A new synthesis in oceanic domestication: The symbiotic development of *loko i'a* aquaculture in pre-contact Oceania

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Introduction

Oceania comprises more than 30 per cent of the earth's surface, and is where some of the world's richest aquatic resources are found. The islands in this region provide an ideal setting for investigating questions of domestication as a biological process between fauna and humans. From an evolutionary framework, the operation of natural selection and evolution can be seen in many examples of cultural practices throughout Oceania. Within Oceania, a combination of food-production technologies and strategies of domestication arose owing to the limited amount of arable land and relatively impoverished terrestrial faunal resources.

In the research reported on here, I examine both aquaculture as a dynamic food production system and the coevolutionary or symbiotic nature of marine procurement strategies in the oceanic world. My objective in this research is to expand conventional views of domestication, by adopting a broader definition of this biological process and outlining the various components that comprise this relationship. During the development of this relationship, humans must acquire control and management of four different aspects of the production system: protection, growth, reproduction and harvesting. This requires a sophisticated understanding of species types and of coastal zone habitats, considering the amount of variation in oceanic ecosystems throughout the archipelagos in Oceania, and reflects the interrelationship these indigenous peoples had with biological species of the *'āina* (land) and the *kai* (sea). As this control increases, the relationship has the potential to become the equivalent to food production and domestication. Not all food production systems in Oceania necessarily controlled all four components, and various activities were done in relation to the marine environment.

Evolutionary Oceania

The study of complex historical interactions between human populations and the ecosystems they inhabited has been the focus of many recent archaeological studies. The historical ecological paradigm has come to dominate theories on human arrival in seemingly "pristine" island environments, relying heavily on the assumption that these natural island ecosystems were stable and unchanging before the advent of humans in the region. On entering previously unoccupied "pristine" island ecosystems, indigenous people initiated a series of changes that reshaped the physical landscape, drastically altered vegetation regimes, and transformed both the composition and distribution of island faunas. Environmental disturbances such as forest clearing and exploitation of wild food sources led to dramatic transformations of the *'āina* (Kirch 1983).

But in this article I focus on the surrounding *kai* associated with these islands, because the expansive seascape in remote Oceania comprises more than 65 per cent of the geographical area. The ocean itself has greater potential in addressing these issues because it is not restricted by size, form and diversity in resources. Thus the ocean provides a neutral testing ground for hypotheses that specify the relationship between humans and their environments.

The fundamental goal of evolutionary theory is to explain the common threads underlying life's diversity. Evolution seeks to explain the unity and diversity in life, and natural selection is the major "editing mechanism" that dictates this change. Natural selection occurs as heritable variations are exposed to environmental factors that favour the reproductive success of some individuals with certain variants over others. Each species develops its own set of adaptations, or features, that evolved by means of this selection process. This theme is the cornerstone of understanding life.

Coevolution is a type of evolution that involves two genetically unrelated species, and occurs whenever the interrelationship of the organisms positively effects the potential survival of each other. It recognises that even at the simplest

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level of inquiry, species coexist in the natural world. This coexistence allows for a richness of species types co-occurring in an area at a particular point in time. In biology, species represent the most basic phylogenetic unit in evolutionary understanding and under natural conditions all organisms are enmeshed in one way or another in a web of relationships with a variety of organisms. In evolutionary studies, species is the unit preferred over higher units such as genera, family, or order. The species level of analysis permits a detailed understanding of the relationship between organisms, thus leading to a better understanding of the principles that govern that interaction.

The approach advocated here adopts a similar framework that views human interaction with the environment as the outgrowth of evolutionary potentials that may develop whenever an animal species feeds consistently on a set of individuals from another species. In evolutionary theory domestication has been defined as a natural process by which animal and plant species are able to increase their fitness. In its basic definition, domestication represents a symbiosis between humans and plant species (Rindos 1980:212). Likewise, in Oceania, traditional aquaculture can be conceptualised similarly as an evolutionary process that incorporates the domestication of aquatic plants and animals to produce a system that increases the carrying capacity of the environment for the aquatic plants and animals selected, and which in turn can support humans (adapted from Rindos 1980).

