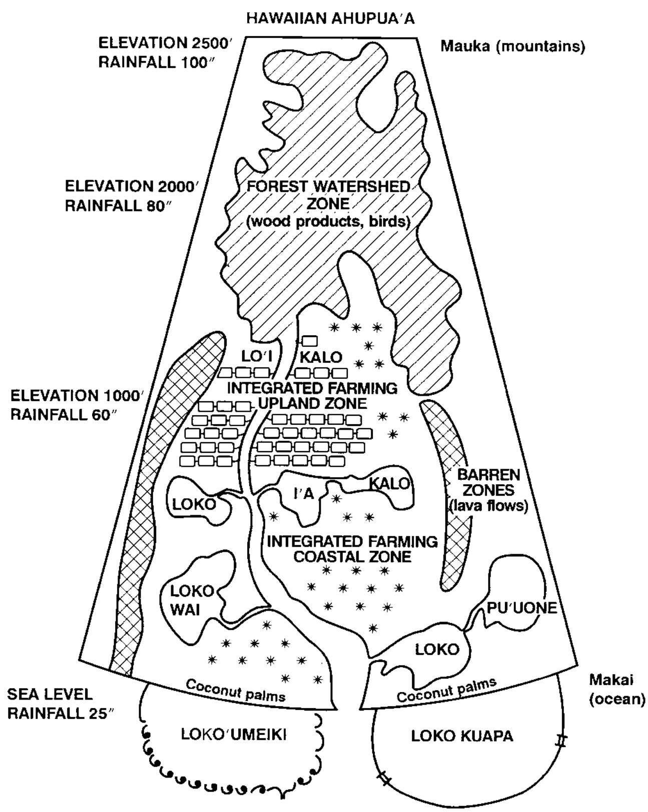

Fig. 2.7 An idealized Hawaiian *ahupua'a* aquaculture ecosystem showing topographic placement of freshwater, brackishwater, and nearshore integrated aquaculture ecosystems on the landscape. Stars indicate placement of settlements. Hawaiian aquaculture ecosystems were diverse, unique, and well adapted to the wide range of natural environments and social structures present. Typical valley ecosystems of this type would be approximately 10 km from mountains to ocean and 10–20 km along the shoreline.

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 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 (Summers, 1964; Kikuchi, 1973), 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 (Costa-Pierce, 1987).

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 ecosystem, which spanned an extensive salinity range of water, encompassed entire valleys, and integrated watersheds and nearshore marine ecosystems in unique and possibly unprecedented ways.

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