LOKO IʻA

A Manual on Hawaiian Fishpond Restoration and Management

Graydon "Buddy" Keala
with James R. Hollyer and Luisa Castro

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College of Tropical Agriculture and Human Resources

University of Hawai‘i at Mānoa

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Preface

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Since work on the manual and its actual publication extended several years beyond Buddy's involvement with the project, final responsibility for the content rests with the co-authors and the editor.

James R. Hollyer

Formerly with the CTAHR Agricultural Diversification Project, and Project Manager, Agricultural Development in the American Pacific

Luisa F. Castro

Assistant Water Quality Coordinator, CTAHR Department of Natural Resources and Environmental Management

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Introduction

Over a thousand years ago, utilizing an advanced system of celestial navigation and double-hulled sailing canoes, people of the South Pacific journeyed far to the north to discover a chain of islands. Those early explorers, in many arrivals over many years, became settlers and created a unique, complex society with a population estimated to have been from six hundred thousand to almost a million people—an amazingly large number. It is logical to ask, "How did this large population sustain itself?"

Almost every culture in the world has practiced aquaculture in some fashion. The ancient Egyptians stocked artificial ponds with fish, the Greeks and Romans raised eels, the Taiwanese walled in tidal areas, and people in the Tuamotos, Society Islands, Australia, Cook Islands, Samoa, and New Zealand entrapped fish by various means. Despite such wide-ranging, ancient aquaculture activities, as W.K. Kikuchi stated in *Prehistoric Hawaiian Fishponds*, only a few cultures used permanent ponds for raising fish.

With the early settlers of the Hawaiian archipelago came the tangible necessities of long-term existence—medicinal and food plants, animals, tools—all carefully packaged on the canoes for the long voyage. Specialists, who taught and shared their knowledge through a system of generational apprenticeships, were among the settlers to ensure proper use of things, although it was not uncommon for one generation to develop practical improvements over the methods of previous generations.

Hawaiʻi is the only known place in Oceania where the people practiced a "pure" form of fishpond aquaculture. In contrast to the rest of the Pacific, Hawaiian fishponds evolved into a unique and sophisticated aquacultural practice. Nowhere else is found either the variety of fishpond types or the quantity of fishpond remains that are found in Hawaiʻi. Hawaiians attempted to utilize practically every body of water for either irrigated agriculture, mostly for their staple kalo (taro, *Colocasia esculenta*), or for fishponds.

The transition from explorers to settlers to a permanent population took place over many generations as a unique culture developed. Inherent in the culture was a social structure of religion, rules, and discipline that provided cohesion for the entire system. All activity included ceremony and ritual, presided over by kahuna, or masters. Religious and spiritual convictions evolved from a deep and profound observation and understanding of and respect for all things natural. In addition to ordinary daily life, the entire natural environment—from the clouds in the highest atmosphere, to the currents of the deepest ocean—was acknowledged to be under the protection of the gods.

Such a large population required vast quantities of food, and the culture demanded this be accomplished in a sustainable harmony, without waste or extensive harm to the environment, which were believed to anger the gods. The production of food included cultivating kalo, which could be processed into poi, and gathering seafood from the ocean and shoreline. Some type of seafood, along with poi or kalo, was part of the staple diet.

Production plots for kalo were extensive, as evidenced by the remnants of terraced contours in many valleys, remains of sophisticated irrigation systems, and large rock-lined enclosures at stream deltas leading into the ocean. Consistent with the rock-enclosed, flooded farming of kalo was the extension of rock enclosures at the point where streams entered the sea. In this brackish-water environment, silver fish were observed to congregate, and the idea of confining them within rock walls led to systems of farming them.

The full-scale development of loko iʻa (fishponds) from mauka (the mountains) to makai (the ocean) dates back over half a millennium. Cultivation and propagation centered on many different fresh and salt-water plants and animals, with the primary species being the prized ʻamaʻama (mullet) and ʻawa (milkfish). An inventory in the early 1900s found 360 loko iʻa in the islands and identified 99 active ponds with an estimated annual production total of about 680,000 pounds, including 486,000 pounds of ʻamaʻama and 194,000 pounds of ʻawa. Loko iʻa were extensive operating systems that produced an average of 400–600 pounds per acre per year, a significant amount considering the minimal amount of fishpond "input" and maintenance effort apparent by that time.

As with the lo‘i and production of kalo, loko i‘a production slid into decline over the past century. Factors contributing to the decline included changing population centers, lifestyles, and economics; land development; elimination of productive ponds; pollution; new systems of land ownership and tenure; introduction of aggressive species; and reluctance to engage in the hard physical labor of lo‘i and loko i‘a. In addition, pressure to become Westernized increased, and opportunities to learn from küpuna became limited.

Today's society better understands, tolerates, and encourages cultural diversity. In this setting, over the past three decades, Hawai‘i has experienced a cultural renaissance and a strong resurgence in all aspects of native Hawaiian culture. The dramatic voyages of the Hōkūle‘a raised the consciousness of all native peoples of the Pacific. In Hawai‘i, a deep desire to learn, share, and practice the traditional native culture is evidenced by a language revival in special schools and classes, the continued growth and practice of hula and all its hidden meaning by diverse ethnic groups, and the eagerness of the current generation to work in the mud of lo‘i and carry stones for loko i‘a walls. Young people throughout Hawai‘i seek kupuna who retain customary practices from whom they can learn, then turn to teach the next generation.

In 1994 the community of Moloka‘i worked diligently and developed a strategic blueprint to address employment, growth, and economic issues for the island. In evaluating the island's assets and resources, Moloka‘i's more than 60 fishponds, encompassing over 1500 acres, were clearly acknowledged as a huge, underutilized potential to create employment and sustainable economic growth opportunities through practicing traditional and modern aqua-farming.

Over the past decade a small but steady effort spawned traditional fishpond restoration and fishpond culture projects on Moloka‘i at Oneali‘i, ‘Ualapu‘e, Keawanui, Kahinapōhaku, and Honouliwai fishponds. The desire to put these historic and cultural treasures back to productive use again, and the availability of federal and state funding for agriculture and economic diversification, created a regeneration of fishpond interest and development on the island.

This document is a product of work done by committed young men and women who put forth their time and energy and challenged themselves to learn and train others in the art of traditional Hawaiian fishpond methods. They made productive contributions to try to apply the lessons as practitioners. For all practical purposes, this document captures the cumulative experiences of the project's efforts. To assist the reader, the first section provides a historical perspective on the physical, biological, and social aspects associated with fishponds of ancient times. A section on pond restoration is included, illustrated with examples from rebuilding the Honouliwai and Kahinapōhaku loko i‘a.

This manual includes a section dedicated to permitting, which is the most frustrating, time-consuming, and costly aspect of fishpond restoration and revitalization projects today. Working with regulatory agencies and a committed permit consulting team, a quicker, user-friendly application process was drafted and used for the application of Pānāhāhā fishpond on Moloka‘i and Kō‘ie‘ie fishpond on Maui. This section was included in the hopes that it will help any organization cut through the permit application redundancy and avoid lengthy delays and unnecessary expense.

This document includes a look at fishpond production and activities associated with farming fish in fishponds today. Use of culture pens and modern culture methods are shown as applied at ‘Ualapu‘e fishpond, including data recording, daily log sheets, water monitoring, and pen construction.

The final phase of a fishpond production cycle, as it pertains to this manual, concludes with the sale and marketing of a viable product. A business section developed for the rural fishpond farmer looks at the economic realities of profit and loss, and the final section describes development of an economic model for fishpond activity.

The information provided is meant to be applicable to almost all fishpond endeavors, but it is not meant as a definitive text on how things should be done. It is hoped that the information gathered can, in its application, be a resource and an avenue for further learning.

The primary focus of this manual is on fishpond production benefits as an economic outcome, but we also hope that revived interest in traditional fishponds creates opportunities for potential new science curriculums for Hawai‘i's youth, opportunities for realizing the satisfaction of rebuilding a "living treasure" for communities, and opportunities for conducting valuable practical research to better understand and manage our future.
Mahalo ke akua. Mahalo kūpuna.

Hawaiian Fishpond History

Loko i‘a, Hawaiian fishponds, are impressive structures. They represent one of the ancient world's most significant and successful aquacultural achievements. Writing about commercial fisheries in the Hawaiian Islands in 1901, J.H. Cobb estimated that about 350 fishponds had been in operation in ancient Hawai‘i. Today, the remains of many of those fishponds are unrepairable, but some could be restored to use. Newly restored loko i‘a could be a vehicle for providing employment, economic opportunity, and fishstock enhancement. Fishponds can also provide educational opportunities and promote the sharing of cultural values for the people of Hawai‘i.

Ho‘olaulima ku na kupuna,
Malama no i ka loko i‘a
E ho‘omau i neia waiwai ho‘oilina.

> Let us work in the manner of our ancestors,
> Let us preserve the fishponds
> To continue this part of our heritage.
>
> —from Summers (1964)

Hawaiian fishpond history

It is not known when Hawaiian fishponds began to be constructed, but some fishpond walls have been carbon-dated to the 1400s. Cobb's estimate of 340–360 Hawaiian fishponds was for the period before the arrival of "Western influence," marked by Captain James Cook's arrival in 1778. In 1901, Cobb identified 99 ponds in commercial production on Kaua‘i, O‘ahu, Moloka‘i, and Hawai‘i. He estimated total output then at 679,692 pounds: 485,531 pounds of mullet and 194,161 pounds of milkfish. The estimates of fishpond yield ranged from 300 to 500 pounds per acre. Using the low end of this range and assuming an average fishpond area of about 18 acres, the annual yield of Hawaiian fishponds in pre-Cook times could have approached 2 million pounds. In contrast, the state Division of Fish and Game (now the Division of Fish and Wildlife) reported in 1975–76 a total fishpond production of only 20,000 pounds of fish, including only 1200 pounds of mullet.

The Moloka‘i experience

In strategic planning meetings in 1994, Moloka‘i residents identified the reutilization of traditional Hawaiian fishponds as a major focal point for economic revitalization efforts. It was assumed during the meetings that with some fishponds back in operation there would also be a "multiplier effect" for the community: other areas of the economy and community would benefit directly or indirectly from fishpond activities. These activities would include contemporary aquaculture production, education, and job training opportunities. Such spin-off efforts would enhance diversified agriculture on Moloka‘i and advance Hawaiian tradition and cultural knowledge as well as develop aquaculture science and provide new research opportunities.

It was estimated by subsequent reconnaissance work that 40 dormant fishponds, totalling 1500 acres, could be brought back into production on Moloka‘i. If each acre produced 300 pounds of mullet under non-intensive production conditions (low stocking rate and minimal inputs), the entire system could yield 450,000 pounds of mullet. At $2.50 per pound, $1,125,000 could be added annually to the Moloka‘i economy from mullet production alone.

Mission statement*

Aquaculture is an industry committed to sustaining the integrity of the rural Moloka‘i lifestyle and its ecosystems. Besides providing marketable products, aquaculture can reduce the human demand on natural stocks.

Vision statement*

Our vision for Moloka‘i aquaculture is to have our people prosper and enjoy an improved quality of life through the development of technical and natural systems centered on the careful stewardship of our land and water.

** from the Moloka‘i Aquaculture Strategic Planning Session, December 1–2, 1994.*

The dramatic decline in the number of ponds and the average yield of those remaining is attributed to various factors, both social and economic, including

- money replacing barter as the standard of exchange
- competition from cheaper imported products
- population movement from rural to urban areas
- loss of traditional fishpond management skills with the passing of people who had them
- availability of alternative sources of employment.

Forces of nature have also played a major role in the destruction of Hawaiian fishponds. These forces include

- lava flows filling in ponds
- tsunami and sea storms filling in ponds or destroying their walls
- land erosion filling in ponds with silt
- mangroves and other vegetation encroaching into production areas
- natural processes of eutrophication, where excessive accumulation of nutrients in the water stimulates excessive plant growth that causes oxygen depletion.

Traditional production systems

Cobb reported that fishponds varied greatly in size, from less than an acre up to 600 acres. The shape of the fishpond, as well as its size, largely depended on the physical characteristics of the shoreline. Therefore, each was unique. Other factors that influenced the fishpond shape included the coastal reef structure, sand barriers, the adjacent land mass, adjoining fishponds, depressions in the near-shore ocean bottom, and other physical features.

Except for some upland freshwater ponds, almost all Hawaiian fishponds were located next to the sea and were nourished with a mixture of fresh and ocean water. This mixture created a brackish water environment. Shallow water depth, maximum sunlight radiation, circulation from tidal and stream flows, nutrients from the runoff of water that had circulated in lo‘i (flooded paddies used to grow kalo), and other organic materials created highly productive, estuary-type environments. Not only were the shoreline ponds more productive than those in uplands, but some Hawaiians also believed that they produced the sweetest tasting fish.

Traditional operations and management

The primary role of the ancient Hawaiian fishponds was not to provide food for the general populace, nor was it for commerce. Rather, the ponds were used to provide a reliable, convenient, and ever-ready supply of fresh seafood for the ruling ali‘i (chief) and the royal court.

The first three types of coastal fishponds described below—loko wai, loko pu‘uone, and loko kuapa—belonged to royalty. These ponds, between 10 and 100 acres in size, were considered a symbol of high social and economic status. A fishpond also symbolized a rich ahupua‘a (major land division), which reflected favorably on the ali‘i as well as on the people living in the ahupua‘a.

Glossary of aquatic species mentioned

Traditional Hawaiian fishpond species

āholehole (Hawaiian flagtail, *Kuhlia sandvicensis*)
akule (big-eyed scad, *Selar crumenophtalmus*)
‘ama‘ama (mullet, *Mugil cephalus*)
awa (milkfish, *Chanos chanos*)
awa ‘aua (ladyfish, *Elops machnata*)
hīnālea (wrasses, Labridae family)
honu (turtles)
kāhala (amberjack, yellowtail, *Caranx mate*)
kaku (barracuda, *Sphryaena barracuda*)
kala (unicorn fish, *Naso unicornis*)
kumu (goat fish, *Parupeneus porphyreus*)
limu (edible seaweeds)
manini (convict tang, *Acanthurus triostegus*)
moano (*Parupeneus pleurostigma*)
moi (threadfin, *Polydactylus sexfilis*)
nehu (anchovy, *Anchoviella pupirea*)
ogo (a seaweed, *Gracilaria bursapastoris*)
‘ō‘io (bonefish, *Albula vulpes*)
‘o‘opu (fish in families Eleotridae, Gobiidae)
‘ōpae (shrimp, in general)
palani (surgeonfish, *Acanthurus dussumieri*)
pāpa‘i (crabs, in general)
pāpio, ulua (jack, *Carangidae* species)
puhi (moray eel, Muraenidae family)
uhu (parrotfish, Scaridae family)
weke (surmullets, Mullidae family)
weke ula (*Mulloidichthys duriflamma*)

Other species mentioned

rainbow trout (*Salmo garidneri*)
ornamental carp (Cyprinoidei order)
tilapia (*Sarotherodon mossambicus)*

The fishpond remained a powerful symbol even after the Great Mahele in 1848, when the concept of land and property "ownership" replaced traditional land management structures. For example, in a study of the leeward side of the island of Hawai'i, it was found that descendants of King Kamehameha I owned seven of the largest fishponds (Kikuchi 1971).

The smaller loko i'a, either natural or man-made, might belong to commoners, those without titles. Fishing rights to these fishponds or traps were bestowed to an 'ohana (family or extended family). These rights were managed, controlled, and kept within the 'ohana to be passed down from generation to generation.

Because the ali'i were occupied with religious and political duties, they appointed managers to oversee the daily operations of a fishpond. These individuals had distinct titles and job descriptions: konohiki, the land overseer of the ahupua'a, and kia'i loko, the resident keeper of the royal fishponds. The konohiki were like land superintendents. The kia'i loko, on the other hand, were responsible for the management, production, harvesting, and protection of the fishpond within the ahupua'a.

The amount of knowledge that these individuals had has been likened to that of any doctoral degree in fishery biology and management—and then some. The keeper's knowledge and position was kept within the family and passed down through the generations. The keeper was very powerful in his capacity as fishpond manager, and his decisions were highly respected and might even be held above those of the ali'i in regard to pond management.

If the work called for many people, commoners were recruited to do maintenance upkeep of the fishponds, but usually the commoners were not allowed to take fish from the fishpond. The fishpond was a proud symbol of a rich ahupua'a to which they belonged. Also, by having a fishpond that had great quantities of fish for the ali'i, the burden of taxes was not as heavy on the commoners' own food supplies. We can suppose that Hawaiian commoners saw a productive fishpond as a partial release from their commitment to provide food for the chief at the expense of depleting their personal resources. Also, it is believed that they were sometimes rewarded for helping to maintain the fishpond when, under special conditions and during celebrations, they were allowed to take fish.

How many ponds can be restored?

In 1973, R.A. Apple and W.K. Kikuchi published a study that began to identify those Hawaiian fishpond remnants worthy of historic preservation. Searching through historical literature, Kikuchi found, documented, and surveyed 335 ancient Hawaiian fishponds. Apple did a survey by helicopter, identified the remains of 157 sites, and evaluated their condition. At that point, 101 of those fishponds were eliminated from consideration because they were either almost completely destroyed or irreparably altered.

Only 56 of the 335 ponds evaluated had any potential use as fishponds. W.D. Madden (1997) sought out these last 56 ponds to find out their potential as productive mullet and milkfish fishponds. Madden rated six ponds as "excellent" for fishpond aquaculture, 15 as "good," and the rest as "fair" or "poor" but still with possibilities as productive systems.

The few fishponds still in commercial production today are used to cultivate ogo, rainbow trout, ornamental carp, and tilapia, as well as some of the traditional native fishpond species including 'ama'ama, awa, āhole-hole, moi, pāpio, 'ō'io, awa 'aua, and various edible seaweeds.

Traditional stocking methods

The primary method of getting fish into the fishpond was by stocking it with young fish, called juveniles or fingerlings. These were usually about 4 inches long and less than one year old. They were caught outside the fishpond, usually in the months of January to March, when they were abundant. The fingerlings were put into a special grow-out pond using dip-nets. This initial pond was smaller than the regular fishpond and free of predator fish species. When the fingerlings had grown to a size at which they would not be subject to predation, they were put into the main fishpond.

Other ways that fish got into the fishpond was allowing them to enter through the mākāhā (sluice gate), but sometimes undesirable species such as jacks and barracuda would also get in this way. And, although there is no documented evidence of fish reproducing within fishponds, some kupuna believe that it occurred, considering the estuary-like nursery environment and the lack of significant pollution.

Provision of nutrients for inhabitants of a fishpond was through both natural means and human management. Nutrients carried to the ponds in drainage and runoff from streams and kalo plots increased productivity at the base of the aquatic food chain, and this effect worked its way up to create natural food sources. Fish were also fed kalo, sweetpotato, breadfruit, mussels, and seaweed. Religious beliefs did not allow the use of any type of animal waste as a nutrient source. The consequence of this restriction was not recognized as a loss at the time, but using animal wastes would have increased production of algae, a valuable food source.

The periodic removal of filamentous seaweed mats from the fishpond was usually done by women. Removing the seaweed mats helped maintain open water surface, which enhanced fish growth and the health of the pond. It also left the nutrients that the seaweed would extract from the pond available for use by microalgae and zooplankton, upon which mullet feed. This maintenance operation was directed by the kia‘i loko and called upon all the women in the ahupua‘a to go in a line to pick out the limu by hand. A bamboo rake called a kope ‘ohe was also used for fishpond cleaning. This rake was dragged behind a canoe, and the outgoing currents swept the silt out the mākāhā and into the open ocean.

When the fishpond became too full of fish or when undesired species became too numerous, long seine and gill nets were used to remove large quantities of fish at a time. These nets were prized possessions of the ali‘i or kia‘i loko. M.A. Kelley described how once it was known where the fish congregated they would be encircled again and again with nets cast from canoes. This method was used in larger fishponds where the fish had a lot of "range" and could often escape harvest.

Types of royal and common fishponds

Hawaiians had five basic types of fishponds, listed here by location, from the uplands toward the sea.

Loko wai

Located inland and mostly of freshwater origin, a loko wai (Figure 1, Type 3) was typically made from a natural depression, lake, or pool whose water was mainly from diverted streams, natural groundwater springs, or percolation from an aquifer. Various ‘o‘opu were commonly found in these ponds.