In the research reported here, I demonstrate how through fishing methods and technological strategies, populations in Oceania were able to develop coevolutionary relationships with selected fish species based on a very sophisticated and multilayered understanding of ecological processes in the natural world. Also, through proper management practices, people were able to maintain the biological integrity of fish stocks for generations, and the biodiversity of each marine region. Within the fundamental biological concept of unity and diversity, it can be seen that people from many of the major archipelagos in Oceania had different methodologies and strategies for fish-related domestication, but all have in common the basic principles of mutualism and coexistence.

Biological advantages of water as a culturing medium

It is important to note that the ocean provides several advantages over land and terrestrial food production.

First, the ocean is relatively uniform and provides a stable supply of marine resources. As a consequence, migrating indigenous peoples of these regions found the sea to be one of the most reliable of all long-term food sources.

Second, in physical terms water bodies are three-dimensional growing spaces. Water occupies the major portion of space in the Pacific Island region compared with land.

Third, the body density of fish and swimming crustaceans is nearly the same as that of the water they inhabit. This means that since they do not have to support their own weight, compared with terrestrial animals they can devote more food energy to growth. Further, because fish are cold-blooded they do not need to divert energy for thermoregulation.

Finally, arable land and terrestrial resources decline from west to east in Oceania. This has led to a dependency on aquatic resources as reliable food sources. In turn, this relationship has led to a system of conservation directed toward the preservation of marine and natural resources, and has regulated the use of inshore and offshore fishing.

Elaboration of fishing strategies and relationships

Aquaculture is a dynamic food production system and the aquacultural ecology of any region is the product of numerous factors interacting over long periods of time. As we begin to understand the functioning and evolution of aquacultural ecology, control is likely to increase as coevolutionary relations intensify. These relations have the potential to become the equivalent to food production and domestication, but this does not always occur. This happens because in some cases during the development of this relationship, only some parts of the aquacultural ecology are completely under human control, while some forms may show relatively little coevolutionary linkage.

For those relations to intensify, humans must acquire control and management over four different components of the production system:
- protection of the selected species from predators;
- control of the reproduction of the selected species;
- regulation of the growth of the organisms; and
- control of the harvesting process.

Not all food production systems necessarily controlled all four components, however, and there was a variety of human activities within each that could be done in relation to the marine environment. These activities with respect to fish species will be identified.

Aquacultural domestication has its origins in fishing, as it was later developed into an integrated system of production. The historically documented fishing strategies of Pacific Islanders exhibited an intimate knowledge of fish, their characteristics, habits and domains. The broadening of the Oceanic subsistence base ultimately led to greater variation in food procuring techniques. Studying these strategies as outcomes of selection first requires an understanding of the biological organisation and distribution of communities in the marine ecosystem.

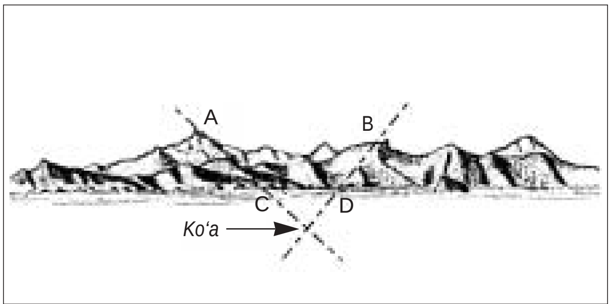

Figure 1. **Offshore fishing grounds (*ko'a* or *toka*).**
An example of the demarcation of the fishing grounds through alignments of shrines (C and D), or other permanent landmarks, both onshore and on ridges (A and B). (*Adapted from Best 1939*)