Loko i‘a kalo

These "kalo fishponds" (Figure 1, Type 4) combined aquaculture with flooded agriculture. Kalo lo‘i were used to raise ‘o‘opu, ‘ama‘ama, and āholehole.

Kikuchi (1976) suggested that diversion of stream runoff for the irrigation of kalo eventually led to fish aquaculture. Irrigated agriculture in lo‘i was enhanced by including fish (loko i‘a kalo), and this led to pure fishpond aquaculture—loko pu‘uone.

Loko pu‘uone

Loko pu‘uone (Figure 1, Type 2) contained mostly brackish water, with inputs from both freshwater and saltwater sources. Fresh water from streams, artesian springs, and percolation from adjacent aquifers was mixed with seawater that entered through channels during incoming tides. This mixing produced a highly productive estuarine environment that is known for its high biological biomass index (Bardach et al. 1972). The most characteristic feature of this type of fishpond was a sandbar, coastal reef structure, or two close edges of landmass that could be connected to enclose a body of water. Typical of these ponds were fish that were able to handle fluctuations of salinity. These fish include ‘ama‘ama, awa, āholehole, pāpio or ulua, ‘ō‘io, nehu, awa ‘aua, ‘o‘opu, kaku, moi, and weke. Various other fish may have been grown, but this depended on water quality, especially salinity level, and the location of the fishpond with regard to migrating species such as akule and nehu.

Loko kuapā

Loko kuapā (Figure 1, Type 1) were strictly coastal fishponds whose characteristic feature was a kuapä (seawall) of lava or coral rubble. They were usually built over a reef flat, with the wall extending out from two points on the coast in an enclosed semicircle. These ponds usually had one or two ‘auwai (channels) that were used mainly for water flushing or inflow, depending on the rising and ebbing of the tides, but were also used during harvesting and stocking.

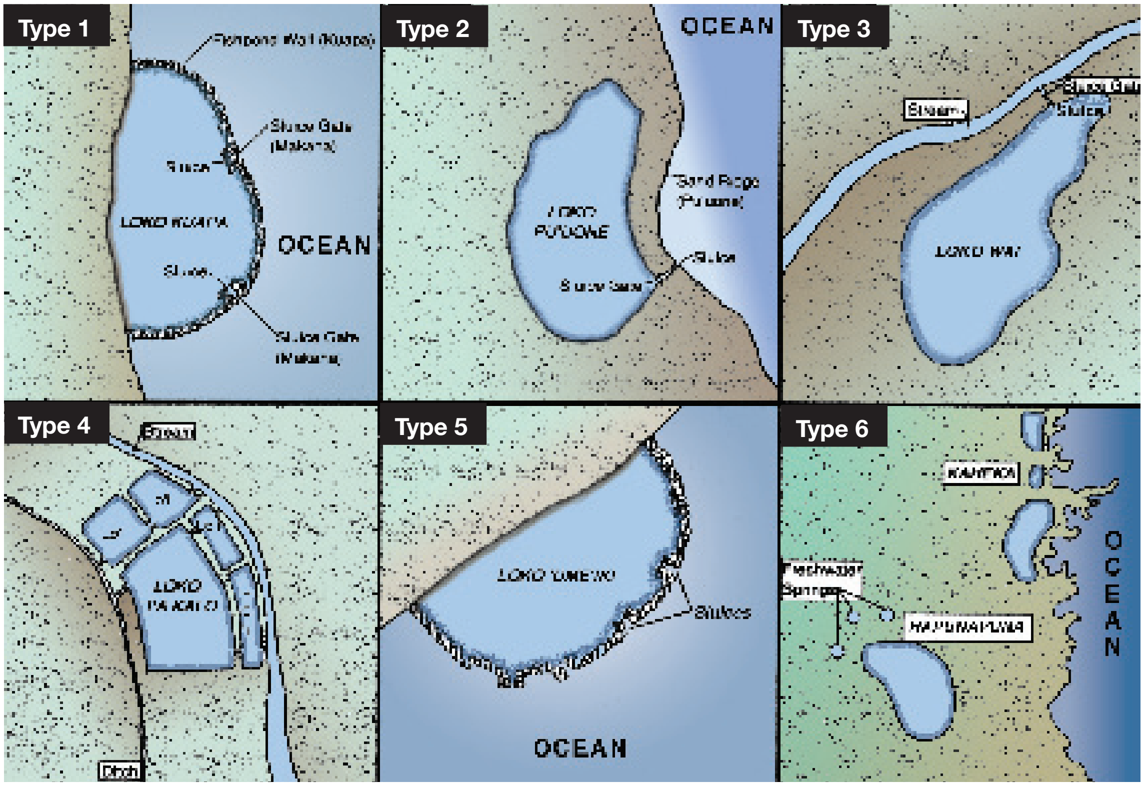
Loko kuapā, because they were enclosed reef flats, had all the marine aquatic sea life that would be expected to be found on a reef flat including kala, palani, and manini. Less common fish sometimes found in these fishponds were the kāhala, kumu, moano, weke ula, uhu, various species of hīnālea, surgeonfish, crevally, goatfish, and even puhi.

Loko ‘ume iki

Loko ‘ume iki (Figure 1, Type 5) were not actually fishponds but rather fish traps. Like the loko kuapä, they

Figure 1. Six types of ancient Hawaiian fishponds.

Source: The figure is reproduced from *Hawaiian Fishpond Revitalization: A Manual*, 1993, Hawaiian Fishpond Revitalization Project and Oceanic Institute. The 1993 publication cited the following as sources for the illustration: R.A. Apple and William K. Kikuchi, 1975, *Ancient Hawaiian shorezone fishponds: An evaluation of survivors for historical preservation*, U.S. National Park Service, Department of Interior, p. 157.; and B. Costa-Pierce, 1987, *Aquaculture in ancient Hawaii*, BioScience 37(5).



were constructed on a reef flat, but loko ʻume iki had "fish lanes," corridors used to net or trap fish going onto or off the reef. Each loko ʻume iki had many fish lanes with fishing rights usually assigned to a family. The traps operated without the use of gates and relied on natural movements of fish. The lanes were usually tapered, with the wide end facing either inward or outward, and anywhere from 10 to 40 feet long.

Traditional fishpond construction

A traditional Hawaiian belief has it that fishponds were built by Menehune, a legendary race of small people who worked at night. Although there has been no documentation of traditional fishpond construction methods, the work is clearly labor-intensive, and large ponds must have taken a long time to construct. The only tools known to have been used were ropes, dragging sleds, and ʻōʻō (digging sticks). It is traditionally accepted that rocks for the construction were transported down from the mountains along a human (or Menehune) chain, sometimes many miles long (Kikuchi 1973).

All materials used for the construction of the fishpond usually came from within the same ahupuaʻa. This pie-shaped land division had its point in the upland mountains and extended down through a valley or valleys and out to the edge of the coastal reef. The ahupuaʻa provided its residents access to both mountains and ocean and the various provisions of these resources necessary for sustenance.

Kuapā

Fishpond kuapä (seawalls) were constructed from many materials including lava rock, coralline blocks, and rubble of rocks, coral, and soil. Small rocks and coral fragments filled interior cracks. Coralline algae, marine plants important in the construction of coral reefs, were sometimes relied upon to provide "cement." The seawall was permeable to water, allowing aeration and water circulation while deflecting oncoming wave energy. The outer (ocean-facing) and inner seawalls differed: the outer wall had a greater angulation to allow some of the deflected current to "clean" or scour the outer rim of the fishpond. The outer kuapä was often 5 feet wide and 3–5 feet deep. The widest and most massive kuapä is Kaloko in Kona, Hawai‘i. This seawall is 35–40 feet wide at its base and over 6 feet high.

Mākāhā

Sluice gates (mākāhā) were the most distinctive and unique feature of Hawaiian fishponds. They were stationary, without any moving parts. The mākāhā was made of wood, typically tree branches about ½ inch in diameter lashed vertically ½ inch apart to two or three pieces of larger wood arranged horizontally in a grid-like manner. The grate structure allowed water circulation and flushing and the influx of fingerlings yet retained fish too large to pass through the grid. There was no traditional location for the mākāhā, but they were positioned to maximize the flow of current throughout the entire fishpond.

‘Auwai

‘Auwai (sluices) were channels of water that connected the fishpond with the sea. In a loko kuapä they were called ‘auwai o ka mākāhā, which means “gates of the channel,” and in a loko pu‘uone they were called ‘auwai kai, or “sea gate.” Both of these ‘auwai systems served to allow water flow, recruitment of juvenile fish from the outside, and, most importantly, harvesting.

The innovations of the mākāhā and ‘auwai probably allowed Hawaiians to progress from fish traps and enclosed ponds to artificial estuaries (fishponds), which could be better controlled and managed. A more recent innovation (introduced by Chinese immigrants in the mid-1800s) was the incorporation of a double mākāhā, two parallel grates set a few feet apart in a fishpond wall, which permitted the trapping of fish between the grates and allowed for easier harvesting by small hand nets (Apple 1975).

Traditional harvesting

To harvest the fish, Hawaiians relied on the natural instincts of mature fish to congregate on the fishpond side of the sluice gate when they sensed the incoming tide. Likewise, mature fish tend to congregate on the ocean side of the fishpond wall during the outgoing tide. A modern fishpond operator (Wyban 1982) reported that only mature adult fish react to this phenomenon, and during the reproductive, spawning season, this congregation is greatly intensified.

Using this harvesting strategy, fish that were “caught” inside the ‘auwai o ka mākāhā could be scooped out with dip-nets according to desired type and size. Thus the keeper of the fishpond could be very selective about the fish caught or released, thereby increasing the efficiency of the operation.

Additional fishpond-related concepts

Royal fishponds were protected by a number of cultural and religious restrictions. For example, any form of pollution by sewage, rubbish, and metabolites was not tolerated. In the latter category, women during their menstrual period were not allowed in or near a fishpond, to avoid “insult” to the guardian spirit of the fishpond.

Another cultural aspect of fishponds were the ceremonial structures associated with them. Kū‘ula (shrines) were built to honor the gods Kū and Hina, his wife. All fishponds had a guardian spirit called mo‘o, which manifested itself in either a lizard or mermaid-like form. It was the duty of the kia‘i loko to make regular offerings to the gods at designated times of the lunar month to ensure the well-being of the fishpond.

The people were also very aware of the need for conservation. To protect the environment from overuse, they instituted a kapu, or restriction system. A kapu restricted fishing during certain months of the year to let stocks rebuild; this applied to designated areas offshore as well as in the fishpond. For instance, a kapu was placed on certain fish when they were spawning. A branch of the hau tree (hibiscus family) marked an area restricted to fishing. Migrating schooling fish like the akule could also be declared kapu. To break a kapu by poaching, as well as by polluting an irrigation system, was punishable by plucking out the offender’s eyeballs, or strangulation until death. These strict kapu ensured renewable stocks and a stable population of fish resources, enabling efficient fishery management from generation to generation.

Other principal food items

Besides fish, other animals and plants living within the traditional fishpond included the following organisms.

Crustaceans

Many kinds of shrimp, generally called ‘ōpae, were found in all zones from the shore to upland streams. There were about 14 different kinds of ‘ōpae, with distinct forms, colors, sizes, and shapes. A few päpa‘i (crabs) were also found in fishponds.

Seaweed

Over 70 distinct species of edible limu (seaweed) were present in Hawaiʻi, found along the seashore and sometimes in freshwater ponds, rivers, and streams. Certain fishponds were chosen to cultivate selected limu. The aliʻi directed workers to segregate choice seaweeds and transplant them into fishpond "gardens" for convenience.

Shellfish

The availability of various shellfish, bivalves, and mollusks is assumed but unrecorded. Hawaiians must have consumed all food resources available from the fishponds, but harvest of these organisms was probably marginal and occasional because of their slow life cycle.

Turtles

Honu (turtles) were occasionally caught and placed in fishponds, where they were kept healthy to be consumed at a later time. Being primarily herbivores, turtles did not hinder productivity by eating fish, but rather they enhanced the pond's overall productivity through consuming seaweed and adding excrement as fertilizer.

Summary

Hawaiian fishponds were one of the most important technological, social, economic, and cultural concepts developed in ancient Hawaiʻi. Their open channels, sluice gates, and unique harvesting methods were technologically unsurpassed by other Pacific cultures. The system was not developed for great amounts of yield but rather for the convenience of the Hawaiian royalty. Fishponds helped to stabilize and solidify the community's social structure, manage natural resources, and enrich the people's relationships with the supernatural gods of their universe. Through conservation management and a thorough understanding of their environment, Hawaiians complemented and enhanced the natural productivity that surrounded them.

Insights into Regulatory Permits Needed to Re-Utilize Traditional Hawaiian Fishponds

Before starting any fishpond restoration work, many permits must be acquired from federal, state, and county agencies. Jurisdiction over Hawaiian fishponds, or loko iʻa, is complex because they occur at the shoreline, a zone that interfaces between land and the ocean. This zone is heavily regulated, and up to 17 permits must be obtained before work on a fishpond can start. The amount of work required in getting these permits is likened to an Environmental Impact Statement (EIS). Permit processing can easily cost $50,000–$80,000 and take several years—without any guarantee of approval.

The permitting process starts with the federal government, primarily the United States Army Corps of Engineers (Corps). The Corps will acquaint the applicant with the permit process and provide a checklist of agencies to contact for federal application requirements. The Hawaiʻi Department of Land and Natural Resources (DLNR), Land Division, issues the Conservation District Use Application (CDUA) and is the agency for most state-required permits and contacts. Some requirements may vary in their application process and cost based on whether fishpond activities are to be performed on private land or on public land under state lease. The following pages outline some of the agencies concerned and provide worksheets for gathering information to develop permit applications.

Permit requirements

Here are the permits required for each government entity. The actual permit process may vary depending on the situation.

Federal permits

Department of Army
↓
Clean Water Act—404
↓
Historic Site Review—Sec. 106
↓
U.S. Fish and Wildlife Service (Review)
↓
National Marine Fisheries Service (R)
↓
Coastal Zone Management (CZM) Consistency Statement

State permits

Department of Land and Natural Resources
↓
Conservation District Use Permits
↓
Environmental Impact Statement (343 HRS) or Environmental Assessment
↓
Coastal Zone Management Program
↓
Dept. of Health 401 WQ Certification
↓
State Historic Preservation Office (four conditional requirements)

County permits

County
↓
Shoreline Management Area (SMA) Permit
↓
Shoreline Setback Variance (Survey)
↓
Grading, Grubbing, and Stockpiling Permit

For state-owned loko iʻa, additional requirements for state-leased fishponds are as follows:

DLNR-Land Management Division
State Lease mechanism
↓
Nonprofit 501(c)1 or 501(c)3 status
↓
Metes and Bounds Survey and Land Appraisal
↓
Lease Rent Negotiations
↓
Right-of-Entry Permit
↓
Insurance Coverage
↓
Building Permit

Implementation of the proposed streamlined permit process

On the island of Molokaʻi there are between 60 and 80 Hawaiian fishponds. In its strategic plan, the community identified these traditional systems as an avenue for education, culture, and economic sustainability. In 1997, the state processed 29 fishponds through the CDUA process and developed a Master Conservation District Use Application (MCDUA). The MCDUA eliminates much of the application process and provides conditions for the permit processing and operations. While providing some relief, this does not eliminate the overlapping complexity of the permits.

As a result of the continuing, intimidating, and somewhat confusing permit processes, residents of Molokaʻi worked with permit consultants to design a procedure that was streamlined and easier to navigate. In addition, the permit consultants worked on making the process timely and affordable so that ʻohana (family) who desire to operate a pond could apply without incurring a financial setback.

Several agencies agreed to exempt the following from the requirements:

a. Certified Shoreline Survey
b. U.S. Army Corps of Engineers, Department of the Army, Section 404 Clean Water Act Permit
c. Department of Health, Section 401 Water Quality Certification

Standardized forms and templates were also created that made the required information easier to gather and fill in, two of which are reprinted here.

Management Plan

Basic information

Name ____ Date ____________________

Mailing address ____

Telephone (Res.) ____________________ (Bus.) ____________________ Fax ____________________

Site, location, and ownership

Fishpond ____

Island ________________________________ County ________________________________

Ahupuaʻa ________________________________ Area of fishpond ________________ acres

Tax map key(s) ____

Pond ownership _____ State _____ Private

If state-owned, tenancy seeking _________ Lease _________ Revocable permit

If private, name of owner ____

Parcel description

Mark with an "X" where applicable.

1. Are you aware of the presence of any endangered native Hawaiian birds?

   ______ Yes ______ No

2. a) Does the fishpond or areas immediately adjacent to the fishpond contain silt?

   ______ Yes ______ No

   If the answer is yes, please indicate areas of observed silt on your attached map labeled Exhibit I.

   b) What is the depth of mud/silt at these observed locations?

   ____

3. Do you plan to remove any silt?

_____ Yes _____ No

If so, how?

____

____

____

a) Is there mangrove infestation within the pond, on the pond walls, or around the pond?

_____ Yes _____ No

If the answer is yes, please indicate areas of mangrove infestation on your attached map labeled Exhibit I.

Do you plan to remove any of the mangroves?

_____ Yes _____ No

If so, how?

_____ By hand _____ Heavy equipment

4. Make a profile of the beach lands within and adjacent to the pond walls in the space provided below. Please refer to the instructional guide. NOTE: If beach erosion is observed, DLNR will be contacted immediately.

5. a) Are there existing recreational uses at the site?

_____ Yes _____ No

If yes, what are these recreational uses? Locate recreational use on your attached map labeled Exhibit I.

_____ Beach _____ Swimming _____ Fishing

_____ Diving _____ Boating _____ Camping

_____ Other ____

b) List alternative sites for any displaced recreational activities listed above. If possible, indicate potential sites on a map.

____

____

____

Scope of work and pond construction plan

6. Describe the scope of work required to repair the fishpond. See instructional guide. Use a separate piece of paper with the following headings: ***Scope of work, Labor, Materials, Machinery***
Attach resume(s) of key person(s) involved in the work, pond reconstruction, and pond operations.

7. Expected period of work repair.

   Start date: __________________________ Completion date: ___________________________

8. When will you begin to raise products in the fishpond? _______________________________

9. Please provide maps, photographs and/or drawings of the existing fishpond wall.

10. Construction plan

   a) Number of persons working to repair the wall ____________

   b) Proposed wall dimensions

   Wall length __________ Wall height __________

   Width at base _________ Width at top __________

   c) Slope of inside wall in degrees

   _____ 10 –20 degrees _____ 20–30 degrees _____ 30–40 degrees

Slope of outside wall in degrees

   _____ 10 –20 degrees _____ 20–30 degrees _____ 30–40 degrees

d) Building materials used in fishpond repair

   _____ Stone _____ Ili‘ili _____ Coral

   Other: ____

e) Are these materials found on site?

   _____ Yes _____ No

If no, which materials are from off site, where are they coming from and how much will be used?

____

____

____

Provisions 11–19: Items to adhere to

11. Precautionary measures, approved by DLNR State Historic Preservation Division (SHPD), to prevent adverse effect to historic sites will be taken for all shore side reconstruction activities (e.g., transport of construction materials).

12. All reconstruction material will come from within the existing fishpond wall and areas immediately adjacent to the wall. Should offsite reconstruction materials be utilized, they will not be from any historic sites. Excess construction materials shall not be disposed in historic sites.

13. The applicant or ʻohana will maintain close coordination with the DLNR-SHPD before, during, and after reconstruction.

14. The applicant or ʻohana will comply with all applicable statutes, ordinances, rules, and regulations of the federal, state and county governments and applicable parts of Chapter 13-5, Hawaiʻi Administrative Rules.

15. The applicant, ʻohana, its successors, and assigns shall indemnify and hold the State of Hawaiʻi harmless from and against any loss, liability, claim, or demand for property damage, personal injury, and death arising out of any act or omission of the applicant, its successors, assigns, officers, employees, contractors, and agents under this permit or relating to or connected with the granting of this permit.

16. Since this approval applies to conservation district use lands only, the applicant or ʻohana is in the process of obtaining the appropriate authorization from the DLNR-Land Division for the occupancy of state lands.

17. The applicant or ʻohana will comply with all applicable Department of Health rules.

18. Any work or construction shall be initiated within one year of the approval and execution of the lease or revocable permit, and all work and construction must be completed within a mutually agreed upon time period, and this may be extended pending agreement by parties involved.

19. Native species commonly found along the shoreline of Hawaiʻi will coexist with the fishponds.

Template 2

[This is a modified permit example of what is being required by the U.S. Army Corps of Engineers]

Basic information

Name ____ Date __________________

Mailing Address ____

Telephone (Res.) __________________ (Bus.) __________________ Fax __________________

Site and location

Fishpond ____

Island ____________________________________ County ___________________________

Ahupua‘a ____________________________________ Area of Fishpond ________________ acres

Tax Map Key(s) ____

Current condition of the fishpond

Please provide maps, photographs and/or drawings of the existing fishpond walls, shoreline areas and areas where proposed pond-related activities are to take place.

Does the fishpond or areas immediately adjacent to the fishpond contain silt? _____ Yes _____ No
If the answer is yes, please indicate areas of observed silt on your attached map labeled Exhibit I.

What is the depth of mud/silt at these observed locations? ____________________________________

Is there mangrove infestation within the pond, on the pond walls or around the pond? _____ Yes _____ No
If the answer is yes, please indicate areas of mangrove infestation on your attached map labeled Exhibit I.

At a medium tide, what percent of the pond walls are visible and intact? _____ %

What current activities are taking place within the fishpond?

____

____

What current activities are taking place in the vicinity of the pond?

____

____

Project proposal

Describe in detail the overall project activities.

1) What you intend to do.
2) Purpose and need for the project. What is the project used for and why?
3) Please provide a map of the proposed project area indicating where work activities are to take place. (See General Information for additional details).

If additional space is required, please attach an extra sheet of paper.

Pond reconstruction activities

Expected period of work repair: Start date: ________________ Completion date: ________________________

Do you plan to remove any silt? _____ Yes _____ No If so, how?

1) Identify type(s) of material dredged (discharged) and amount(s) of each material in cubic yards (e.g., rock, sand, clay, concrete, etc.).
2) Where will dredged material be deposited?
3) If dredged material deposited upland of project site, identify deposit site and remedial steps if necessary to prevent runoff back into the water cycle and pond.
4) Please describe the benefits of the project (e.g., reconstruction and reuse of historic cultural property, job creation, fish production, community and self empowerment)

If additional space is required, please attach an extra sheet of paper.

Mangroves

Do you plan to remove any of the mangroves? _____ Yes _____ No If so, how?

_____ By hand (including chainsaw) _____ With heavy equipment

Walls

Please provide maps, photographs, and/or drawings of the existing fishpond wall.

Number of persons working to repair the wall ____________

Proposed wall dimensions Wall length __________ Wall height __________

Width at base _________ Width at top __________

Slope of inside wall in degrees: _____ 0–10 degrees _____ 10–20 degrees _____ 20–30 degrees

Slope of outside wall in degrees _____ 0–10 degrees _____ 10–20 degrees _____ 20–30 degrees

Building materials used in fishpond repair _____ Stone _____ ‘Ili‘ili _____ Coral

Other: ____

Are these materials found onsite? _____ Yes _____ No

If no, which materials are from offsite, where are they coming from, and how much will be used?

____

Pond operations

When will you begin to raise products in the fishpond? ______________________________

What type of products are being raised and by what methods?

____

What periodic maintenance activities will be needed to maintain the fishpond?

____

____

____

The proposed project will comply with all state, federal, and county regulations and ordinances. No adverse impacts are foreseen with this project.

Applicant’s Signature ____ Date ___________________

Major control powers over aquaculture uses of lands and waters.

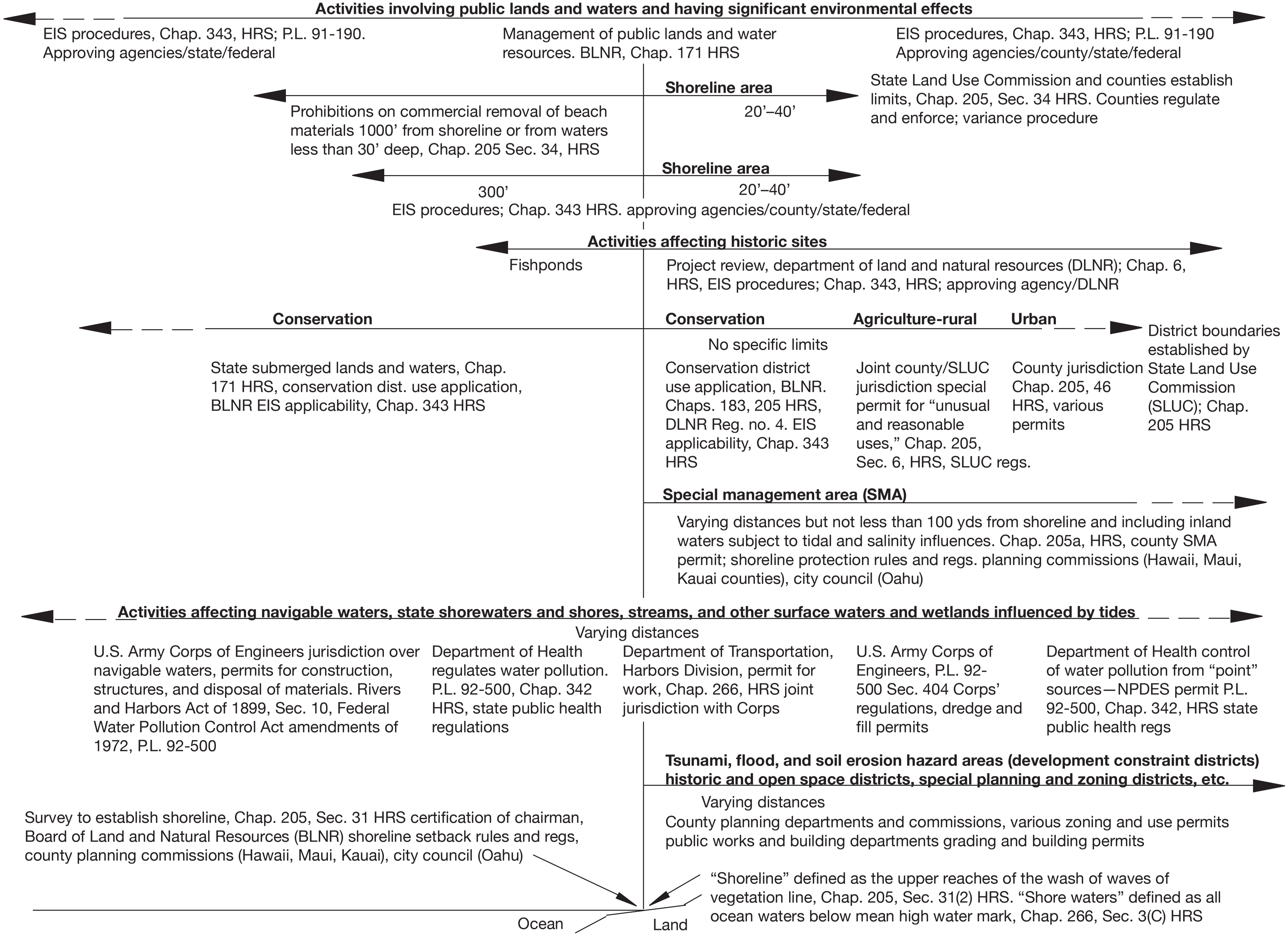


Diagram adapted from *Aquaculture Development for Hawaii—Assessments and Recommendations*, Hawaii Department of Planning and Economic Development, Aquaculture Planning Program, 1978, which had adapted it from *Existing Control Powers Within the Coastal Zone*, Planning Department, County of Hawaii, Sept. 1976.

Hawaiian Fishpond Restoration

Hawaiian legends often credit the Menehune as the contractors for fishponds, which were said to have been completed overnight. More likely, building a fishpond in ancient Hawai‘i required multitudes of people from the apuhua‘a to labor extensively at the task of gathering rocks and constructing the pond's walls. Today, recent projects to restore fishponds provide insight into the effort required to construct these aquaculture systems centuries ago. The following chapter gives details on the methods adopted in rebuilding fishponds on Moloka‘i, as well as some guidance about obtaining the necessary permits to undertake a fishpond reconstruction.

A contemporary rock wall restoration on Molokai‘i.

Before any physical labor starts . . .

Restoring a fishpond can be very rewarding work, but it can also be very hazardous if you are not physically prepared *and* careful. Lifting rocks can be highly injurious to the back, hands, legs, and feet—anyone undertaking to assist with this work should understand that. The safety tips on the next page provide advice on how to reduce the chances of injury.

Pre-restoration reconnaissance

An essential first step, well before the restoration work begins, is to make an assessment of the existing features and characteristics of the fishpond. This is not necessarily "permit-mandatory," but it is the foundation for the process of acquiring a permit. Having the basic information we suggest will assist in beginning the planning and implementation of a safe and effective restoration effort.

Over a period of several days, or longer, closely examine the fishpond to be restored and the surrounding area. Observe and take notes on the differences during changing tides, winds, and weather conditions. Take detailed measurements and record your observations on the pages of a water-resistant notebook. Take photographs, and make sketches.

Get a good start on the planning process

- Measure the width of the original footprint of the wall.
- Count how many mākāhā were in the wall.
- Note the size, location, and number of displaced rocks.
- Measure the water depth at high and low tides.
- Note whether the water is clear or murky, and when.
- Note whether there is a sand, coral, or mud bottom.
- Identify and count, if possible, any limu and fish around the remaining wall areas.
- Note the condition of the shoreline (e.g., mud or sand)
- Note the plant and animal life on the shore.
- Note the activities around the pond (houses, roads, boating, etc.)

Once the restoration work has started:

- Keep a daily record of observations about the pond and its biology.
- Take detailed pictures frequently to document the restoration process.

Safety tips

According to the National Safety Council's accident facts, back injuries are the most common type of work injury. Bending over to pick up and place stones can put a great strain on your back. To help avoid back problems, follow this advice:

- Make sure your footing is solid—this is especially important in wet areas.
- Keep your back as vertical as possible by centering your body over your feet.
- Size up the load you are about to move. Pick up one side, and see if you can handle it comfortably. Get help if the object is too bulky or heavy. Use a hand truck, dolly, or floating device, as appropriate.
- Get a good grip and keep the load close to you.
- With your stomach firm, lift the object using your leg muscles, not your back muscles.
- Move your whole body as you go. If you need to turn while holding the object, don't twist. Turn by moving your feet in the direction you want to go.
- Avoid overreaching for objects at or above shoulder height.
- Stretch and warm up your muscles before you start any bending, pulling, or lifting work.

Safety tip—protecting hands and feet

A good pair of gloves is a must. Cloth and leather gloves do not last more than two to three days. Synthetic gloves work best, but they need to be rinsed out and dried daily to keep them from getting smelly from fungus growing in them. Do not allow anyone to work without closed shoes and gloves—the ocean is full of hidden creatures and unsafe surfaces that can result in serious injury.

Personnel

8 strong and healthy individuals (at minimum)

Supplies

First-aid kit
Cellular telephone
Drinking water
Nutritious food
Sunscreen, hat, sunglasses
Long-sleeved T-shirt
Shoes or boots with sturdy bottoms
Heavy-duty rubber (synthetic) gloves
Back brace

Equipment

Flat raft or barge
ʻŌʻō (prying bars)
Plastic baskets (heavy-duty)
Pickaxes
Hard tine iron rakes
Cargo netting
Dragging sled
Canopy or tarp for shade
Chairs to sit and rest

Restoration

Restoring a fishpond can be a long process from a paperwork standpoint as well as from a physical perspective. It can easily take well over a year to acquire all the permits that are needed *before the first rock can be moved*. It can also cost $10,000 (or likely more) in legal costs and fees to process all the necessary documents. This waiting time can be trying financially and emotionally, so patience is a must. Patience and perseverance, however, can be rewarded!

This section starts with some advice on permits and traditions, then covers the basics of reconstructing a fishpond, and then the basics are generally applied in examples of two types of fishpond.

Permits

The first step in restoring a fishpond is to have *ALL* of the required permits before any reconstruction work is done. Missing just one permit is enough to halt a restoration project and could result in legal action being brought against the restorers. *Do not proceed* without the proper permits. The information gathered in the pre-restoration reconnaissance will be necessary in filling out the permit applications.

A restoration mind-set based on Hawaiian traditions

The patience and perseverance that is required to begin, sustain, and complete a fishpond restoration is embodied in two Hawaiian philosophies: Hoʻomanawanui, "take your time and do not rush," and kūlia i ka nuʻu, "strive for the highest, and do your very best." It goes without saying that hard work from beginning to end is the cornerstone of fishpond restoration. However, the proper respect for these historic cultural treasures signifies an appreciation of the genius, intellect, and hard work of the Hawaiians who built them in the first place. Respectful actions suggested while working on the fishpond include

A small-scale model (about 5 feet across) was constructed to learn the process of restoring a fishpond.

- listening to your leaders and advisors
- staying focused on what you are there to do
- avoiding horse-play or showing off when lifting and moving rocks.

Other considerations to keep in mind:

- Planning, leadership, and discipline are essential to keep the effort going.
- Talk about and reherse the process of lifting, carrying, and placing rocks; talk also about what to do in an emergency.
- Morale needs to be kept high thoughout the project, so make the effort to praise the work that is being done and to celebrate small accomplishments.
- Once the reconstruction process is under way, rotate workers through different jobs as their strength, desires, and abilities dictate; work rotations combined with rest periods help break up the day and make for a safer environment, because boredom and fatigue can create harzardous conditions when working with heavy rocks.

A crew practices fishpond wall construction on land, where it is easier and safer to learn the process.

Reconstructing a Hawaiian fishpond—An overview

Being organized and methodical when restoring a fishpond can increase the safety and efficiency of the project. The following steps provide general guidance on how to reconstruct a fishpond. Each situation will be different, but thoughtful planning will help reduce uncertainty if an unexpected situation arises. It is almost certain that the rebuilding process will take longer than expected. Take time at the end of each work day to make sure there are physical supports on partially finished sections of the wall. If this is not done, the ocean might wash out sections of the wall before work picks up again. Following are some basic procedures.

Preparing the pond wall foundation, with the pond layout staked in the background.

1 Assemble all the necessary tools and equipment as noted in the list given previously. A well stocked first-aid kit is a must. At least eight healthy, strong individuals will be required to perform the heavy lifting, so pre-planning and recruitment are necessary. Make sure there is adequate water and healthy food at all times to keep up fluid and energy levels, and be mindful of the impact of the sun on exposed skin. Have shaded rest areas if possible, and take regular and frequent breaks.

2 The first reconstruction task is to find the niho stones: the old footprint of the wall. This should already be known from the reconnissance work done for the permits. If the footprint can be found at the shoreline, it is where rebuilding should start. If this point cannot be located, start where the original footprint is closest to the shore. Use the largest stones for the bottom, ocean-facing side of the wall. Begin to reestablish the inside and outside walls by following the original footprint as closely as possible.

3 Next, dig out any stones within the working area, stacking them by general size and shape near the work site. This step can reduce the time it takes to locate an appropriate stone. Think carefully about how these piles are located so the stones do not need to be moved more than once.

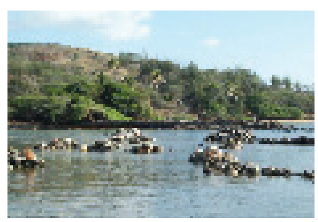
4 When placing one rock on top of another, place it 1–2 inches inside of the front edge of the lower rock. Each rock should slant or lean toward the center of the wall. This way, gravity pulls them inward toward the middle of the wall rather than outward or to the side, in which case they might fall off the end of the unfinished wall section.

As the outside and inside walls begin to rise above the pond floor, the middle of the wall is filled with smaller rocks, which do not have to be placed in any particular way. As the ocean-facing side of the wall is built up, be sure to support the first layer of rocks with at least 2 feet of supporting rocks inside the wall so that waves do not topple it.

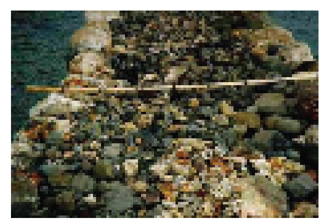
Rock wall construction work includes face-setting, filling, and feeding the setters and fillers with rock materials.

As the wall is built up from the bottom layer of rocks, the "seams" between adjacent rocks should be staggered. In other words, the next rock should be placed over the seam between the two lower rocks. Try to face a flat side of the rock outward, because that side will be exposed to wave impact and needs to deflect the energy of the waves. Long, narrow rocks should be placed pointing toward the center of the wall. This will add strength to the wall.

To determine the final height of the fishpond wall, consult a tide chart to identify the highest annual tide for the locality. The wall should be as tall as the highest possible tide, plus 1 foot. The highest possible tide usually ranges from 4–5 feet above the average high tide water mark, depending on the time of month and year. Consult a tide calendar for this information. A review of historical data on major tides of the past 20–50 years in the area of the fishpond restoration is important. The water should never go over the wall during the highest tide if it is planned and built correctly, so build for a 20–50-year high tide or for waves brought on by abnormal weather.

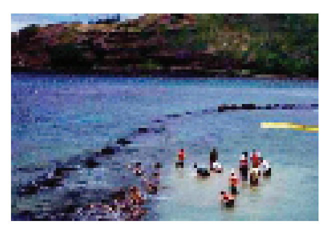


Low tide reveals piles of rocks ready for wall construction.

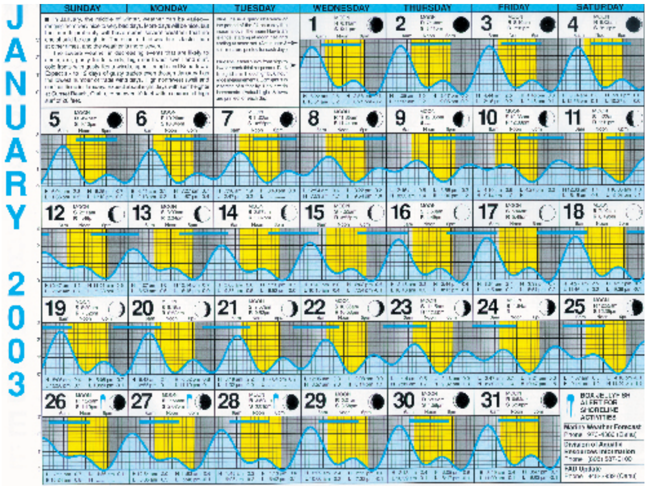


A wall interior, filled with small-rock rubble.

A team approach to moving large rocks with an ʻōʻō is aided by the rocks' bouyancy in water.



Honouliwai fishpond restoration, early stage.



A monthly tide calendar.

Using an ʻōʻō to move rocks too heavy to carry.

5 A team of at least eight people is needed to keep the job running smoothly, safely, and efficiently. This allows two teams of four, each with two "feeders" and two "setters." If there are extra people, they can help to "feed" (transfer) and stack rocks near the wall, or to carry small rocks in plastic baskets to fill the wall, or to set up another team of four. Additional people can also help support the workers by bringing out water, food, and supplies to them.

To begin rebuilding large sections of the wall, there should be two people setting rocks on the outside wall and two people setting the inside wall. Two people feed rocks to the outside team, and two more feed the inside team.

The most experienced rock setters should be the ones setting the rocks that create the base or footprint, with the secondmost able setters building the wall up to the required height. As the outside and inside walls go up, the middle needs to be filled with large and small rocks so that the wall can withstand wave and tide action. Without this internal support, the wall will collapse on itself when hit by a large wave.

Before a rock is hoisted onto a wall, a close examination of the wall is needed to determine where the rock should land and finally come to rest. Similarly, the rock's surfaces need to be examined to choose the best surface to fit on the rocks already in the wall. The "face" is the side that will face the outside of the wall, while the "sit" is the side of the rock that will sit on the lower two rocks on the wall. It is important to plan where the rocks are going to fall, because it is inefficient and inconvenient to move the larger rocks more than once.