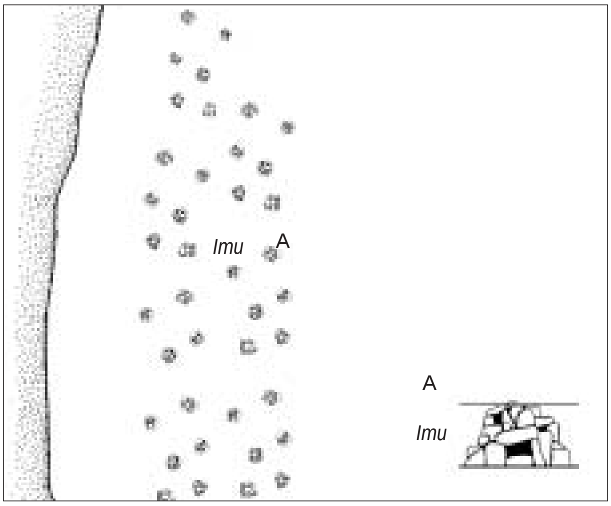

Figure 2. **Fish shelters (*imu* or *umu*)**
Fish shelters are artificially constructed reef along inshore or lagoon areas that would normally lack natural reefs. These piles of rock (A) or coral serve as habitat for numerous fish species, and seek to increase biodiversity in barren areas. (*Adapted from Hunter-Anderson 1981*)

The marine ecosystem is divided into three major zones: 1) the pelagic, or offshore zone; 2) the benthic, or subsurface habitat area; and 3) the inshore and coral reef zone. My objective here is to determine how human activities in these different zones display aspects of food production through coevolution, or symbiosis.

Ko'a, or fishing grounds, and offshore harvesting

In the pelagic zone, fishing grounds were important areas where a variety of fish species congregated. These fishing grounds were termed *ko'a* (in Hawaiian) or *toka* (in Maori, Best 1939:4–5) and were located in areas with depressions in the ocean floor or those with rocky prominences extending upward from the ocean floor. Those grounds where pelagic species were consistently found were identified by the intersection of lines extending out from two prominent terrestrial landmarks. In Hawai'i these two bearings were made with stone shrines, also known as *ko'a*, on the shores, mountain ridges, or other topographical features (Malo 1951). By aligning oneself between these markers, the fishing ground was found (Fig. 1). Some of the fish species found in these areas were barracudas (*Sphyraena* sp.; *kākū*), suckfish (*Remora remora; ono*), marlins (Istiophoridae; *pelu*, *a'u*), common dolphinfish (*Coryphena hippurus; mahimahi*), yellowfin tuna (*Thunnus albacares; 'ahi*) and flying fish (*Cypselurus simus; mālolo*). Often, fishers could spot fishing grounds by watching from the shore, noting schools of these fish going in a certain direction before disappearing. The preservation of the *ko'a* was vital for sustainable resource management, and fish were often fed edible excess waste food such as sweet potato, (*Ipomea batatas, 'uala)*, so that fish growth could be monitored. Assisting fish growth and monitoring fish populations ensured that the resources would not be reduced below a critical level and provided a very reliable and quick means of procurement. These fishing grounds often served as indicators of the biological health of the surrounding pelagic zone. If the ground was mismanaged and overfished, it would, in turn, affect the entire area, as it would take time for other fish to establish themselves in the habitat and replenish the resource.

Fish shelters as inshore protection

In certain areas of Polynesia such as Hawai'i, and in places in Micronesia, fish shelters, called *umu* or *imu*, were common features along shorelines that helped provide protection and regulated the growth and reproduction of inshore fish species (Fig. 2). These fish shelters were artificial reefs made of rock or coral piles with enough space between the rubble to allow for algal growth on the surfaces (Kikuchi 1973:78). These stones functioned in the same way that naturally occurring rock outcroppings and coral reef habitats do, by providing a hard substrate necessary for the basic formation of reef bottom communities. Besides providing stability and some protection from predators, these shelters also helped to regulate fish growth and potentially increase fish stocks by serving as artificial homes for fish to congregate and reproduce. Some of the prominent fish species that inhabited these shelters were squirrelfish (*Myripristis* spp.; *u'u*), unicornfish (*Naso unicornis; kala*), surgeonfish (*Acanthurus triostegus; manini*), goatfish (*Parupeneus multifasciatus; moano*), greater amberjack (*Seriola dumerili; kāhala*), parrotfish (*Scarus* spp.; *uhu*), and eels (Muraenidae; *puhi*). These types of fish shelters are also found in Yap, where there are fields of mound constructions called *ulug* that work in a similar way to *umu* (Hunter-Anderson 1981:86). It was the simplest of all aquacultural features, and its location was determined by a lack of naturally occurring coral and rock shelters.