Rocks that cannot easily be carried can be moved with a team each using an ʻōʻō (a thick rod made of steel or strong wood). The tip of the ʻōʻō is placed under the rock, with a smaller rock used under the ʻōʻō to increase leverage. The large rock is rolled inches at a time and used as the base of the wall.

Putting basic reconstruction skills to practice: Two examples

The overview presented above provides some general guidance on how to reconstruct a fishpond wall. The dimensions and strength of a fishpond wall are determined to a large extent by the length of the wall and the bottom contour of the reef fronting the fishpond wall. A fringing reef acts as a wave energy buffer and can reduce the strength of a wave by over half. If there is a shallow reef or sandbar close to the wall, the wall may need to be significantly higher and wider than if this were not the case, because the wall needs to be able to withstand most of the force of the waves. Following are two examples of fishponds that illustrate this distinction. Honouliwai fishpond has a reef abutting it, so the rocks needed to be very large, whereas the Kahinapōhaku pond has a large fringing reef in front of it, allowing the pond wall rocks to be smaller.

Honouliwai fishpond

Honouliwai fishpond has a narrow reef to protect it, so the fishpond wall's rocks are wide and long so it can withstand the almost unrestricted force of waves and tides. Both the width and height of the wall average 5½–6 feet. Because the wave force is large, the rocks that were originally used to build it were large as well. Large rocks require special tools and handling to place

An experienced setter is stacking the shore face and the interior cross-section of the wall.

Honouliwai fishpond completed.

them on a wall, and workers need to be extremely careful when handling very heavy rocks.

Moving rocks

With the rocks used to build a pond like Honouliwai, it sometimes took four to eight strong people to handle a single rock. To help with that effort, a large cargo net was used. The rock was rolled onto the center of the net, and the workers would surround it. Once their footing was firm, they grabbed the edges of the net and lifted the rock off the ocean floor. They then walked the rock to the location near the wall where it was to be placed. The rock remained underwater during transport so that the bouyancy of the saltwater would make it somewhat lighter. Because these rocks were so large, all eight workers were often needed to transport and hoist them into place.

It was easier to move rocks from the shoreline to the wall during low tide, but it was easier to hoist the rocks onto the wall during high tide, as the rocks were in the water for more of their trip from the pond floor to the wall. The workers lifted on the chant of "one–two–three—*up*!" Good momentum starts while the rock is in the water; once the rock leaves the water, the team's follow-through and coordination is important to get the proper lift height and to land the rock safely on the wall.

A normal hoist would include four workers holding the cargo net at the bottom of the wall and two workers on top of the wall holding onto an edge or corner of the net. All would pull together, with the bottom four responsible for getting the momentum of the lift going and the top two responsible for the follow-through after the rock leaves the water and lands on the wall. The two workers on the wall would service several cargo net teams and be responsible for preparing the wall to receive the next rock. For rocks that were too big to be moved with a net, an ʻōʻō was used, as previously described.

The more planning done before the final placement of rocks onto the wall, the easier and faster it was to build the wall. It took a lot of time and effort to move each rock into its final position once it was on the wall. The trick to minimizing the number of adjustments needed was to hoist the rock and have it land as close as possible to the final position and be in the proper orientation.

Concentration, teamwork, and a resolute "can-do" attitude were essential in keeping accidents from happening. Care was taken never to allow the team to become tired or bored. For the first few months, the work only took place for half a day, as muscle fatigue made things dangerous. It took time for the workers to condition their bodies for this kind of hard work.

Environmental impacts

Turbidity and siltation was minimal during this restoration. When a rock was lifted up with a pickaxe end or an ʻōʻō, coral or mud silt came up with it. The silt would drift with the current for 2–6 yards and then dissipate or settle back to the bottom of the pond. Moving rocks to the wall by hand or cargo net produced negligible amounts of turbidity. Water quality was not a problem, as the pond bottom had very little silt.

Kahinapōhaku fishpond

The Kahinapōhaku fishpond had a large fringing reef fronting it, which provided a good deal of protection. The base of the wall, according to the original footprint, was approximately 15 feet wide, but it was only 10 feet wide near the shoreline, being out of the direct wave impact area.

The Kahinapōhaku fishpond kuapā was damaged by a major storm surge that caused it to collapse. The wall collapsed outward, toward the ocean, which may seem odd because the waves came from that direction. Actually, the waves washed over the seawall and the back-surges against the inner wall pushed it outward as the waves retreated. Repair to this breach took about two days. If fish are being cultured in the fishpond, immediate repair is critical or losses will result. Damage can also allow undesirable fish species to enter.

Moving rocks

Due to the reef fronting this fishpond, the rocks used in this pond were smaller, "one-man" size, which a strong person could generally carry alone. This made for less dangerous working conditions. Rocks could be moved and placed on the wall with less pre-planning, because once placed on the wall they could be easily moved around to find a perfect fit. Two four-person teams, one on the inside wall and the other on the outside wall, worked well at this fishpond.

In many places, the original footprint could not be found. As a result, the setter had to slow down and align the wall using as many reference points as could be found. Sometimes rocks had to be removed to realign the wall.

Workers at this fishpond had more independence and needed less teamwork than those at the Honouliwai pond because the rocks were smaller and as a result the wall went up faster. The setters, however, had to move slower and more deliberately to follow the original footprint and place the rocks properly. While being careful, those doing the fill could work as fast as they wanted by just throwing smaller size rocks into the middle of the wall. More hours per day could be put in because the rocks were smaller and the physical toll on the workers' bodies was not as high as with the Honouliwai fishpond. The Kahinapōhaku pond's rocks represent the typical size of rocks found in most fishponds on Molokaʻi. Thus it will be easier to rebuild and to maintain this fishpond after storms and high surf.

Passing large stones down a line.

Aerial view of Kahinapōhaku fishpond with half of the wall completed.

Collapsed pond wall at Kahinapōhaku.

Kahinapōhaku's unrestored wall with original rocks.

Kahinapōhaku fishpond wall completed.

Environmental impacts

There was very little turbidity at this site, so the impact of the restoration project was negligible.

Rock wall construction

The photo above shows a short inside wall; some fishponds are totally rock-lined, inside and out. This cross-section depicts the angled, trapezoid-shape stacking. Two large niho (base) rocks are on the bottom corners. The main rock-setters created the "footprint," using the niho to provide the foundation of the wall for other stackers to build upon with smaller fill stones. Angular rocks are easier to set than round ones, and the wall will have better structural integrity.

Note the progression of the next base rocks. In stacking the rocks along the sides, offset the next stone about 2–3 inches toward the middle to get the angled slope front and back. The edging rock surfaces are also angled inward, adding to the integrity of the wall as waves and tides batter it. Smaller, less angular stones and also ili'ili (pebbles) can be used as fill.

In the other photo, the wall is complete. Note the

A cross-section of a wall's "footprint."

A completed, filled-in wall section.

line-up of rocks on the right side going backwards. This is how it should look. Initially it may look like the stones are not lining up, but after 30–50 feet it should start to look more and more like a fishpond wall. It is a good idea to have a practice session to build a small wall, then get up on it. If you can walk along the top edges without the wall collapsing, you have built a sturdy wall.

In the end . . .

Pride and knowing the cultural importance of the restoration effort played a significant role in restoring both the Honouliwai and Kahinapōhaku fishponds. This aspect of these projects cannot be overemphasized—appreciating the history, culture, and community involved brought everyone closer as a team. Above all, those involved experienced a rejuventation of Hawaiian culture and applying its practices to bringing a fishpond back to life by restoring its walls. It was not simply a physical effort, but a mental and spiritual effort as well. Those reconstructing a Hawaiian fishpond gain immense pride of accomplishment and respect for the knowledge and skills the ancient Hawaiians possessed but which are not always adequately appreciated in today's world.

Equipment for Pond Operations

Land tools

"Land tools" are used to develop and maintain the facilities on land that are necessary in the operation of a fishpond. From left to right: plastic basket, pick-axe, shovels, ʻōʻō (digging tool), rakes (hard tine and flexible), boots, back brace, gloves, flagging tape, and 300-ft tape measure; missing from picture: post pounder.

Water tools

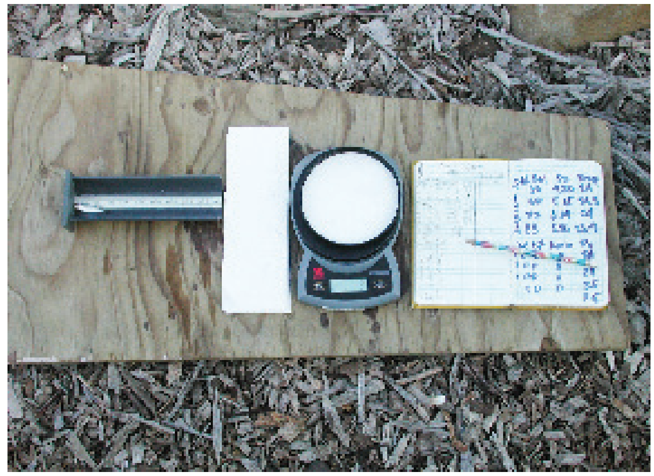
"Water tools" (below, right) are necessary for fish production efforts in the water. They are used for sampling, harvesting, stocking, and transferring animals from one system to another. Clockwise from left: large fish net, plastic basket, cooler, reusable ice packs, bamboo dip-net, seine, gloves, and scoop nets.

Fingerling collection supplies

Fingerling collection supplies (below) are used to capture fingerlings for transport, sampling, or health assessment. A fish tranquilizer, MS-222, provides sedation for reducing stress during transport. Collection equipment shown includes a 5-gallon bucket with a battery-operated aerator and a bamboo dip-net; not shown are a small mesh seine net, scoop nets, and an 8-ft, ⅜-inch mesh casting net.

Sampling equipment

Sampling equipment is used frequently to measure the animals cultured. The data collected allow feed calculations based on fish growth and the total biomass of the production system sampled. From left to right: a homemade fish measure for small fish; paper napkins; a portable, battery-operated, 0–200 gram balance; and a waterproof data tablet.



First-aid kit

The first-aid kit is mandatory equipment that should be well stocked at all times. Special items useful for fishpond first aid include duct tape, vinegar, meat tenderizer, and an eye wash bottle. Vinegar or meat tenderizer is used to relieve pain from jellyfish stings. (Meat tenderizer contains an enzyme that breaks down the proteins in the jellyfish venom, which irritate the skin and cause pain.)

Recordkeeping

Logbooks and data sheets are used for recordkeeping (see the chapter on *Optimizing Pond Health* for examples of records to keep). A data sheet can be created and printed with a computer program. Water quality, fish production, and sampling data are entered on the paper spreadsheet and later typed back into the computer spreadsheet for analysis and transformation to produce additional data useful for production management. Special waterproof paper can be purchased for field recording.

Water analysis

Water quality testing to assess and monitor pond health is done with testing kits. By placing a sample of water in a container and adding chemical reagents at specific intervals, the sample changes color, which is compared with color gradient charts to determine the levels of ammonia, nitrate, and nitrite in the water, and its pH.

The Hach™ salt-water test kit is an example of an economical kit that provides valuable information, on site and quickly. Kits for the four parameters mentioned above can be purchased for under $50 to provide approximately 50 tests per parameter.

Dissolved oxygen

A dissolved oxygen meter is used for water quality monitoring of culture ponds or other marine environments. Because a good dissolved oxygen meter is essential to any aquaculture operation, don't waste money on a cheap one—expect to pay $600 or more for a good one. These meters are fragile instruments and should be handled with care.

Treat a dissolved oxygen meter like an expensive camera. With care and proper maintenance, a good one can last for years. For example, the meter shown here was still in use after over twenty years of service.

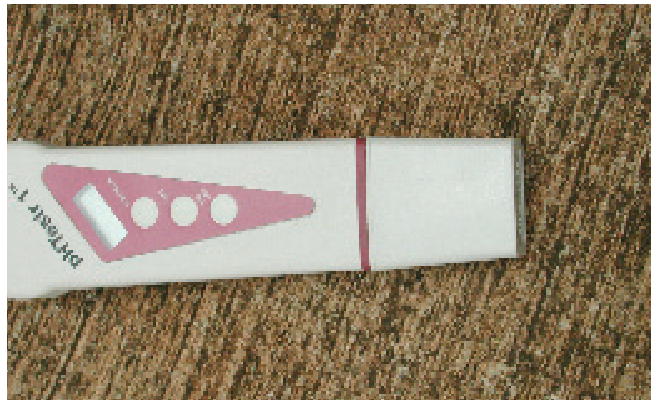
Refractometer

Refractometers measure the salinity of water in parts per thousand (ppt) or in density. Besides salinity, these instruments provide information for calibration of the dissolved oxygen meter.

To use a refractometer, load the viewing platform with a few drops of sample water. Take care to not allow any air bubbles onto the viewing platform. If bubbles are present, reload the viewing platform. Look through the viewing lens while facing the sunlight. Fresh water is zero ppt salinity, while full-strength sea water is 32–34 ppt.

Water pH

A pH meter measures the electrical potential of a solution and converts this data into a pH reading. This meter is sometimes used instead of the reagent/sample container method. The unit is portable and can be used in the field for an unlimited amount of time or until the battery needs replacing.



This water quality test kit (made by LaMotte) is used to analyze nine parameters: NH_3, NO_2, pH, alkalinity, carbon dioxide, chloride, dissolved oxygen, hardness, and temperature. Note: the kit comes in fresh and salt water versions.

Sample handling

Food mills or food grinders crush feed to appropriate sizes for the various sizes of fish in the pond. Take large-pelleted feed and grind it to a smaller grain if smaller-pelleted feed is unavailable. Use scoop nets with different size netting material as sieves for separating ground feed into fine, medium, and coarse fractions. Keep the various sizes of feed in different food containers.

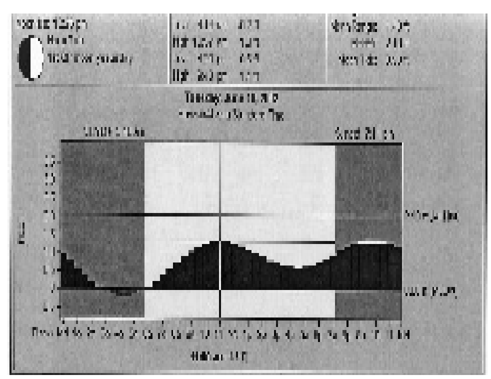
In-pond transport

A barge provides a platform for group viewing, feeding, carrying supplies and materials around the fishpond, and transfering and harvesting fish. The barge in this photo is constructed of six plastic floats, is 8 ft by 12 ft, and can carry approximately 2000 pounds.

A small dinghy is a useful vehicle for transportation to and from pen culture systems for feeding and water quality testing. The boat also services the production operations by transporting supplies and materials. The boat in this photo is also equipped with a small, 12-volt electric motor (not pictured).

Tide calendar

A tide calendar shows daily tide predictions for specific areas. These calendars are essential for fishpond operations, because the monthly projections help in scheduling activities. By understanding tidal heights and durations at various stages, pond operators can determine the best scenarios for harvesting, transporting fish, and other tasks. Tide charts need to be adjusted for each locality, as they differ slightly in timing from one site to another.



Net-Pen Production

Hawai'i's land, ocean, and cultural environment has changed irrevocably since the times when fishpond aquaculture flourished, and the conditions under which those marvelous innovations were traditionally managed are gone.

Managers of the ancient fishponds could call upon the entire populace of an ahupua'a for assistance with construction, repair, and maintenance. Today, significant effort is required to rebuild fishpond walls and renew pond ecosystems, but the social structure that once provided that labor is also generally gone.

In ancient times the shoreline ecosystem that was modified by Hawaiians to create an environment to raise fish and other seafood products was relatively pristine. Today, environmental factors such as invasive plant and marine species, land development for agriculture and urban uses, and redirection of freshwater streams have contributed to degradation of shoreline conditions to various degrees.

Modern net-pen technology

The methods illustrated in this guidebook utilize modern net-pen materials in fishponds and combine traditional pond management methods with applicable contemporary technology.

Net-pens for aquaculture enclose areas within a fishpond and confine fish to a particular location. Their use is about as old as aquaculture itself, starting with carp growers in China 2000 years ago. Today, net-pen production in the open ocean and bays makes a substantial contribution to the total amount of farm-raised seafood, thus proving the success of the methodology. The benefits of net-pens include the

- ability to culture species within ponds that can no longer provide a secure, safe enclosure for the fish
- ease of production management (e.g., stocking, sampling, harvesting)
- transportability of materials to almost any desirable site for construction
- manageability of invasive and predatory species.

These systems are not without risk, however, and if production is too intensive, negative impacts (such as high stock densities and feeding rates and increased levels of animal waste pollution) can result. In ancient times, a fishpond's natural productivity was carefully nurtured rather than overly exploited. Traditional fishpond production was "extensive," meaning fish culture was conducted with a minimum impact or expense to the system. This resulted in low yields (somewhere between 400 and 600 pounds per acre per year). By comparison, in today's "intensive" systems, the practice would aim to produce over 2000 pounds per acre per year, with increased labor, capital, and system impacts, both physical and biological.

Traditional Hawaiian production utilized mullet and milkfish as the primary culture species. These two herbivores are, at the same time, the most important biological maintenance tools of the fishpond. Feeding directly into the primary productivity level of photosynthetic and benthic (ocean bottom) organisms, these species maintain the fishpond's environmental integrity.

The mullet/milkfish production rates proposed in this guidebook are conservative and would appear to be a feasible starting point within a typical fishpond system, ocean and weather conditions considered. More site-specific variations in chosen culture species, water character, water quality, and management style should be equally assessed throughout the production run and adjusted where applicable.

Net-pen culture within a protected area can function well with other aquaculture activities that may go on in adjacent locations within fishponds, such as the cultivation of limu, coral, or even aquarium species. The materials to be used in construction of the net-pen are readily available, and the methods of construction require only hand tools and basic construction skills.

Net-pen design parameters

The fundamental purpose of any net-pen is to provide a secure, safe enclosure for the species being cultured. Developing a diagram on paper is recommended before doing any work in the water. The diagram should take into consideration measurements and parameters such as pen height, surface area, stocking density and water depth. Special consideration should be given to plan for the highest possible tide, because the top of the net-pen should never go below the water level, which would allow fish to escape. The average water depth in a fishpond is approximately 4 feet. Tide fluctuations can range another 2½ feet once or twice annually. The net-pen can be as large as the total pond area will allow, but using a size that serves production "workability" is most practical.

Two types of net-pens have been used in production trials on Molokaʻi. Rectangular net-pens were constructed for nursery culture, from the initial stocking to about ¼–½ pound size. Then the fish were transferred to large, round pens for growing out to a harvestable size of over 1 pound. Thus there were two different net-pen shapes and production management styles.

As a general rule, net-pen culture requires a total pond area approximately 10 times the area in which the fish are confined. For example, a rectangular net-pen 50 by 100 feet has an area of 5000 square feet. A single net-pen of 5000 square feet requires approximately one acre (45,600 square feet) of water surface area. In other words, in a pond one acre in size, one net-pen of 5000 sq ft area could be constructed. In a pond 10 acres in size, up to 10 net-pens of that size could be constructed.

A circular net-pen with an 85-foot diameter has an area of 7,880 square feet. In terms of the area confined within a given length of net, a circular net-pen is more economical and efficient because it provides 36 percent more pen area than a square one.

Considerations before building a net-pen

When building a net-pen, the following practices should be followed or taken into account:

- wear solid footwear to protect feet
- wear shirt, hat, gloves, eye protection, and long-lasting sunscreen to reduce sun exposure
- wear a back brace for support when lifting
- two or more people are needed, depending on pen size
- size of final pen depends on projected production

Before building a net-pen, gather the following equipment and materials:

- rolls of ¼–1-inch plastic mesh (11 guage)
- boat, raft
- post pounder
- rope, ¼ inch or more thick and about 20 ft longer than the radius of the circle
- ultraviolet-resistant plastic cable ties, 11 inches and 7–8 inches (for example, a 300-foot circumference pond needs about 1000 ties, 300 11-inch ties and 700 7–9-inch ties)
- wire clippers
- T-posts ("T-stands"), 8-ft or 10-ft; ⅝-inch rebar to extend posts if necessary

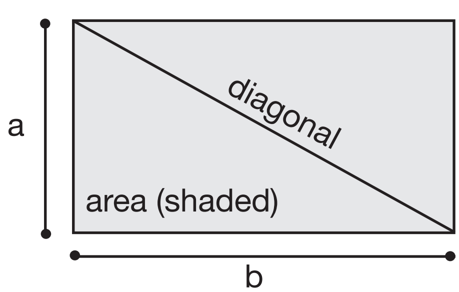
Rectangle calculations

area = a x b

perimeter = 2 (a + b)

if square, a = b

diagonal = $\sqrt{a^2 + b^2}$

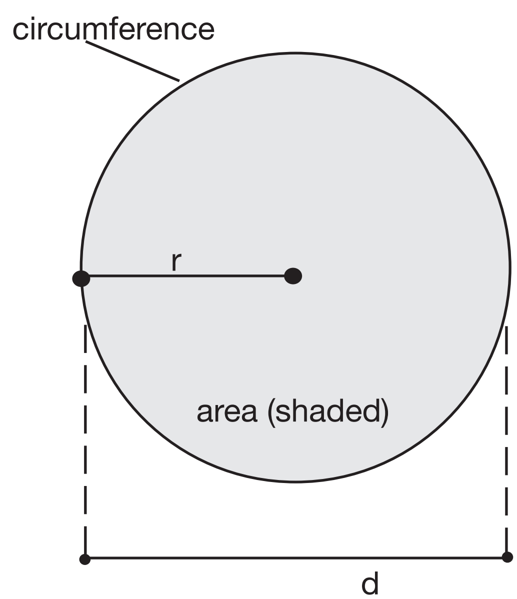


Circle calculations

circumference = $2 \pi r = \pi d = 3.1416 d$

area = πr^2

r = radius, d = diameter, $\pi = 3.1416$



Check the site for level floor (step 1).

Drive in the center post (step 2).

Net-pen construction

Net-pen construction usually takes place in water that can be as much as chest deep, and it is very difficult to illustrate the actual process as it takes place underwater. Therefore, we constructed a demonstration net-pen on land to better show the details of this process.

Step 1

If possible, identify an area within the fishpond that is 1½–2 times the size of the planned net-pen, because adjustments in the pen's placement may need to be made. After identifying a site that may meet the biological and physical needs for production, make a thorough inspection of the site using a mask and snorkel. Next, slowly walk over the projected area; for a large area, it helps to have several people, 10–15 feet apart. Although bare feet can allow a better feel for the bottom, injuries are highly likely, so boots or shoes should be worn at all times. Probe the bottom with a rod or stick to "feel" depths below any layer of sediment on the pond floor.

The ideal site placement for a net-pen should have the following characteristics:

- bottom contour: flat and level
- bottom type: coarse sand
- water quality: best possible or high in dissolved oxygen
- water flow: light, consistent flow with tide
- wind currents: open to prevailing tradewind
- water depth: about 4–6 feet
- accessibility: close to the work and storage facility.

Step 2

With the net-pen area chosen, drive a T-post in where you want the center of the pen to be.

Step 3a

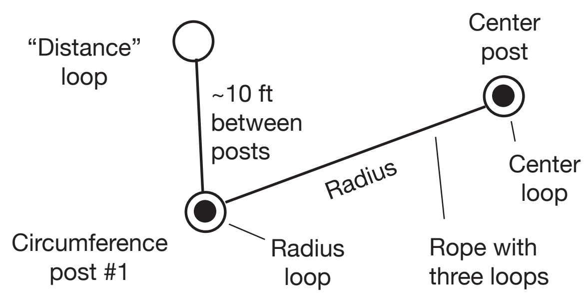
Tie a loop in the end of the rope and put it over the post. Measure the pen radius distance from the center post, and tie another loop in the rope at the length of the radius. Holding the rope near the center post and gradually letting it pass through your hands, walk around the center post in expanding circles until you reach the circumference, at the end of the radius. This allows you to check the floor area within the circumference for any problems, particularly for imperfections near the circumference that may hinder the flat lay of the pen's side.

Position the first circumference post at the limit of the radius.

Step 3b

Pull the rope out to the circumference and hold it tight and level. Drive the first circumference post straight down to a depth that has a solid foundation and still provides enough post height to keep fish in at the highest tide level. Circumference posts should be spaced about 10 feet apart, at most. Because the ocean bottom and netting materials will differ with the circumstances, the posts may need to be less than 10 feet apart to provide the wire mesh with sufficient support. Determine the number of circumference posts needed by dividing the desired circumference of the pen by 10 feet, or whatever other distance is desired between posts.

1. Drive the first circumference post at the end of the radius.

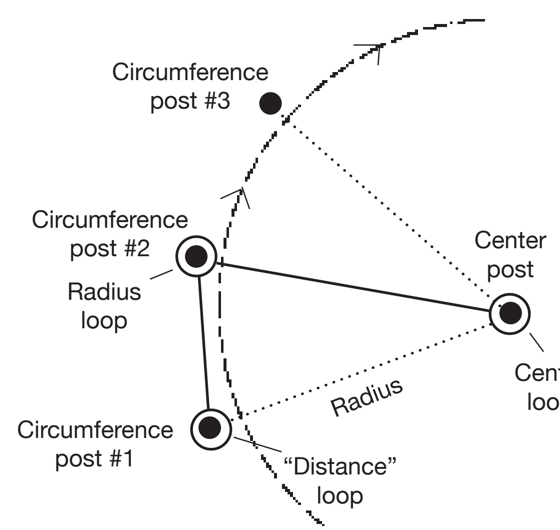


Use the rope find the location of the second circumference post (see diagram).

Step 4

Make a third loop in the measuring rope to define the chosen distance between circumference posts (10 ft or less). Using the first circumference post as a starting point, put the "distance" loop over it and pull the radius loop so that the two parts of the rope are tight, loop-to-loop. This will define the location of the next post on the circumference. Continue clockwise around the circle, moving the distance loop to each successive post pounded in, and using the radius loop to find the location for the next post.

2. Put the "distance" loop on the first circumference post and pull the radius loop tight to find the next circumference post. Then, keep shifting the "distance" loop clockwise to complete the circle of circumference posts.



Finish driving in the circumference posts (step 5).

Lay out the mesh near the circumference posts (step 6).

Step 5

Repeat Step 4 to find the place to drive each successive circumference post. Continue until the circle of circumference posts is complete. Don't hesitate to adjust the distance between circumfrence posts if you hit a problem area and the post is hard to drive into the pond bottom. In general, putting the posts closer together is preferred to their being farther apart, because it increases the net's stability. However, when adjusting post-to-post distance, it is best to keep the radius rope tight so the circumference remains circular. Don't worry about having the distance between the last and the first posts be the same as between the other circumference posts, because it should always be shorter.

Step 6

Collect the materials for attaching the plastic-coated wire mesh to the posts. This outer screen, of about 11 gauge plastic with a 1 x 1 inch mesh and 4 feet wide, is a heavy-duty material to keep out crab and eel predators and to add integrity to the pen structure. It may be advantageous to have a few people assisting in this activity. Also useful is a boat, raft, or other water vehicle to carry materials and supplies to the net-pen site.

Start to unroll the wire mesh next to the net-pen site. The wire mesh will partially sink when this is done in the water. Pull the front edge of the wire mesh and lay it along one side of the pen circumference. If not many people are helping, hold the mesh upright as it unrolls; otherwise it will tend to lie flat on the pond floor.

Start lifting the mesh up and wrapping it against the posts (step 7).

Step 7

Do not try to lift the wire mesh upright until its bottom edge is brought as close as possible to the circumference support posts. If a level site has been chosen, the top edge of the wire mesh will be level. If an uneven site has been chosen, the wire mesh will either lean in or lean out. Level the site bottom manually, using a shovel; if the bottom cannot be made level, it may be necessary to move the pen to a better location. Continue to adjust the wire mesh around the circumference posts.

Bring mesh upright against the circumference posts (step 8).

Tie mesh to the circumference posts (step 9).

Step 8

Starting on one side of the pen, stand the wire mesh up against each circumference post and continue around the pen until the mesh is upright and tight against all the circumference posts. Recheck to make sure the wire mesh is flush against the circumference post from top to bottom. Use plastic cable ties to attach the wire mesh to the post, placing one every 8–10 inches.

Step 9

Shown at right above is the appropriate method for attaching the mesh to the post with plastic cable ties. When attaching the cable ties, one person is needed to stand inside the net-pen to help secure the cable tie, which is inserted through the wire mesh and around the post by the person standing on the outside. Start from the bottom and secure ties about 8–10 inches apart, moving upward. If another panel of wire mesh will be added to increase pen height, leave the top of the lower panel loose (no cable ties) to allow for the upper panel to be tucked in between the T-post and the inside of the lower panel. Now, if it is necessary to increase the height, attach the plastic mesh, rebar, and additional upper panels to the T-posts using 11-inch ties. Continue this process until all posts but the last one has mesh on it.

Overlap the mesh together to complete the pen (step 10).

Step 10

Pull the wire mesh ends together and overlap them a minimum of 1½–2 feet on the last post. The overlap should be level along the top and bottom, then secured tight to the circumference posts. It is important to have posts at the area of overlap for strength; if a post is not there already, add one.

Pound rebar into the ocean bottom to add height to the mesh wall (step 11).

Add mesh to increase pen wall height (step 12).

Step 11

Often an additional panel may be needed to add height to the top of the net-pen for periods when tides are at their highest. To increase the net-pen height, the circumference post must be tall enough so that the wire mesh can be securely connected at the top. If the post is not tall enough, a piece of ⅝-inch rebar longer than the post can be attached to raise the overall height of the post. To attach the rebar to the post, the post must first be embedded in the ocean bottom about 8–10 inches. With the post pounder over the rebar, carefully pull the post out of the way and pound down the rebar. Note: if it is known that additional height is necessary, this step can be also done when the original T-post is driven into the ocean bottom and before the first mesh panel is attached.

Step 12

Any mesh panel needed to extend the height of the pen should be inserted between the rebar and T-post supports and the lower mesh panel. Cable ties should be connected only to the bottom half of the support post during the first wiring. The extension panel is slid down between the T-post and the lower mesh panel until it is at the desired height. The two panels need to be as tight as possible so as not to leave gaps at the overlap where animals can enter or exit the net-pen. Working on two to three posts at a time, always be vigilant to maintain the top edge of the extension panel as level as possible all the way around the net-pen. The lower mesh panel can usually be used as a guide when the pen is on a level location, because the lower panel should already be level and even with the ocean bottom. Continue securing the top panel, as described, until the net-pen is completed. Additional lengths of extension panel that need to be added are "spliced" in at the side edges first, then secured to the bottom panel.

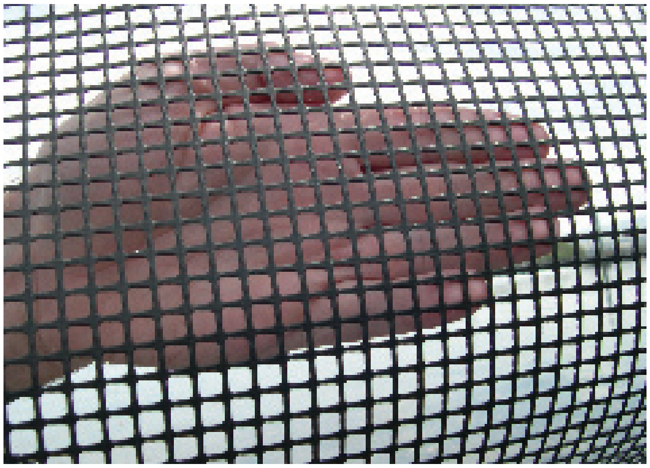
Add more ties to bind the layers of mesh.

Finishing up

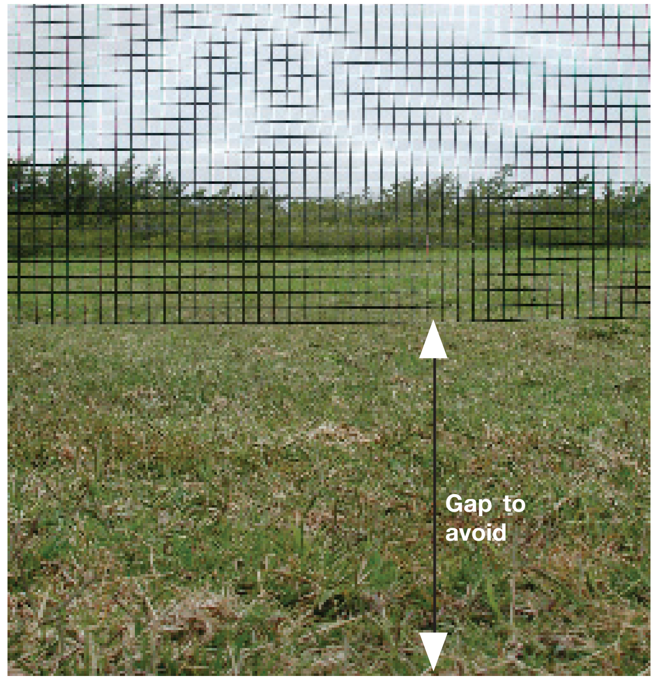
Initially, cable ties are used to loosely secure the shape of the net-pen and all its parts. Follow the initial tying with additional cable ties, making sure there are no gaps. When the water is clear, check the pen's "attachment" to the ocean floor by diving to see if there are any gaps between the mesh panel and the ocean bottom. These gaps can be easily closed with small stones and sand. Perform all checks well in advance of stocking the net-pen. It is essential to re-check the net-pen for holes, broken ties, etc., every few days, because fish can escape quickly through holes in the net-pen.

Shown here are two mesh panels being secured laterally. A two-person cable-tying team is needed to poke the ties through the wire mesh to wrap them around the T-posts. Use ties that are at least 7 inches long. Each section, from one post to the next, will need between 20 and 40 cable ties. This will depend on mesh size, pen height, a good top-to-bottom panel seal, and desired strength. It is most economical to purchase ties in packs of 250–500 per package. Heavy-duty 11-inch ties in black (UV resistant) are preferred for post tying, because the ties connect both post and mesh at the same time. 7–8-inch UV-resistant cable ties are used to secure panels to one another where no post is available. Expect to use three to four times as many small ties as big ones. A 300-foot circumference pond needs about 1000 ties, 300 of the 11-inch ties and 700 of the shorter ties. Always have plenty of extra ties in both sizes for general maintenance and in case of emergencies.

Here a cable tie is being pushed through for connection. At this depth underwater, connecting is done mostly by feel because, even with a mask, the water will be turbid from the work activity. Bending the tie in half will keep it in a "U" shape while poking it through. Attach the ties as close to the post as possible from both sides.



Once the outer mesh is installed, an inner mesh needs to be installed in the same manner using 7-inch cable ties. Appropriate mesh sizes range from ¼ to 1 inch, depending on the size of the animals to be contained. Begin with a ¼-inch inner mesh material for fry (fish ½–1 inch long) then change to a ½-inch or ¾-inch mesh for fingerlings (fish 3–4 inches long). Final grow-out should be conducted in net-pen material that is 1-inch mesh, assuming it is appropriate for the species. The interior PVC netting will need to be changed periodically. As the fish grow, they produce more organic matter, which accumulates more rapidly on the tighter-weaved netting material. Changing the mesh size allows more water filtration, decreases the potential for biofouling, and promotes better water conditions.



The final net-pen placement should be carefully surveyed for flatness and any obstructions in the path of its edge. It is common to overlook dips or depressions along the bottom edge of the mesh panel. Try to avoid this as much as possible. If a gap is unavoidable, fill it with small rocks and sand. The fill should cover the gap and more, along its length and beyond its sides, and be mounded above the depression itself. These spots need to be checked often to ensure the fill does not wash away.

Net-pens at ʻUalapuʻe: rectangular pens in the foreground; two circular pens in the background.

Seedstock acquisition and pond seeding

Cultured seedstock may be available from aquaculture facilities such as the Oceanic Institute at Makapuʻu on Oʻahu, the Natural Energy Laboratory in Kona, or the state's Anuenue Fisheries Research Center in Honolulu. The fry stock should be about ½–1 inch long at a minimum. Researchers at Oceanic Institute have always experienced better transfer and survival rates with larger fish.

Animals are boxed, transported in insulated containers, and transferred from their source to neighboring islands via air cargo. A small truck and trailer takes shipments to selected fishponds for acclimation and stocking. Initially, between 10,000 and 15,000 fry can be stocked into a nursery pen system, then transferred to larger-mesh pens as they grow.

Natural recruitment, or collecting fry from the wild, is economical but must be done with a collection permit from the Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Aquaculture Development Program. Mullet fry can be found around brackish water riverbeds and estuaries from February through May. Milkfish fry occur in late summer to fall. Equipment for fry collecting includes ⅛-inch seine nets, ⅛-inch mesh throw nets, scoop nets, a small battery-powered aerator, and 5-gallon buckets (see the chapter on *Equipment for Pond Operations*). Experienced fishpond operators claim that it is easier to capture 100 1-inch fry than one 3-inch fingerling. The larger fish tend not to school like the younger fry, making it more difficult and time consuming to capture enough to stock a net-pen.

Limu culture should be included in the production strategy both for water quality benefits and economic return. Limu seedstock has been developed and can obtained from Ke Kua ʻAina Hanauna Hou at Pūkoʻo on Molokaʻi. Limu "patches" of sporulated stones can be set up inside and outside pen enclosures. Production areas can be visually monitored for growth (see the chapter on *Limu Production*).

Fish food

High-protein fish foods manufactured by companies such as Moore-Clark are excellent for fish, but these feeds are expensive and may be difficult to obtain. Rangen and

Limu seedstock on mesh “pillow.”

Fish stock finglerings in bag.

Purina are proven brands of fish food that are generally available at reasonable prices. Fish food with high soy or grain meal content is not recommended. We have found that the grain feeds, although cheaper, are less nutritious. In some cases we also experienced the feed going rancid quicker in Hawai‘i’s humid climate. It is not recommended to ever give fish food that you think may be going rancid.

Purina Trout and Salmon Starter, #00 to #3 size pellet, can be fed to fry and fingerlings. Purina 350 floating feed can be used for feeding larger fish to market size. Newly stocked fry can be fed twice a day, with the daily feed ration weighing five percent of their total body weight, as determined at the previous monthly sampling. Determine this by taking a few random samples of the animals, weighing each sample, and dividing by the number of animals in the sample; take the average of the samples measured. Multiply the average weight per animal by the estimated total number of animals in the culture pen to obtain the “total standing biomass” (TSB). The TSB is then multiplied by 0.05 to give a daily feed amount which is divided by the number of feedings. Re-check this monthly during sampling activities. For growing out fish, feed once to twice a day at three percent of their total body weight.

It is important to note that these feeding rates are for a closed system, without the benefits of supplemental foods. Fish cultured in net-pens often obtain a large amount of supplemental foods, such as micro- or macro-phytoplankton and zooplankton, from the pond bottom substrate and the net-pen fenceline. Observations of fish shape, size, and condition, and periodic weight sampling, allow the operator to adjust to lower feed amounts through the grow-out phase. This saves money and helps creat less organic waste.

Data recording

The net-pen’s production activities should be recorded in two separate log books. One log should be designated specifically for recording water quality, feeding, weather conditions, and animal observations. A second log should record the day’s work, such as maintenance and repair, sampling, predator control, fish transfer, limu harvest, etc.

Basic water quality parameters to monitor twice daily are dissolved oxygen, tide, temperature, and water salinity. Other water quality parameters such as ammonia, nitrate, nitrite, and pH should be monitored weekly using a test kit designed for salt-water aquaculture farmers. This type of test kit can be purchased for under $50 and includes several months worth of testing materials.

Animals should be sampled monthly for growth and general health. Feed rates can be adjusted based on size, weight, and total standing biomass calculations.

Data and recordkeeping become an important management tool for the pond operator and should indicate seasonal, biological, or cyclical trends. These trends, once determined, allow the operator to make production decisions that may impact business profitability, fish culture management, and operational methods.

Optimizing Pond Health

The biological environment

To better understand how to optimize pond health in active fishponds, it is useful to study the aquaculture methods developed by the ancient Hawaiians. Their fishpond site choice was often based on freshwater input, as the brackish water environment caused by mixing fresh and ocean water created a natural fish nursery environment. The use of mullet and milkfish, species adapted to brakish conditions, as the main cultured species was an efficient way to maximize productivity. The naturally occurring currents and seasonal tides of the location defined times for stock recruitment or harvesting.