In Samoa, these heaps of stone were called *taufatu*, and were similarly collected and piled in areas lacking reefs, and in areas that had reefs to attract fish. Once fish settled the habitat, Samoans would surround the pile with a net and take the stones away one-by-one. The fish were trapped as they gradually escaped the *taufatu*. This process of culling fish was relatively easy and required a relatively low investment of energy for food production.

Fish traps in inshore tides and currents

Methods of trapping fish were common throughout the Pacific as were strategies that regulated and controlled the harvesting component of food production. Trapping is very effective for catching large numbers of fish in the inshore zone. On a small scale, basket traps and net traps of various sizes and shapes have been important in capturing fish (Reinman 1967). This controlled method of harvesting eventually developed into large structural traps made of basalt and coral in the inshore area throughout Oceania. The more common type of trap was the *pā*. The *pā* was constructed in the inshore area or found in channels between the reefs or islets and is still common throughout the Cook Islands, Tuamotus, Society Islands, Mangareva, Samoa, and the Hawaiian Islands. A *pā* can range in shape from a simple V-shaped enclosure to a very complicated labyrinth, with a number of enclosures in a single trap. It functioned with the tides. The walls of these traps became wholly submerged at high tide (Reinman 1967:125; Hunter-Anderson 1981; Stokes 1909), allowing fish to swim freely into the structures, yet trapping them within the enclosure when the tide dropped. In other parts of Oceania, *pā* traps are found on both sea and lagoon reefs, or between islets in a single atoll (Reinman 1967:128). One of the commonest forms resembles a large stone arrow with the point facing the sea or lagoon. These types of traps are also common in the Marianas, Palau, Yap, Lukunor and Nanoluk, Ifaluk, Ponapae, the Gilberts, and Kapingamarangi. Some of the principal species of fish that were found in the *pa* were wrasse (*Thalassoma ballieui; hīnalea*), surgeonfish (Acanthuridae; *manini*, *pūalu*), and the daisy parrotfish (*Chlorurus sordidus; uhu*). Driving was the method used to frighten fish into nets, and was done by slapping the water and frightening the fish into weirs or capturing them with a net.

Perhaps one of the most interesting developments in this fish trapping method is the construction of what Hawaiians called a *loko 'umeiki*. These fish traps were much larger, and were constructed by building a wall in an arc from two points from the shoreline, providing protection from predators. Although many of these traps superficially resembled shoreline ponds with low semi-circular walls, their distinguishing characteristic was a series of breaks with lanes that led into and out of the pond area (Fig. 3). These open lanes were oriented to the longshore currents, taking advantage of the natural tides and flow of the ocean. The lanes connecting the traps with the ocean were used to catch fish migrating down the coastline. These fish were attracted to the surge of water at the lane entrances, and the possibility of finding herbivorous-stocked ponds. Fishers simply laid a net facing the sea across the opening of the lane to capture fish on the incoming tide. When the tide reversed, fishers faced their nets toward the traps capturing fish as they swam out toward the sea. The principal fish species found in these traps were usually highly mobile fish that travelled in schools, such as bonefish (*Albula vulpes; 'ō'io*), yellow surgeonfish (*Acanthurus xanthopterus; pūalu*), goatfish (*Mulloidichthys* spp. and *Pseudopeneus* spp.; *weke*), parrotfish (*Scarus* spp.; *uhu*), round herring (*Etrumeus teres; makiawa*), bigeye scad (*Selar crumenophthalmus; akule*), mackerel scad (*Decapterus macarellus; 'opelu*), skipjack (*Katsuwonus pelamis; aku and Euthynnus affinis; kawakawa*), and sharks.