The complex aquatic food web begins with a primary chain of productivity that transforms organic and inorganic detritus and other "nutrients" into some form of plankton (i.e., phytoplankton, unicellular algae, microbenthos, etc.). This primary productivity depends on sunlight and the photosynthetic process for its growth. Green and blue-green filamentous algae found in Hawaiian fishponds are also light-limited. Turbidity and light play an important part in this growth, which is the base for the food chain and also determines the productivity of fish that are feeding on the algae.

Animal plankton (zooplankton) is also another key factor adding to the pond biomass. Zooplankton feed on bacteria or phytoplankton, and in turn are fed upon by larger fish and crustaceans. This food chain goes through many intermediate steps as it progresses until it reaches humans.

Because the species raised in ancient Hawaiian fishponds were mostly autotrophic (depending on self-nourishment) their productivity depended on what was happening at the base of the food chain—plankton and algae. And because fishponds are estuary-like, they have high yields of primary productivity. The traditional Hawaiian fishpond operators were able to efficiently exploit this high productivity by "cultivating" milkfish and mullet, both herbivorous fishes. This was how the traditional fishpond operation allowed a consistent yield of fish with little or no need for fertilization or supplemental feeds.

Food web and food pyramids

Although a traditional fishpond may have had a diversity of species, the dominate species of fish were milkfish and mullet. These fish are herbivores, feeding on phytoplankton. Other fish, such as barracuda, a predator, depend for survival on a more complex web of interactions among other species—barracuda eat lizardfish that eat shrimp that eat polychaete worms that eat phytoplankton. This type of web has much interdependency and less independence. Herbivores, on the other hand, have only one step from the primary productivity of algae.

Using this subsystem, traditional Hawaiian fishponds made a great leap in production yield by eliminating biomass inefficiency and excess links in the food web in order to seek their end products. In a food pyramid there is a normal energy loss of 90 percent for respiration and body functions, which leaves only 10 percent for the next level. Therefore, a system using milkfish and mullet, which feed at the bottom of the food chain, enabled more productivity of the food pyramid (i.e., 1000 pounds of algae and detritus makes 100 pounds of herbivorous fish, which makes 10 pounds of humans).

Therefore, the greatest yield in pounds of fish is harvested from the herbivorous links of the food chain. Early Hawaiians exploited this and knew to increase production of microbenthos and larger benthic algae by applying organic fertilizers (i.e., greenery or starch foods) and making shallow ponds for maximum light penetration. This system, applied through practical conservation and management techniques, set Hawaiians and their fishponds apart as early pioneers of aquaculture.

Traditional water quality environment

Water quality in traditional Hawaiian fishponds was somewhat static, in that there was little fluctuation. In a totally controlled monoculture system, most parameters of importance, i.e., dissolved oxygen, water exchanges, temperature, nitrogen, etc., are monitored and manipulated to some degree to meet the desired conditions for the species cultured for harvest. By comparison, a traditional Hawaiian fishpond had very little room for water quality control and manipulation, which forced traditional aquaculturists to better understand the "total system." This big-picture approach looked at

- the interrelationship of species cultured in the pond
- the cultured species' life cycle in relation to seasons, moon phases, and other animals
- water flow and exchanges resulting from moon phases and changes in tides
- seasonal recruitment of new stocking material and harvests timed to moon phases
- polyculture of complementary and beneficial species for pond health and fish food production.

Today, as modern pioneers of this traditional art form, we have the ability to better understand and traditionally culture fish using modern technology and sciences.

The basics

The basic life needs of any cultured species, plant or animal, need to be available in the environment they live in. Therefore, the quality of water and the understanding of various physical and biological properties or parameters is a primary concern. These properties must be tested and measured regularly to assist the aquaculturist in maintaining a healthy growth environment for the cultured species. In addition, any physical or biological changes that happen in the culture will directly affect the cultured species and the system itself, as they are interconnected via the water interface.

Disclaimer: The aquaculture instruments identified in the section *Equipment for Pond Operations* are the instruments used with our project, but they are not the only instruments available. Ours choices were based in part on economic considerations; some high-priced, multi-parameter testing meters cost as much as a new car.

Physical and biological components

- ***gases:*** oxygen (O_2), carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulfide (H_2SO_4) and methane (CH_4)
- ***minerals:*** calcium (Ca), manganese (Mn), sodium (Na), potassium (K), magnesium (Mg), aluminum (Al), zinc (Zn), copper (Cu), molybdenum (Mo), cobalt (Co), carbon (C), phosphorus (P), and others
- ***soluble organic compounds:*** sugars, fatty acids, humic acids, vitamins, amino acids, peptides, proteins, urea, plant pigments, and others
- ***suspended inorganic materials:*** suspended colloidal clays and coarse suspensions of soil particles
- ***suspended organic materials:*** living phytoplankton, zooplankton, fungi, bacteria, and colloidal or suspended remains of organisms in stages of decay.

Current water quality environment

There are dozens of biological and physical factors ("parameters") that can be sampled and monitored in a fishpond. Of these, and in general, most fishpond monitoring should look at the most "impactful" parameters. It would be beneficial in the initial start-up year to regularly test as many parameters as possible and to develop site-specific baseline data and records of the fishpond over a production season or year. If the fishpond is the receptacle of industrial or urban upland run-off, being able to test for fluorocarbons, pesticides, agricultural run-off, etc., is important.

The most important parameters to monitor regularly, as often as daily, are temperature, dissolved oxygen, salinity, and pH; the ions ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-) can be checked weekly. Changes in these parameters happen quickly and will impact the system quickly due to the interrelationships among them. For instance, high oxygen and temperature will cause more respiration by animals, which then cause chemical changes in the system that impact the fish. Less important water parameters include hardness, phosphates, carbon, suspended solids, and dissolved solids.

For each parameter there is an *optimum level* for the cultured species to thrive. *Range of tolerance* is the *limit* within which the cultured species can survive. *Toxic* levels are lethal. Note that not all species have the same culture needs and ranges. If a polyculture situation is desired, the culture parameters of the primary species should be cross-checked and noted.

Temperature is one of the prime factors affecting growth. Each species has a specific temperature range it can tolerate and an optimum range for growth. For efficient conversion of food to fish weight, water temperature must be kept as close to optimum as possible. Water temperature affects feeding, reproduction, immunity, and metabolic rates in aquatic animals.

Factors that affect water temperature include: ambient air temperature, direct sunlight, depth of water,

Temperature Conversion	
°F = (9/5 °C) + 32	°C = 5/9 (°F – 32)

circulation and currents. Abrupt changes in temperature can stress fish and even result in disease problems. It is important to monitor and record temperature on a regular basis, usually first thing in the morning and again in the afternoon. Temperature can be measured using a thermometer; either Celsius or Fahrenheit will do. To prevent breakage, purchase a thermometer with an encased body. Also, many dissolved oxygen instruments already have a temperature function.

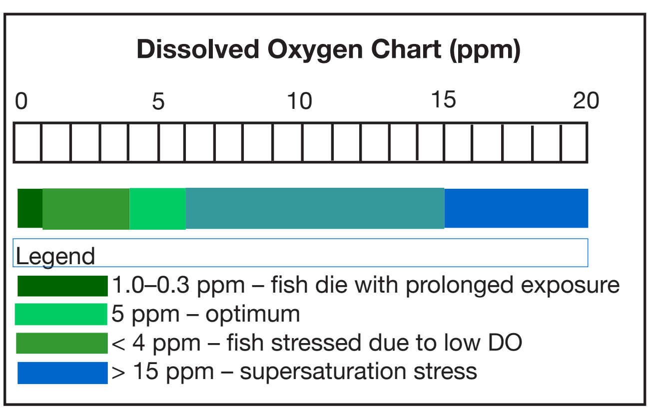
Dissolved oxygen (DO) is the amount of gaseous oxygen dissolved in water and is measured in milligrams per liter (mg/l) or parts per million (ppm). All fish need oxygen to survive, and monitoring this parameter is the most important daily activity a pond operator should perform. The DO meter is any pond operator's best friend. These instruments cost from $400 upward.

A DO concentration of 5 ppm is considered optimum. Fish begin to experience stress when DO levels fall below 4 ppm, and they die after prolonged exposure to levels of 1 to 0.3 ppm. Under certain conditions water can become supersaturated with oxygen, above 15 ppm, and this also will cause stress in fish.

Temperature and salinity both affect the oxygen-holding capacity in water. As temperature and salinity of the water increases, the amount of available D.O. decreases. Other factors influencing DO levels include stocking density, weather and climate, fish activity (feeding and respiration), photosynthesis by algae, run-off, decomposing organic material, etc.

Oxygen comes into the water when molecules of oxygen (O_2) gas from the atmosphere diffuse into the water, and through photosynthesis. In outdoor culture systems DO can fluctuate greatly, because during the day sunlight causes photosynthesis, and at night O_2 is used for respiration. Signs of low DO levels affecting fish include

- sluggish movement
- not eating
- gasping for breath
- grouped near water inlet
- slow growth
- disease and parasite problems.



Salinity is the concentration of dissolved sodium chloride (NaCl) measured as grams (g) of salt per kilogram (1000 g) of water or parts per thousand ($^{0}/_{00}$). Pure seawater in Hawaii varies from 32 to 34 ppt, although some systems can become hyper saline at 40 ppt. A refractometer is the simplest and quickest method to measured salinity.

pH is a measure of the acidity or alkalinity of the water, expressed on a scale of 1 to 14. It is based on the number of active hydrogen ions, (H^+) in solution. A pH of 7.0 is neutral, values below 7 indicate acidity, and values above 7 indicate alkalinity. Pure water is neutral, tap water is 7.7–8, clean rainwater is about 5.6, "acid rain" is 3.5–5.5. pH is an important parameter affecting several key changes in chemical processes and parameters, such as the nitrogen cycle. Most fish survive over a pH range between 6 and 10, but each species has its ideal pH level for optimum growth and good health.

pH can be measured quickly and precisely using a handheld, battery-powered pH meter. Less expensive but less accurate measurements can be attained using litmus paper. Other methods include pH test kits (See section on *Equipment for Pond Operations*).

Ammonia (NH_4) is a waste product of protein metabolism or breakdown by aquatic animals, but it is also naturally present in small amounts in water bodies. In certain forms and concentrations it can be toxic and can increase in proportion to pH and/or temperature. It can be measured with a basic saltwater chemical test kit.

Nitrite (NO_2) is the basis of organic matter decomposition by nitrifying bacteria oxidizing ammonia. Nitrite levels above 0.55 ppm can be toxic to "oxygen-to-blood transfer" processes in fish. Nitrite levels may also increase due to over-feeding, high fish density, phytoplankton "crashes," etc. Nitrite can be measured with a basic saltwater chemical test kit.

Nitrate (NO_3) is the final product in the nitrification process and does not typically have any toxic effect on culture animals, but it will influence plant growth by acting as a fertilizer. It can be measured with a basic saltwater chemical test kit.

Turbidity is a term used to describe suspended solids, such as silt. These small particles prevent sunlight from reaching phytoplankton that produces oxygen and food. Wind, bottom-feeders, run-off, inorganic silt, phytoplankton, erosion, rain, etc. can cause turbidity. Turbidity can be measured with a turbidity meter, but the more common and cheaper method is using a secchi disk. The depth of the water surface to the point in which the disk is not visible is measured in cm from the surface. A measure of 80 cm is not very turbid whereas a measure of 15 cm and less is turbid.

Important Things to Remember

Records and data keeping become an important management tool for the pond operator and will indicate seasonal, biological or cyclical trends. These trends, once determined, allows the operator to forecast production decisions that may impact business profitability, culture management and operational methods. Keep daily records of the day's work, such as maintenance and repairs, sampling, predator control, fish transfer, limu harvest, etc. A daily log identifies routine tasks, such as water quality, feeding, weather conditions, and animal observations. Basic water quality parameters to monitor twice daily are DO, tide, temperature, and salinity.

More specific water quality parameters such as ammonia, nitrate, nitrite, and pH should be monitored weekly using an aquaculture farmer's saltwater test kit. This type of test kit can be purchased for under $50 and allows several months' worth of testing.

Animals should be sampled monthly for growth and general health. Feeding rates will be adjusted based on size, weight and total standing biomass calculations, which are reviewed by analyzing data. At the end of this section are four samples of logs and worksheets that can be easily duplicated and used to keep records for managing a fishpond.

Summary

Over time and with diligent recordkeeping, a fishpond operator will see that conditions in a fishpond are somewhat constant and predictable, much like the coastal conditions outside of it. Natural seasonal changes, as well as tide and moon phases, provide cycles for production management. Unpredictable storm weather or other climatic phenomena are less probable and are not a good gauge for anything other than crisis and catastrophe planning.

It is important to monitor the water quality, as it affects the fish. It will be valuable also to integrate other "natural mechanisms" that provide clues and insights about pond conditions. Ancient Hawaiians had no instrumentation, yet they produced a sufficient food supply over centuries using similar systems and culture methods.

Step back and take a big-picture approach to connect relationships between instruments, production animals, observed daily fishpond conditions, and your five senses. Over time, and with keen observation, these rhythms and patterns will become more obvious and expected. You will find less need for the rigors of daily water quality collecting and will "depend on your fish or the weather to tell you how things are."

Suggested monthly growth and feeding log: stocking and other information

	1	2	3	4	5	6	7	8
Stocking date								
No. fish stocked								
Species								
Where obtained								
Sample no.								
Total weight								
Average weight								
% body weight gained[1]								
Average weight								
Length:weight ratio								
Type of feed								
Total weekly feed[2]								
Average wt. feed daily[2]								

[1][gain / previous weight] x 100; [2]kg or lb

Overall system grid

	Pen 1	Pen 2	Pen 3	Pen 4	Control	Traditional
Pond size						
Production						
Harvest size						
Market price						
Production cycle						
No. fish harvested						
Culture species						
Interest rate						
Fish marketing style						
Death loss						
Labor needed						
Fingerling size						
No. fish stocked						
No. fingerlings needed						
Feed conversion est.						
Feed amount:						
Feed cost						

Record of harvest sample

Record of harvest

Date of harvest: ______________________________

Start time of harvest: ______________________________

Method of harvest: ______________________________

Duration of harvest: ______________________________

Number of fish harvested ______________________________

Condition of fish ______________________________

Total weight of fish harvested ______________________________

Sold to ______________________________

Sold for $/lb ______________________________

Total weight sold ______________________________

Number and weight of fish given away, if any ______________________________

Number and weight of fish used for marketing/promotions ______________________________

Notes for future harvest: ______________________________

Notes and other comments:

Suggested weekly routine (WQ = water quality)

	Monday	Tuesday	Wednesday	Thursday	Friday	Sat./Sun.
8:00	Management meeting	Feed, check WQ	Feed, check WQ	Feed, check WQ	Feed, check WQ	Weekend feeding duty
8:30		Limu loa	Production systems	Fish production	Fish production or market	Check WQ
9:00	Feed, check WQ					
9:30						
10:00						
10:30						
11:00	LUNCH BREAK					
11:30						
12:00	Limu loa	Limu loa	Production systems	Fish production	Fish production	
12:30						
1:00		Market limu				
1:30						
2:00						
2:30						
3:00	Clean beach and nursery	Clean-up, put away supplies	Clean beach and nursery	Clean-up, put away supplies	Clean beach and nursery	Weekend feeding duty
3:30						
4:00						
4:30	Check WQ	Check WQ	Check WQ	Check WQ	Check WQ	Check WQ

Troubleshooting Fish Culture Problems

The working fishpond

One of the biggest challenges for any fishpond operation is to identify a problem and be able to remedy it. Preferably, the fishpond operator will be proactive and avoid as many problems as possible. Unlike land-based agriculture, aquaculture occurs under water, making it difficult to regularly "inspect" production, as would be possible on land. For example, trade winds stir up particulate matter from the pond floor, and activities such harvesting or cleaning also create turbidity that makes the pond water less clear. Add to this the typical shy nature of fish, and observation for any purpose becomes difficult.

Several natural opportunities aid observation of the health of the operation. These opportunities occur

- under weather conditions with no wind
- in the early morning before the daily wind starts
- during extremely low tides
- after a phytoplankton "crash" (die-off).

By far the best and most consistent times to observe fish are when they feed. They need to eat, are conditioned to a feeding schedule, and should readily come to the surface at feeding times.

If there is no supplemental feeding with a prepared pelleted feed, then much of the feeding observed will not take place. If you are not going to feed, a periodic fish sampling will show how well or fast the animals are growing. Observation can be done during sampling, as well as when there are sunny, windless days. Also, polarized sunglasses can greatly enhance visibility of fish from above the water surface.

As an observation method, sampling fish has some limitations. A sample group represents a small number of the total, and it may not truly be representative of the conditions of the population. The act of sampling (i.e., handling) is very stressful to the fish and may lead to diseases being contracted or spread. Therefore, it is best to learn how to make close observations and to start recognizing behavior and changes at feeding times. In general, these changes in behavior are indicators of something else happening to the animals.

Changes to the fishpond's environment and water quality, along with weather conditions, are usually considered external impacts. The animals' health is the next obvious condition to monitor. Lastly, there are a number of other ways to manage potential production losses, including checking for the following occurrences:

- feed that is rancid or moldy, not fresh
- predators in the pond, such as barracuda, eels, and crabs
- fencelines with holes or split seams
- evidence of poaching, which can be detected by checking for bruises on the fish caused when escaping capture nets.

Behavioral observations

Observable indicators of healthy feeding behavior include fish that

- "swarm" close to the feed site
- "hit the surface" as soon as feed is tossed
- actively feed together as a school (group)
- display a feeding pattern that is consistent over time.

Observed indicators of animals under stress or problems include fish that are

- not feeding at all
- eating less than the normal amount
- dead or separated from the larger group
- "gulping air" at the surface
- showing discoloration or spots on their scales
- swimming erratically and quickly (predators inside pen)
- display other non-typical behaviors.

These are general indicators of something wrong within the system. In the beginning, problem-solving will be complex and will need to be addressed as soon as possible. In general, allowing a problem to occur for too long will result in catastrophe. In your log book, write down your analysis of the problem and list solutions or reasons for solving your problem. Don't hesitate to consult someone knowledgeable—your stock may depend on it.

Active swarming indicates a healthy feeding population.

Over time, and with good recordkeeping, problems will be easier to identify. The following sections give some common answers to typical situations. This is by no means a comprehensive discussion, as these issues are complex in nature and there are site-specific, animal-specific, and weather-specific conditions that must also be accounted for.

Non-instrumental observations

If there has been a period of heavily overcast and windless days, phytoplankton production will be reduced, creating a situation of low dissolved oxygen (DO) levels. If there are cloudless days for some time without wind, phytoplankton may "crash," consuming oxygen in the process. This may be temporary but is stressful nonetheless. If this occurs, stop feeding, wait for the tide to bring in new water, and avoid DO levels below 3 ppm.

Fishpond operators will find that the animals themselves provide the best information on how they feel and what they want. This intimate connection between operator and animal will be the best relationship to develop. Again, for example, fish that do not eat when they normally would suggests an oxygen problem. Fish that are "gulping for air" early in the morning suggest critically low DO levels. If this occurs, do not feed, check the tide charts for the next high tide for water exchange, and monitor the DO level.

Diseases and parasites are other problem areas that may be detected during feeding. Skin discolorations, spots, fin erosion, erratic swimming, or other strange behaviors are usually signs of disease or parasites. A few dead fish each day usually indicates some type of slowly spreading disease or parasite problem. Progressively more dead fish each day is a sign of a very serious disease problem. Dying fish or fish with suspected diseases or parasites should be diagnosed, or sent for diagnosis, immediately.

Hawaiʻi is supportive of aquaculture and the state has facilities to assist with diagnostics through its state-run fisheries, disease diagnostics lab, and University of Hawaiʻi aquaculture extension programs. Contact your nearest aquaculture extension office or state fisheries specialist for information on the proper way to package and ship fish samples. Take a live sample of fish and a water sample to the nearest fish disease diagnostic lab and have it tested. Besides diagnosing the problem, the extension agents may be able to suggest treatments for your problem. In some cases, as with internal diseases, a medicated feed could be purchased and fed to the animals.