Aquacultural *loko i'a* production systems

The general Hawaiian term for these aquacultural ponds is *loko*, or *loko i'a*, derived from the proto-Polynesian word *roko*, meaning pond or lake (with *i'a* or *ika*, meaning fish). Aquaculture technology

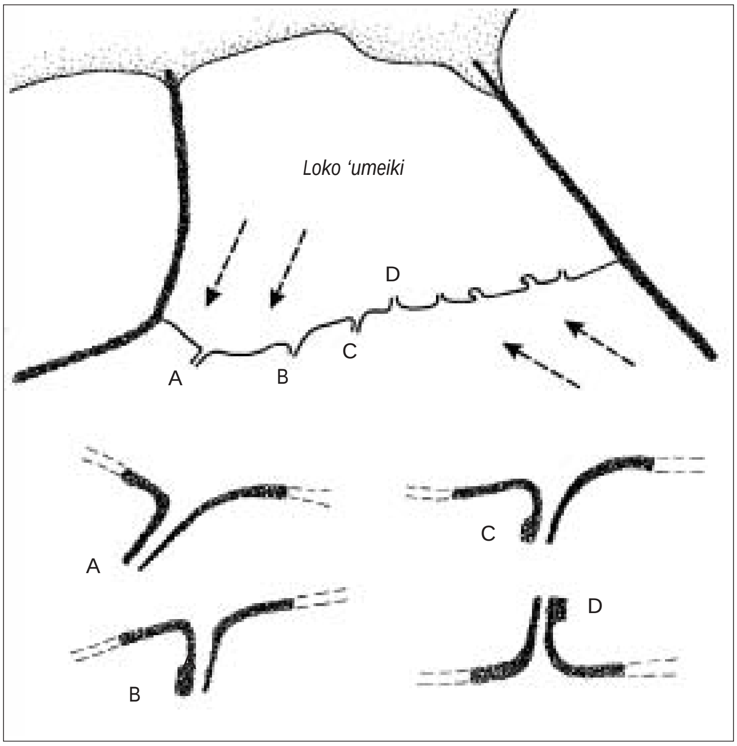

Figure 3. **Fish traps (*loko ʻumeiki*)**

Fish traps use the currents and tides to capture fish. The fish trap, *Paʻiliʻili,* shown here is wedged between two fishponds. Details of three outer canals (A, B, C), and one inlet canal (D) are shown. Note the large wall sections on canals B, C and D. These were features used to accommodate fishermen, as nets were used to capture fish migrating along the shoreline.
(*Adapted from Stokes 1909 and Costa-Pierce 1987*)

was an innovation that developed in few places in Oceania, with the most intricate systems established in the Hawaiian Islands. Four basic types of fishponds were used in pre-contact Hawaiʻi. These were not regarded as a single entity, but as one link in a continuum of food production technologies (Kikuchi 1976). Aquacultural ponds were part of a continuous system that spanned the inland ponds to the sea and created a series of environments, each of which was structurally homogenous and temporally stable. The various fishponds ranged from four types within the *ahupuaʻa* (traditional land tenure system):

- *loko iʻa kalo*, or freshwater taro fishponds,
- *loko wai*, or freshwater ponds,
- *loko puʻuone*, or brackish water ponds, and
- *loko kuapā*, or ocean fishponds (Costa-Pierce 1987:325).

Humans were able to control these environments through a number of activities that managed reproduction of the species, their growth, and the harvesting process. This coevolutionary relationship allowed Hawaiians to provide an artificial selective advantage of certain fish species over others, by excluding predators and competing aquatic fauna in these environments. In turn, humans were able to procure a highly reliable food production source within a system that utilised a variety of strategies and management skills. For the purposes of this article however, I will focus only on the *loko kuapā*, or ocean fishponds.

In this process of domestication two species of herbivorous fish were targeted for obligatory coevolutionary relations in the Hawaiian Islands, flathead mullet (*Mugil cephalus; ʻamaʻama*) and milkfish (*Chanos chanos; awa*). Both are diadromous species, meaning they can migrate between fresh and salt water in a catadromous life cycle. This unique ability is a key aspect to their biological reproductive cycle, which requires them to go from freshwater and brackish-water habitats to the sea to spawn. After they hatch and mature they return upstream to the fresh and brackish-water areas. This ability to live within a fresh to salt-water continuum allowed for a specialised type of domestication that used a harvesting process that followed a schedule of seasons and the reproductive cycles of the selected fish species. Besides mullet and milkfish, a number of secondary domesticates were capable of establishing themselves, such as weeds, in the aquaculture in all phases of salinity. Although not targeted for domestication, they were able to adapt to such systems and provided humans with a secondary source of protein. These secondary domesticates evolved with the same selective pressures as the primary domesticates, as they both evolved in the same environment. They were able to enter the aquacultural system the same way mullet and milkfish did, and had similar feeding habits. The core group of species that made up this secondary domesticate assemblage included gobies (Eleotridae and Gobiidae*; ʻoʻopu*), Hawaiian flagtail (*Kuhlia sandvicensis*; *āholehole*), goatfish (Mullidae*; weke*), and ladyfish (*Elops hawaiensis*; *awaʻaua*).

An aquaculture example: walled seaponds

Seaponds (*loko kuapā*) represent the culmination of evolutionary potentials between humans and fish species. There were highly valuable for subsistence food production as well as for the political economy. These seawater ponds were characteristically built either by closing off the mouth of small bays or extending outward in an arch between two points along the shore. The walls were constructed with consideration for the flow of the ocean current along the reef and at times produced a linked effect along substantial distances of shoreline (Fig. 4). The main isolating feature of these ponds were seawalls (*kuapā*), constructed of coral and basalt rock. Most ponds were designed to have depths of only 0.6–1.0 m, so that light could penetrate the water and provide energy for the growth of algae for fish to feed on (Kelly 1989:3). Many times, the seaward face of the wall would slope outwards, whereas the inner face was more vertical, enabling the pond to efficiently withstand and absorb wave energy (Kikuchi 1973:54).

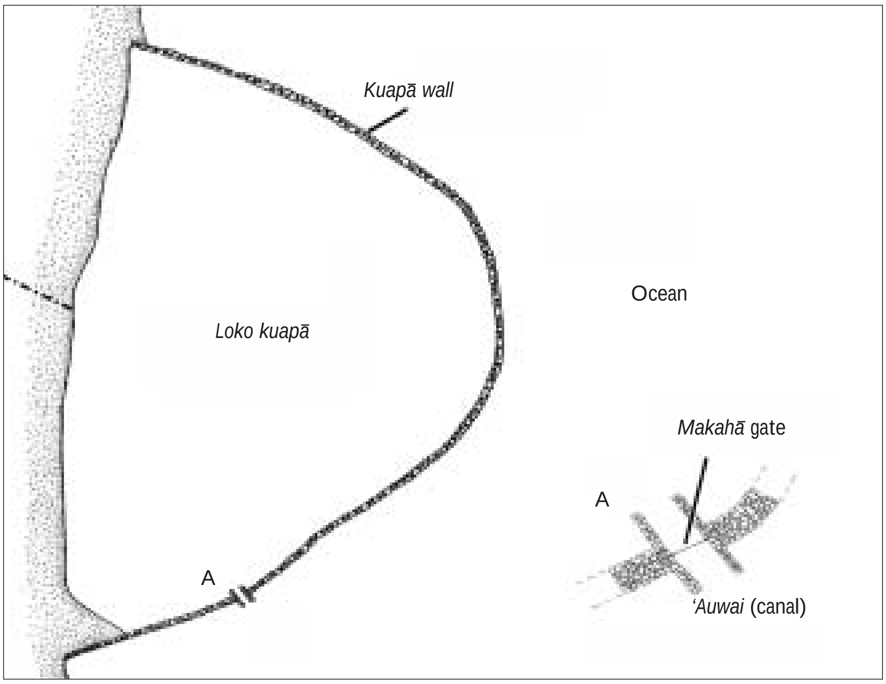

Figure 4.

Loko kuapā were ponds built along the shoreline usually on top of a reef flat with basalt rock and / or coral to form the *kuapā* wall. Controlled harvests were accomplished by using the canal ditch, a net, and gate system (*adapted from Kikuchi 1976; Summers 1964; and Costa-Pierce 1987*). The *makahā* (A), or sluice gate was permanently fixed in the *'auwai*, or canal connecting the pond to the open ocean.