Water quality problems

Excessive nutrients in the water, possibly caused by too much feed, can create an unhealthy or toxic water quality situation in your culture system. This is usually identified by visual changes in the water's color. Rapid color changes, surface scum, intense color, odors, and extreme weed growth are associated with water quality problems. These conditions are symptomatic of excessive nutrients from feed, sediment in runoff from the land, or overstocking. Monitor water quality and try to keep readings of nitrogen (ammonia and nitrate) at acceptable water quality parameters. If need be, reduce feeding, transfer overstocked fish to another pen (if possible), and continue to monitor water quality. Be careful not to transfer sick fish.

Strong odors are an indicator of decaying plant material, which consumes oxygen as part of the decomposition process. Other than reducing feeding, adding oxygen to the system may be warranted. When aeration is extremely necessary but not readily available, a small outboard motor can be used to create propeller aeration. Another solution is introducing new water via tidal exchanges, with the highest exchanges occurring with the new and full moons.

Dissolved oxygen stress is the primary cause for fish culture problems. Make it a habit to measure DO levels twice a day. Testing first thing in the morning measures DO availability without photosynthesis. Testing again at

Scrubbing netpens reduces biofouling.

Scum growth on the pond walls indicates water quality problems.

the end of the day, before sunset, can provide an indication of the level of DO as a result of photosynthesis.

The critical concern for any fishpond operator will be to recognize and prevent potential problems before they arise. This will happen over time and with familiarity with the site and culture systems. In general, it will take a full year of observation, because every season has its own characteristics. Learning this will assist in formulating culture schedules based on the animals' spawning, growing, and maturation rates.

Other problems and observations

Biofouling is a common cage problem. Biofouling is the growth of algae and bryozoans (soft-bodied, jelly-like animals) on the sides of the mesh. These creatures restrict water flow through the netpen, thereby causing water quality problems, including low dissolved oxygen. Periodic scrubbing may be necessary to remove biofouling. Scrubbing should be done at high tide when there is higher DO.

Regular observation is needed. It is always a good practice to dive or snorkel in the netpen once or twice a week, more if necessary. Keep good records, as they often can provide clues leading to solutions to problems. Learn from your mistakes, and don't hesitate to get help when you don't know the answer.

Various water quality monitoring instruments and test kits.

Limu Production

Limu (edible seaweed) can be cultured in the ocean, in a fishpond, or in a netpen. The typical Hawaiian fishpond is capable of sustaining many types of edible and saleable animal and plant species, often at the same time. Many fishponds in Hawaiʻi may already be home to various limu species. Limu production can be a profitable enterprise when cultured in netpens along with fish. In general, the limu in a limu-fish system uses the nutrients from unconsumed fish feed as fertilizer. At the same time, the limu consumes much of the nitrogen that is excreted when the fish discharge waste products. As a result, the entire limu–fish production system is "cleaner" than a system with only fish.

Ogo—harvested, cleaned, weighed, and bagged to be sold at a local market.

Basic requirements for limu production

Biological and physical parameters vary according to the species cultured, but the following general conditions and practices should help to grow limu successfully:

- observe areas where limu is already found
- salinity varies, so know your species and their salinity ranges
- have a source of nitrogen, either added ammonia or from land runoff
- there should be a consistent tidal exchange for sufficient nutrient supply, oxygen, and carbon dioxide
- the water should be free of pollution and excessive fresh water (in the case of ogo, *Gracilaria*)
- have a clean water supply
- ideal temperature of 81–86°F and salinity of 30–35 parts per thousand
- water should be moving rather than stagnant
- a rocky, coral bed substrate is best for seed attachment
- have a water depth not less than 18 inches at the lowest tide to prevent direct exposure to air.

To find out if a particular area is suitable for limu production it is important to

- do water quality tests to understand daily and seasonal variables; begin testing twice a day (early morning and late afternoon) over a period of two weeks followed by several times a week for several months
- use a mask and snorkel or diving gear to get familiar with the ocean bottom where the limu production might take place; look for other competing species or animals that might eat the limu.
- scout a number of locations to find the best site within a fishpond or net-pen.

Establishing growth tests

Once the basic biological and physical needs of the desired limu species have been met, it is time to run a few small-scale production tests. It is important to create and provide various growing media for spores to attach and new plants to take hold. Microscopic cystocarps (seeds) can attach to almost anything, but a secure substrate is best. Substrates that have been tried include enclosed coral plastic mesh "pillows," wire mesh, floating PVC trays, floating baskets, and stones. The best success so far has been with fist-sized stones.

Like many land plants, limu is a seasonal grower in the wild. The best growth occurs during the spring through fall months when the days are long and water temperatures warm. "Seeded" stones (pieces of rock that have a little piece of limu firmly attached) are collected from lagoons and transferred into fishponds and net-pens. It should not take more than 100 "seeded" limu

A basket of stones ready to be "seeded."

A production rack brought to the surface for harvest.

stones to start a limu production bed if the water quality is right. Some limu varieties will develop sexually and seed the netpen continuously throughout the growing season, while other limu will need to be restocked with new seeded stones.

The business of limu

While fish production is typically the primary focus for a fishpond and netpen system, limu sales can generate cash flow in a short period of time. This is due to limu's fast growing, grass-like characteristics. In season, limu can limit its own growth if left to grow too long, and, like grass, it grows better when periodically cut for harvest. It is possible to be marketing limu weekly within the first production season and every season thereafter if the system is maintained in optimal condition.

The concept of growing limu is similar to growing a land vegetable crop. The initial setup of the system and its resources will take some effort. There will be on-going maintenance in terms of weekly weeding of unwanted limu and checking limu areas for any problems. As the limu starts to become harvestable, gathering and preparing the product for market becomes one of the most labor-intensive parts of the operation. Many hours will be spent on processing and picking out unwanted types of limu that grow within the main crop. Expect to market weekly, or if the limu is a slow grower, biweekly.

Hints for seaweed production in a fishpond or net-pen

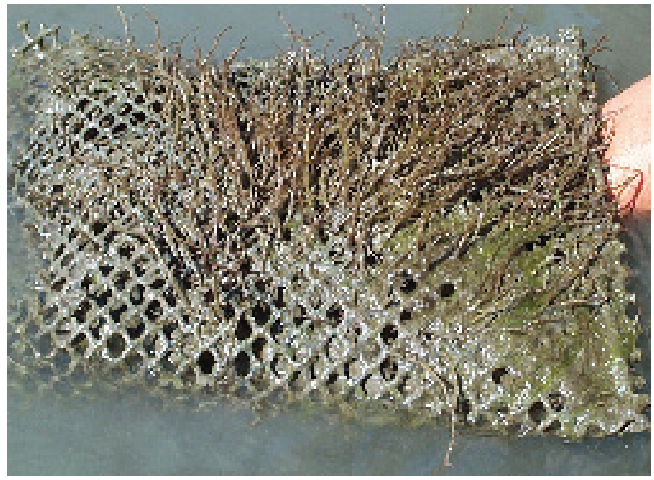
- Study the subject and make a plan.
- Consider the site-specific parameters of the area where you plan to produce.
- Do a physical and biological assessment.
- Keep your production plan more extensive (as opposed to intensive) to reduce stress and impact on the pond ecosystem and environment.
- Keep accurate production and sales logs and records to assist in decision-making and problem-solving.

Limu on Molokaʻi

Molokaʻi is known for its *Gracilaria parvispora*. To many consumers it is known as limu ogo or limu loa. This limu, along with many others, grows well along the coastal areas of Molokaʻi. In many fishponds, this limu is not only able to grow but can actually flourish.

The ʻUalapuʻe fishpond project on Molokaʻi is

An ogo spore, attached to a rock, sends out its first branches.



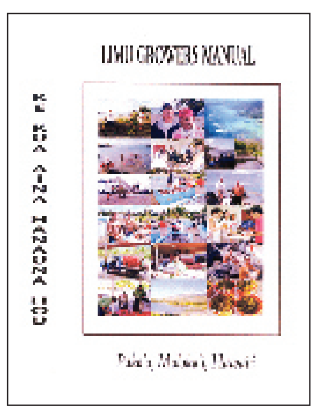
Ogo on a plastic mesh "pillow."

culturing two limu, limu loa (*Gracilaria parvispora*) and limu ʻeleʻele (*Enteromorpha* species). Limu loa is already integrated into netpen fish production systems, and limu ʻeleʻele is in commercial research and development.

The Molokaʻi community was very fortunate to have had the support and assistance of Ke Kuaʻaina Hanauna Hou (KKHH), a local limu ogo wholesaler, who has conducted production and market research and encourages and supports backyard growers through training and buy-back initiatives. Their role is to provide the grow-out training and to provide seedstock (seeded stones). The most difficult steps of hatchery, nursery, and maturation are done at their farm. The backyard grower then takes the seeded rocks home to grow out in protected areas such as fishponds and net-pens. KKHH then buys back the final product for resale.

Further reading about limu production

This section is just a primer on limu production. The resources below provide additional information and details.



To order copies, contact:

Ke Kuaʻaina Hanauna Hou
HC-01 Box 741
Kaunakakai, HI 96748-0741

Phone: 808-558-8393
or 808-558-8933
Fax: 808-558-8453

An Outline for Writing a Business Plan for a Fishpond

Revitalizing a fishpond is exciting because the potential impact is significant. Yet without a “road map” to guide the business aspect of the project, it is easy to get lost. While not all revitalization projects will require outside funding, having a business plan can help guide many decisions by illustrating the best choices for uses of limited resources.

The plan helps to organize costs and benefits, risks and rewards, and inputs and outputs so that the potential worthiness of the idea is conceived with a high level of clarity. A business plan is an organized, written document that allows the testing of ideas before the first stone is moved or the first fingerling is placed in the pond. The plan is an inexpensive way to “test the water” of an idea before a lot of effort and expense goes into it. Unfortunately, writing a plan is often not as much fun as getting outdoors and working to see a dream come true, so it requires the pond operators to be diligent and focused on the plan phase for a period of time while putting the ideas down on paper. It is this writing process that reveals the true strengths and weaknesses of an idea, and this is the time to find ways to compensate for any weakness in the grand vision.

Today, business plans are very common and generally have the same format. Of course, the type of business discussed in the plan will provide the plan with its uniqueness. Generally, a business plan contains:

- cover page
- table of contents
- executive summary
- business description
- marketing factors
- management and accountability
- project schedule
- identification of critical risks
- financial information
- conclusion
- appendixes.

This section provides a guide for developing a typical fishpond business plan. Each plan component is followed by the types of information typically included.

Outline of a general fishpond business plan

Cover page

1. Title of project
2. Contact information

Table of contents

1. Index to the business plan sections

Executive summary

Briefly summarize, in short sentences, what is being proposed. Subsequent sections of the business plan will provide more details.

1. What are the objectives or projected outcomes for using the fishpond?
2. Which species will be cultured in the pond? Which production techniques and management methods will be used to culture those species?
3. What and where is the market or markets for the final product? Is there room in the market for the product, and how was this conclusion reached? Is the market sustainable over the long run? What is the competition in the target market?
4. Describe relevant skills and experiences of yourself and the others involved in the venture.
5. Provide a brief description outlining the following:
   a. start-up costs
   b. operational costs
   c. investment capital needs (for start-up and operations)
   d. projected gross revenue and profit for every year for five years
   e. rewards and benefits beyond financial gains.

The introduction

The introduction page “introduces” the business plan to the reader and provides the following information:

1. Introductory statement about what topic the document will cover.
2. Date the document was written.
3. Author of the document.

Business description

1. Describe the fishpond site (use maps, photos, etc.)
   a. Ownership status
   b. Infrastructure (access road, water lines, power, etc.)
   c. Biological, physical, and environmental description of the fishpond
   d. Critical risks with fishpond site (e.g., potential liability issues)
2. Permit status
   a. Necessary permits, licenses, etc. to operate as the business plan describes
3. Facilities and equipment
   a. Status and condition of fishpond
   b. Repairs required and estimated costs
   c. Equipment and supplies and their costs
   d. Other needs as project commences
4. Operations plan
   a. Describe in detail the products that will be cultured, their life cycle, the duration of culture to market size, etc.
   b. Identify the capacity of various production subunits and potential growth of the entire project
   c. Describe the recordkeeping for each species, required feed and care, monitoring and sampling plan, potential problems with the system, and potential remedies
   d. Describe the production schedule for the short and long term
   e. Describe the harvest, postharvest, and processing procedures, and the plans for transport to market
   f. List any remaining aspects of the operations.

Market factors

This section describes the market and marketing aspects of the business plan. This important section should provide the pond operator with the ability to understand the economic potential of the marketplace before actually investing time and money.

1. Describe the product(s) and how they will be marketed
   a. How shipped off-island?
   b. Packaging needed
   c. Wholesale or retail?
   d. Value-added product—smoked, dried, etc.
   e. Off-season availability
2. Describe the market analysis for the products to estimate if it will be a viable undertaking; what are the best, worst, and middle estimates?
3. Mention specific market targets, such as ethnic groups; seasonal variability advantages; and plans for developing new markets or products
4. Describe pricing and estimated sales
5. List specific sales outlets—get a letter of commitment
6. List transportation options and calculate the cost to get products to market

Management and accountability

This section identifies the personnel involved with the project and their duties, responsibilities, and time requirements. Sometimes the pond operators do everything from feeding to selling to banking. In other situations, a spouse, partner, or employee will assist with certain aspects, and those individuals need to be identified, their jobs described, and the time requirements identified.

1. Identify the personnel involved and their relevant qualifications
   a. Pond owner
   b. Pond manager
   c. Others
2. Develop a production schedule and identify responsible person(s) for each task; i.e., who, what, when, where, how, and how long
3. Identify training needs
4. Discuss records and bookkeeping accountability

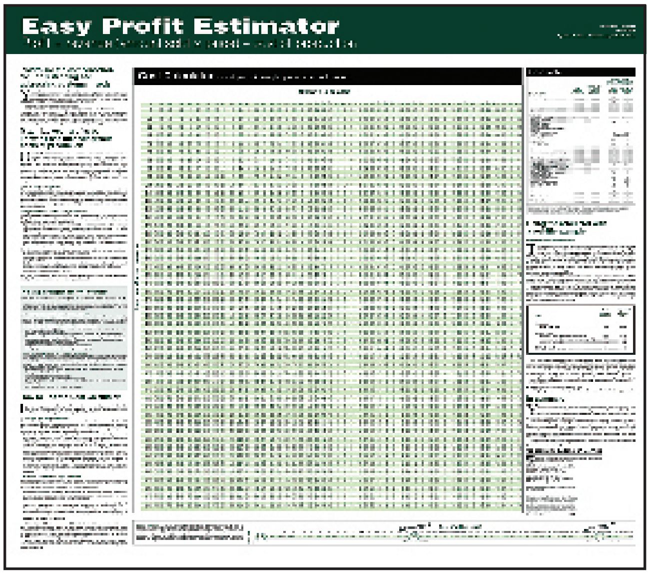
Project schedules

This section looks at the flow of operations from the beginning. It should include a sequential list of tasks and timelines from the starting point to expected completion. A flow or gant chart is sometimes helpful to “see” the whole flow of how the transformation and implementation process will take place.

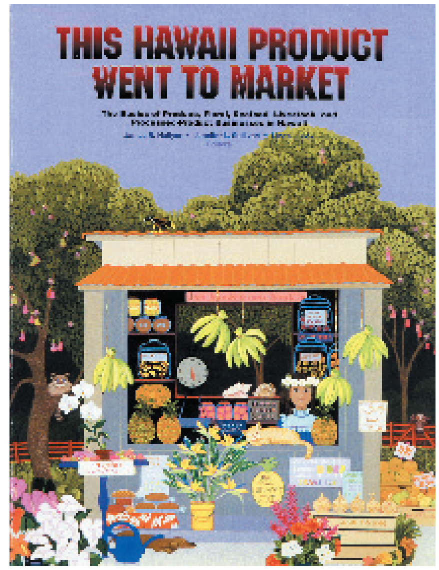
Start-up tasks include the things necessary to start: permits, pond revitalization, acquisition of fry, the preparation of nursery systems for fry, transport of fry to pond, and so forth. Depending on products to be cultured, some steps may be different. Estimated dates of starting and ending should be clearly identified on a calendar, even if these dates are tentative.

Ongoing tasks will be those that are expected to be routinely performed once the start-up tasks are complete. It may be simpler to address these issues in distinct phases. For example, operations, fry/nursery, grow-out, harvesting, and restocking. Again, tasks should be set to timelines. This will be useful in management decision-making.

Some business resources available from UH-CTAHR.



Quick revenue and costs estimates can be made using this handy poster, *Easy Profit Estimator*.



For more guidance on business plans and help with some of the content needed for them, consult *This Hawaii Product Went to Market*.

Identification of critical risks

This section identifies critical risks that may go wrong and mitigation measures, if any, to remedy the situation. Probable risks factors include weather conditions, disease, vandalism, changes in the market, new competition, etc. Describe, as best as possible, how to address these risks and minimize production losses.

Financial information

This is an important section because it specifies the amount of investment someone is willing to make and predicts whether and when a profit will be realized at some point in the future.

1. Forecast of production—this section identifies the product in terms of amounts produced and sold and the timing of such activities.
2. Capital costs—includes all cost factors involved in the proposed plan, such items as materials and supplies, permits or licenses, processing, packaging, transport, marketing, labor, salaries, etc.
3. Pro forma—describes the ability to seek a profit, minus all costs. This should be developed for a 3- to 5-year projection. Included in this section will be the dscription of revenue generation—assumed yield, price per pound, etc. Costs of production will be listed under expenses and should include items such as construction, supplies, office, equipment, maintenance, marketing, general excise tax, land taxes, permits and fees, etc. The pro forma will identify bottom-line profitability based on expenses, revenues, and net income.
4. Financial need—from the pro forma and other considerations, the costs for this operation will surface, allowing identification of the level of financing needed to initiate and potentially complete the business plan. This need will be listed under capital costs and working capital.

The summary

The summary is a brief analysis of what the business plan entails. If done well, the business plan acts as a justification of whether the pond operator should proceed or not, and why. Some attention should be paid to listing the qualifying factors indicating why this is a prudent undertaking.

Appendices

Appendices include any additional information to promote the business plan, especially if one is seeking outside financial assistance. Included in this section are letters of interest, resumes, news reports, market studies, photos, diagrams, market commitments, etc.

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Economics of Revitalizing Hawaiian Fishpond Production

Kent Fleming, Graydon Keala, and William Monahan

Fishpond construction in Hawai‘i started about 1,000 years ago and reached its zenith in the early 19th century. The ravages of great waves and storms combined with the decline of the native population left most of the ancient ponds unused by the end of the 19th century. Today, however, there is an opportunity to revitalize these ponds and perhaps to make them productive, profitable, and culturally rewarding once again. Fishpond production has the potential to be the largest component of Hawaiian aquaculture. We describe here an economic model of fishpond production. The model shows fishpond aquaculture to be profitable in some circumstances.

Archeological and historical evidence suggests that Hawaiian fishponds were constructed as early as AD 1000 and continued to be built until the 1820s. Fishpond construction intensified beginning in the late 1500s and early 1600s when the Hawaiian population was rapidly expanding and sociopolitical systems became more complex. Various estimates place the number of fishponds at one time from 300 to 500, ranging in size from less than an acre to over 100 acres.

The products of the original ponds were primarily reserved for the chiefly rank, the ali‘i. However, as Hawai‘i became increasingly democratized in the late 19th-century, the ponds became a valuable food source for all of the people. For complex social and physical reasons, today there are only a dozen ponds actively farmed and properly managed. However, the potential now exists for economic revitalization of neglected ponds. Revitalization involves applying modem aquaculture technology to ancient pond management skills.

The challenge of fishpond revitalization is to create an economically viable and environmentally sustainable aquaculture enterprise which also provides cultural benefits to society. Productive fishponds are culturally, educationally, environmentally and aesthetically rewarding, however it is difficult to quantify these social benefits. The present analysis focuses on the profitability of operating a revitalized fishpond.

Economic considerations

Some observers have characterized the ponds as being “dormant ocean farms.” This analogy helps one to view fishponds as another component of the overall agriculture economy. As in many other areas of Hawai‘i’s diversified agricultural economy, fishpond successes have often been small, family owned and operated farms, businesses which do not require a substantial cash flow to pay hired-labor or high ownership costs for land and capital investment.