Canals or *'auwai* were constructed into the walls of the ponds to stock, harvest, and clean the ponds with minimal effort. The canals connected the ponds directly to the sea and had a single fixed grate, called the *makahā*, made of dense native woods. This open gate allowed for the incoming tide to periodically flush the enclosed pond, and allowed very small fish to pass freely in and out of the pond, thereby creating a stock supply. Herbivorous fingerlings entered the pond through narrow openings in the sluice gates and fed on the algae within the walls of the pond. The openings in the sluice gate also allowed clean seawater with its nutrients and diluted oxygen into the pond. The ponds protected herbivorous fish from carnivorous predators outside the walls, and provided them with sustenance from the microbiota and algae that grew in its estuaries. There are seventy distinct algae species edible to both humans and herbivorous fish in Hawaiian waters. Propagation of selected algae in brackish and saltwater areas was accomplished by finding epiphytic algae attached to rocks and pebbles (Tilden 1905:142). These were collected and transported to the fishponds (Titcomb 1952:77). The reproduction of the selected algae species was facilitated by manually dispersing spores into the water column.

It is important to point out that the selected algae would not proliferate in the pond without the assistance of humans for propagation, cultivation and maintenance. As the fingerlings fed on the microbiota and diatoms, they grew in size and became too large to escape through the same narrow sluice gate openings they had used to enter the pond.

Secondary and tertiary walls were constructed within the pond to compartmentalise it into more workable, segregated areas, and to protect fingerlings in areas that were too shallow for smaller predatory fish (Kikuchi 1976:57). Fish harvesting was timed and scheduled on the reproductive cycles of the selected fish. During certain times, milkfish and mullet returned from their fresh and brackish-water habitats to spawn in coastal seawater. The *makahā* closed off the migratory return route of the fish and created a relatively easy process, increasing dramatically the success of harvesting (Costa-Pierce 1987:327). Proper management called for periodic cleaning of the pond by