Fishponds in a high state of disrepair may never become profitable if the capital required for restoration, including the extraordinarily complex permitting process, is excessive. (Proceedings of Hana Symposium II, 1993) There is a significant cost in time and money to obtain the many permits and reviews currently required. Restoration costs can be somewhat mitigated if greater flexibility in the use of modern construction machinery and materials is permitted in building and repairing fishpond walls and gates. However, the annualized costs of this long-term investment must be justified by the potential income.

The economics of fishpond production is further complicated by the absence of a well defined market. The potential production is enormous. For example, Paul Bienfang of the Oceanic Institute reported that fishpond production on Moloka‘i alone (300 acres) could produce five times the entire 1992 aquaculture output in Hawai‘i. (Proceedings, p. 15) However, the market for this level of production must be clearly defined and carefully developed. Individual consumers, fish markets, and restaurants expect a reliable supply of a quality product at a reasonable price. Fishpond operators may find it particularly profitable to supply the out-of-season demand. There are also other potential markets that growers may wish to develop. For example, with the depletion of Hawai‘i’s reef population, there may be an opportunity to supply the state with fish for “stock enhancement,” i.e., for restock-

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ing the native fish populations. Mullet and milkfish can also be used as live baitfish. Fishermen find mullet and milkfish as attractive as traditional bait and more hardy (*Hawaiian Fishpond Revitalization: A Manual*, 1993).

Hui O Loko Iʻa, an association of fishpond owner-operators, has been established to share management knowledge and expertise, to encourage cultural and historical awareness, and to cooperate on market development. In light of the successful models of smaller-scale production systems in other enterprises and recognizing the inherent cultural value of traditional fishponds, economic development efforts directed toward restoration of fishpond production will likely concentrate on the scale of a "cottage industry" operated by a "multiple-income farm family" in close cooperation with other similar families. A plantation-scale, industrial-style, centralized approach to fishpond production would appear to be inappropriate.

Methodology

An economic model of fishpond production was created based on data from currently operating fishponds. Production practices in the operating section are typical of the well managed fishponds, but the operating input costs are typical rather than average. In order to use the fishpond model effectively, one needs to possess a good understanding of fishpond production practices. A technical description of the various production practices is beyond the scope of this economic analysis but is available in the 1993 manual.

Leung and Rowland (1989) have designed a computer spreadsheet model for the financial analysis of shrimp production. It is flexible enough to accommodate the evaluation of other aquaculture systems. The shrimp model, for example, can include a hatchery component. By contrast, the fishpond model is specific to the situations encountered by an operator of a revitalized traditional fishpond. Shrimp aquaculture is an intensive, relatively industrialized production system fundamentally different from the extensive production system of fishpond aquaculture.

The shrimp model is more comprehensive than the fishpond model. For example, the shrimp model takes into account the time value of money, providing a discounted cash flow, the internal rate of return (IRR), and the net present value (NPV) for a proposed investment. The fishpond model, by contrast, focuses on a typical year of operation before tax. Therefore, the fishpond model should be viewed primarily as a management tool. If one needs to obtain financing or evaluate a proposed investment, the fishpond economic analysis functions only as the first step in the process of a complete financial or investment analysis, an example of which is well articulated by the shrimp model.

Producers need to decide which variety or varieties of fish to raise and how often and to what degree to stock the pond. The varieties raised will usually include one or more of the highly desirable traditional species: mullet (ʻama ʻama), milkfish (awa), and moi. The different feeding habits of mullet and awa make them a compatible combination for our example pond. The pond is stocked two times a year at the rate of 1,000 fingerlings per acre/stocking. We are assuming a 60% survival rate (i.e., a 40% mortality rate), thus 2,000 fingerlings would yield 1,200 fish for market. These would average about 0.75 pounds each, or 900 pounds per acre per year.

Most traditional fishpond production will not involve feeding a supplement to fish beyond the early "starter" stage. In our example the nursery stock is fed for 90 days. Users of this economic model can choose either to feed or not to feed, and if feeding, to feed either a starter or a grower supplement. Finally, the producer must decide upon a marketing plan. Some may choose a batch processing strategy, that is, stocking a pond, growing and harvesting the entire crop at one time, and marketing the fish all at once. The marketing plan will of course depend upon the nature of the market demand. A more difficult although potentially more profitable management strategy would be to harvest and market weekly, and to include fish for both direct consumption and bait. This management plan is the strategy illustrated in the fishpond economic model. The computer program calculates harvest costs based on the yield assumptions and the preferred marketing plan.

The ownership arrangements in the ownership part of the model are also meant to reflect a typical situation. Currently, much of the land devoted to traditional fishponds is leased. The example pond assumes leased land, but any ownership structure can be used. Fishpond production is relatively labor-intensive, but there may be some opportunity for mechanization. The example farm is not mechanized, but a wide range of production techniques can be considered. The "bottom line" for the operations component of the model is gross margin, the gross revenue minus all of the operating costs, the amount available to pay for the ownership costs. The ownership "bottom line" is economic profit, the gross margin minus the value of all of the ownership resources (i.e., the management, capital and land resources) and an appropriate adjustment to account for the riskiness of the enterprise.

Most farmers (whatever their business enterprise) do not include the full value of their labor, management and owner equity in their profitability calculations. They often think of their "profit" as the residual of their farming effort. However, economic profit includes the value of all productive resources. The return to the farmer should equal or exceed the value of his labor, management, and owner equity. If these returns are at least equal to their values, the fishpond can be considered to be "profitable." (In practice, the actual receipt of these returns may need to be postponed in order to "cash flow" a fishpond operation.)

Economic profit, as opposed to "accounting" or "financial" profit, is a better measure of true farm profitability because it is net of all costs, not simply cash costs. In the long run we would expect economic profit to equal zero because all "out-of-pocket" expenses will have been paid and all productive resources, such as land, labor, management, and the owner's capital investment, will have received a "fair" return, i.e., a return at least equal to their value. We would therefore expect that significantly positive economic profitability would attract more producers into the industry, and that negative economic profitability would encourage producers to exit the industry.

Results

The complete results are provided as Tables 1 and 2, the computer printout of the model and example calculations. The "basic assumptions" and the bold italicized figures represent data entries provided by growers. However, any of these entries (variables) can be altered to fit another user's situation. The results are specific to the growers who provided information, and they may be viewed as fairly typical but not necessarily average. By contrast, the non-italicized (i.e., upright) figures indicate computer calculated results or fixed categories for which no entry is necessary or possible. The model must be used with the appropriate data to obtain meaningful results for a specific fishpond.

The summary results (Table 3) are obviously easier to read than the complete results provided in Tables 1 and 2. However, the detailed results have two important advantages. First, the "transparency" of the spreadsheet approach allows one to observe exactly how each of the costs were calculated. And secondly, the greater detail enables a current or prospective fishpond operator to see what kinds of data are needed in order to calculate the profitability of a specific fishpond operation. With the appropriate data growers can use the economic model, with a university extension agent, a consultant, or on their own, to calculate enterprise profitability and to consider the economic impact of proposed or anticipated production, marketing, or policy changes, that is, to answer strategic "what if?" questions.

The question most commonly asked of an economic profitability analysis is, "How much money could an owner/operator typically expect to earn annually from this enterprise?" In other words, what is the financial profit (the returns to owner equity, management, labor and risk), given a specific set of assumptions?

(a) Value of equity: This grower invested 60% of his own money into the total investment of $36,200, that is, $21,720. (This investment allocates only $5,000 for the permitting process, perhaps an unrealistically low figure given the high level of regulation.) The grower feels he only needs to receive 5% on his equity, therefore his annual return to equity is $ 1,086. (If any land were owned, an imputed rent would be included here.)

(b) Value of management: He will provide all of the management, and the value of management is estimated to be 5% of the total annual gross sales ($45,360), which amounts to $2,268 annually.

(c) Value of labor: It is assumed that he will provide all required labor, estimated to be 815 hours per year. The annual value of this labor, assuming $7.50 per hour, plus benefits at 33% of the wage rate, is $8,131. Finally, as the risk-taking entrepreneur, he is entitled to the return to risk.

(d) Value of risk-taking: This value is the allowance for risk (estimated as 4% of the gross sales or $1,814) plus the economic profit, in this case $25. (If the economic profit were negative, the returns to equity, management and labor would be reduced after the risk contingency was used up.) In our example total returns equal $13,324.

A break-even price is the price required to cover costs given a specific yield; a break-even yield is the yield required to cover costs, given a specific price. This analysis calculates the break-even price (per pound of fish sold) required to cover the operating costs and the total costs, given the assumed yield. It also calculates the break-even yield required to cover operating and total costs, given a specific price per pound. When the gross margin equals zero, all operating costs will have been paid. In the short run, growers will continue to produce as long as the gross margin is positive. When the economic profit is zero or greater, all costs of production will have been paid. We would expect growers to continue producing in the long run as long as the economic profit is positive. In our example the annual marketable yield per acre is 900 pounds (i.e., pounds of fish sold) and the weighted average price for each pound of yield is $3.15. Therefore, in order to cover all operating costs, a producer would have to receive at least $2.12 per pound or 606 pounds per acre; in order to cover total costs, he would need to receive at least $3.12 per pound of fish sold or 891 pounds per acre. Since he is receiving 30 per pound more than his minimum break-even price, we may assume that he would be inclined to remain in the industry.

Summary and conclusions

Functioning traditional Hawaiian fishponds have cultural, environmental, educational, aesthetic, and economic benefits. Our study focuses solely on the economic profitability aspects; it does not consider either liquidity (i.e., cash flow) or solvency. Fishpond production provides a highly desirable food source for the community and offers an income for the fishpond operator. Today, a few fishponds are operating successfully, but the current state permitting process forces most to remain dormant, to continue as a part of one of Hawaii's more important underdeveloped economic resources.

The fishpond model is intended as a management tool. To the extent that it better enables one to organize fishpond production data into useful economic information, it can lead to better economic decision-making. It allows one to quantify the actual economic performance and to project the potential economic profitability. It is not however a substitute for a full investment analysis.

While fishpond production is potentially profitable, profit margins are small, as they often are with agricultural enterprises. The profitability of any particular operation will depend upon the quality of the owner/operator's management and marketing efforts. The operating costs are quite variable and must be closely monitored and controlled. The annual ownership costs are relatively more fixed because they are largely a function of the initial capital investment. Therefore, the start-up costs (which include the costs of completing the permitting process and complying with the attendant regulations) must be reasonable. The market must be well defined. Marketing will in most cases involve more than simply providing a commodity. It will include more creative possibilities, such as meeting the specific demands of chefs, of fisherman (for baitfish), and of agencies interested in restocking. Finally, these markets must be carefully developed and maintained.

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TABLE 1. GROSS MARGIN Typical annual (1994) gross income, operating costs and gross margin.

ASSUMPTIONS:

1 Annual stocking rate	2,000 fish/acre/year	9 Ave. harvest size	0.75 lb.
2 Stock pond	2 times/year	10 No. of harvests	52 times/yr.
3 Survival rate	50% fish stocked	11 Size of pond	16 acres
4 Ave. size fingerling	2 ounces each	12 Labor wage rate	$7.50 per hour
5 Feed fingerlings @	3% of body wt.	13 Benefits as %	33% of wage
6 Feed fingerlings for	90 days	14 Debt/asset ratio	40%
7 Ave. grow-feed conv.	2.85 #feed/#gain	15 Bank loan rate	10.0% calc. wt. ave. cost of
8 Feed growers for	0 days	16 Return on equity	5.0% money = 7.0%

I. GROSS INCOME:	% of mix:	# of units:	units:	$/pound	$/acre:	$/pond	% gross
A. Mullet	***70%***	630	lbs./acre/yr.	***$3.00***	$1,890	$30,240	66.7%
B. Milkfish (awa)	30%	270	lbs./acre/yr.	***$3.50***	945	15,120	33.3%
I. Total gross income =	100%	900	lbs./acre/yr.	**$3.15**	2,835	**$45,360**	100.0%

II. OPERATING COSTS:		# of units:	units:	$/unit:	$/acre:	$/pond	% gross
A. Growing costs:	*Per pond/yr basis*						
1 **Stocking**	*Hrs./stocking:*		*$/lb. sold =*	**$0.56**	**$503.74**	**$8,060**	**17.8%**
a. Mullet		1400	fingerling/ac.	***$0.25***	350.00	5,600	12.3%
b. Milkfish		600	fingerling/ac.	***$0.25***	150.00	2,400	5.3%
c. Labor to stock	***3.0***	6	hrs./pond/yr.	$9.98	3.74	60	0.1%
2 **Feeding**	*Min./day/pond:*		*$/lb. sold =*	**$0.12**	**$103.57**	**$1,657**	**3.7%**
a. Feed for nursery stock		675.0	lbs./pond/yr.	***0.46***	19.41	311	0.7%
b. Feed for finishing stock		0.0	lbs./pond/yr.	***0.46***	0.00	0	0.0%
c. Labor to feed	***45***	135.0	hrs./pond/yr.	$9.98	84.16	1,347	3.0%
3 **Maintenance**	*Min./day/pond:*		*$/lb. sold =*	**$0.26**	**$233.17**	**$3,731**	**8.2%**
a. Supplies	*Enter total $/fishpond/year =>*			N.A.	62.5	***1,000***	2.2%
b. Labor	***45***	273.8	hrs./pond/yr.	$9.98	170.67	2,731	6.0%
4 **Operating interest**		***10.0%***	*$/lb. sold =*	**$0.05**	**$42.02**	**$672**	**1.5%**
	Total growing costs =			**$0.98**	$882.50	$14,120	31.1%
B. Harvesting costs:	*Per pond/yr basis*						
1 **Harvesting**	*Hours/harvesting:*		*$/lb. sold =*	**$0.07**	**$64.84**	**$1,037**	**2.3%**
a. Harvest labor	***2.0***	104.0	hrs./pond/yr.	$9.98	64.84	1,037	2.3%
b. Miscellaneous	*Enter total $/fishpond/year =>*			N.A.	0	***0***	0.0%
2 **Packing & shipping**			*$/lb. sold. =*	**$0.05**	**$46.39**	**$1,169**	**2.6%**
a. Ice		25	lbs./harvest	***$0.50***	40.63	650	1.4%
b. Packing labor	***1.0***	52.0	hrs./pond/yr.	$9.98	5.76	519	1.1%
3 **Marketing**			*$/lb. sold. =*	**$1.02**	**$915.60**	**$14,650**	**32.3%**
a. Excise tax		$45,360	gross /pond	4.17%	118.22	1,892	4.2%
b. Transportation to market		52	trips/year	***$25.00***	81.25	1,300	2.9%
c. Marketing labor	***4.7***	244.4	hrs./pond/yr.	$9.98	716.13	11,458	25.3%
	Total harvesting costs =			**$1.14**	$1,026.83	$16,856	37.2%
	II. TOTAL OPERATING COSTS =			**$2.12**	**$1,909**	**$30,976**	**68.3%**
III. GROSS MARGIN	*Gross income minus operating costs =*			**$1.03**	**$926**	**$14,384**	**31.7%**

TABLE 2. ECONOMIC PROFIT Typical annualized ownership costs, economic & financial profits, and gross margin & economic profit break-even analysis.

III. GROSS MARGIN	*Gross income minus operating costs =*			**$1.03**	**$926**	**$14,364**	**31.7%**
IV. OWNERSHIP ("Fixed") COSTS:			*Pond basis*	*$/unit:*	*$/acre:*	*$/pond*	*% gross*
A. Management resource			*$/lb. sold =*	**$0.22**	**$198.45**	**$3,175**	**7.0%**
1. Management fee		$45,360	gross /pond	*5.0%*	141.75	2,268	5.0%
2. Office overhead		$45,360	gross /pond	*2.0%*	56.70	907	2.0%
B. Capital resources	*cost:*	*life:*	*Repairs, tax, ins.*	**$0.51**	**$460.62**	**$7,370**	**16.2%**
1. Permits & reviews	*$5,000*	*10*	*0.0%*		44.49	712	1.6%
2. Pond restoration	*$15,000*	*10*	*0.0%*		133.48	2,136	4.7%
3. Other start-up exp	*$2,000*	*10*	*0.0%*		17.80	285	0.6%
4. Pen encl. & nets	*$4,000*	*3*	*5.0%*		82.76	1,324	2.9%
5. Oxygen meter	*$1,200*	*5*	*3.0%*		16.04	257	0.6%
6. Other equipment	*$1,000*	*5*	*4.0%*		12.74	204	0.4%
7. Truck	*$7,000*	*3*	*5.0%*		144.84	2,317	5.1%
8. Other machinery	*$1,000*	*7*	*6.0%*		8.47	136	0.3%
9. Other cap. expens	*$0*	*5*	*4.0%*		0.00	0	0.0%
Total capital investment =	$36,200	5.0%	rtn. on equity of	$21,720	$67.88	$1,086	2.4%
C. Land resource	*value:*	*term:*	*interest:*	**$0.14**	**$125.00**	**$2,000**	**4.4%**
a. Mortgage paymen	0	20	10.0%		0.00	0	0.0%
b. Base lease rent payment	*Enter total $/fishpond/year =>*				93.75	*1,500*	3.3%
c. Percentage of gross over	*0.00%*		*$0.00*		0.00	*0*	0.0%
d. Imputed lease rent	*Enter total $/fishpond/year =>*				0.00	*0*	0.0%
e. Property tax, etc.	*Enter total $/fishpond/year =>*				31.25	*500*	1.1%
D. Risk contingency	$45,360	gross /pond	**4%**	**$0.13**	**$113.40**	**$1,814**	**4.0%**
IV. TOTAL OWNERSHIP COSTS =				**$1.00**	**$897**	**$14,360**	**31.7%**
V. TOTAL COST OF PRODUCTION =				**$3.12**	**$2,807**	**$45,335**	**99.9%**
VI. ECONOMIC PROFIT =				**$0.03**	**$26**	**$25**	**0.1%**

Financial "Profit":		*$/unit:*	*$/acre:*	*$/pond*	*% gross*
Value of labor, assuming	815 hrs./yr. =	$0.56	$508.20	**$8,131**	17.9%
Return to labor, management, owner equity & risk =		$0.93	$832.76	**$13,324**	29.4%

BREAK-EVEN ANALYSIS: Gross margin = μ; economic profit = π	*μ /ac./yr.=$0*	*π /ac./yr.=$0*	
In order to cover operating & total costs, μ & π, respectively, must be >= $0:	*when:*	*when:*	
given the current ave. yield of **900** lbs sold/ac/yr, break-even ave. PRICE =	**$2.12**	**$3.12**	$/lb sold
given the current ave. price of **$3.15** /lb. fish, the break-even YIELD/acre/yr. =	**606**	**891**	lbs sold

TABLE 3: SUMMARY OF RESULTS (from Tables 1 & 2 above)

Gross Income:	*Lbs sold/yr*	*$/pound*	*$/pond:*
Total sales =	14,400	**$3.15**	**$45,360**
Operating costs:		*$/pound*	*$/pond:*
Growing costs:			
1. Stocking		$0.56	$8,060
2. Feeding		$0.12	1,657
3. Maintenance		$0.26	3,731
4. Op. Interest		$0.05	672
Total growing costs =		$0.98	$14,120
Harvest costs:			
1. Harvesting		$0.07	$1,037
2. Packing		$0.05	$1,169
3. Marketing		$1.02	$14,650
Total harvesting costs =		$1.14	$16,856
Total operating costs =		**$2.12**	**$30,976**
Gross Margin =		**$1.03**	**$14,384**
Ownership costs:			
1. Management		$0.22	$3,175
2. Capital		$0.51	$7,370
3. Land		$0.14	$2,000
4. Risk contingency		$0.13	$1,814
Total ownership costs =		**$1.00**	**$14,360**
Total costs =		**$3.12**	**$45,335**
Economic profit =		**$0.03**	**$25**
Financial profit:	*hours:*		
Value of labor	815	$9.98	$8,131
Value of owner equity		$21,720.00	$1,086
Rtn. to labor, mgmt., equity & risk		$832.76	**$13,324**

College of Tropical Agriculture and Human Resources

University of Hawai‘i at Manoa

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