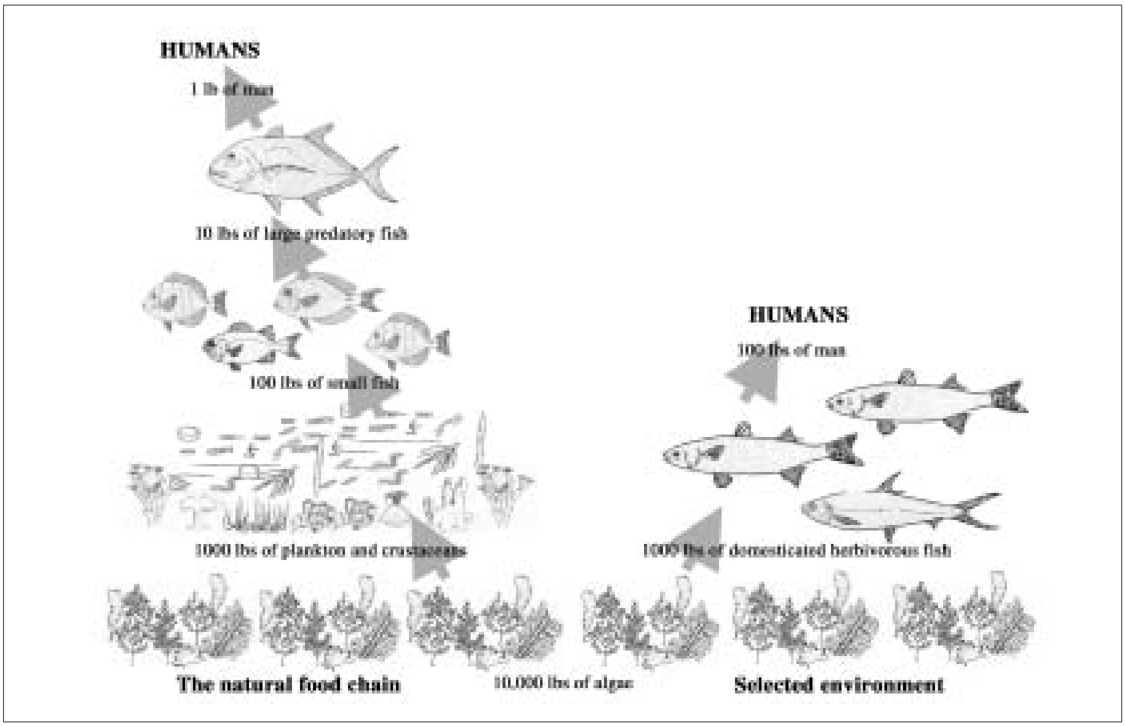

Figure 5. **The selective development of the herbivore link in comparison to the natural food chain.**
To the left is an illustration of the natural food chain with an energy conversion ratio of 10:1 from one link to another. To the right is an illustration of how the aquacultural ecology was a hundred times more efficient because of: (1) cultivating selected algae species, (2) domesticating herbivorous fish species, and (3) effectively reducing the number of predator species in the habitat.
(*Adapted from Hiatt 1947; Kelly 1989*)

breaking up the existing biota layer of algae to encourage new growth of benthic microbiota. This process of cleaning was accomplished by opening the sluice gate and flushing the system with the incoming tide. In some cases ponds became filled with silt after heavy rains. This silt could potentially harm algal growth, so weighted bamboo rakes, called *kope 'ohe*, were towed behind outrigger canoes to help facilitate movement of the accumulated sediment out of the ponds. This innovation of the *makahā*, or sluice gate, was very important because it allowed new seawater to enter the pond, bringing in fresh oxygen and nutrient flow of microplankton, and plankton in which other non-competing secondary domesticates feed (Hiatt 1947). The incoming water also brought opportunities to trap or catch larger predatory fish that flock into the sluices looking for prey. This was done simply by harvesting the larger fish in the sluice with small hand nets.

At least 22 species of edible marine life flourished in these ponds as secondary domesticates (Costa-Pierce 1987:326). In addition to the selected mullet and milkfish, and core assemblage of secondary species that could transverse with them through the different environments, there was a wide range of other inshore species that occupied this habitat. Some of these were threadfish (*Polydactylus sexfilis*; *moi*), anchovy (*Encrasicholina purpurea; nehu*), bonefish (*Albula vulpes; 'ō'io*), bigeye scad (*Selar crumenophthalmus*; *akule*), Hawaiian ladyfish (*Elops hawaiensis*; *awa'aua*), jacks (Carangidae; *pāpio* and *ulua*), as well as the crab (*Metopograpsus messor; 'alamihi*), numerous reef fish and invertebrates.

Aquacultural protein yields

One of the most innovative aspects of the aquacultural food production system was its ability to use the herbivore link in the biological food chain. Whereas the average yield theoretically increased over time because of the elaboration of coevolutionary relations, the absolute yield at any given moment was a function of specific environmental conditions. A natural food chain can be expected to produce a ratio of 10:1 in terms of conversion of one link to another (MacGinitie 1935). The cultivation and domestication of herbivorous fish species makes it possible to skip two steps in the natural order of the food chain. Herbivorous fish directly feed on the minute algae, organic detritus and diatoms growing on the larger algae on the bottom of the pond (Fig. 5). Thus, the natural food chain efficiency and protein yield was enhanced and multiplied a hundred-fold (Hiatt 1947; Kelly 1989) as the grey mullet and milkfish acted as bottom feeders and were directly harvested by their only predator, humans.

Discussion

Domestication is a biological process between animals and humans that developed through reciprocating relationships between humans and their environment. By adopting an evolutionary framework we are able to have a better understanding of the components that make up this domestication process. By looking at the different strategies that target reproduction, protection, growth and harvesting, it is clear that the symbiotic nature of this relationship is employed in many cultural practices throughout Oceania. Without breaking down the components that make up this process, many of these cultural practices and marine procurement strategies would continue to be overlooked, as they would not fit traditional view of what constitutes "domestication".

In Oceania, the marine environment has always been a reliable food source and hopefully this study has shown how it can be a neutral testing ground for questions of human interaction with the environment. The goal is to understand the basic principles that governed the relationship humans had with other species and with the environment as a whole. The larger purpose of this research is to serve as a foundation for future dialogue and discussion of the subject in oceanic research.

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