

East meets West: Hawai'i, a lesson for aquaculture development in the United States. Part II: aquaculture today

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In Part I (December 2009), the history, tradition and roots of aquaculture in Hawai'i were explored. In Part II, contemporary aquaculture in Hawai'i is examined to characterize production, adherence to traditional "ecoethos" and discover why waitresses, bus drivers and store clerks in Hawai'i are largely aware and supportive of aquaculture, a situation that is arguably unique in the United States. Perhaps those of us in the forty-nine states residing on the North American continent can learn and apply some of the insight gleaned over the centuries and currently applied in Hawai'i to our largely fledgling aquaculture pursuits.

Contemporary commercial aquaculture in Hawai'i reflects both traditional values and willingness to absorb new approaches. More than 30 species are cultured by 100-110 farmers that grow freshwater species (70 percent) and brackish or seawater organisms (30 percent). Culture protocols range from small-scale systems that mirror traditional fishpond management and yields, to sophisticated, complex operations that produce large numbers of aquatic organisms in intensively managed systems. Regardless of species grown and scale employed, a conscientious effort to respect the environment and Hawaiian traditions is pursued.

The Basics

Relatively low cost and user-friendly recirculating aquaculture systems operated by one or a few individuals are increasingly integrated into classrooms as hands-on instructional tools that breathe life into science, a subject that young people too often view as boring, dull and irrelevant. Additionally, the systems provide young people a contemporary aquaculture link with their traditional fishpond heritage. Similar systems are peppered throughout Hawaiian backyards as the local populace grows fish, principally Asian catfish or tilapia, for personal consumption. The compact, ecologically friendly systems use a settling basin or screen and biological filter to concentrate solid and metabolic wastes generated by fish so they can be repackaged into hydroponically grown herbs, tomatoes, lettuce, onions and other edible plants, also destined for personal consumption (Figure 1).

Backyard operations introduce people to aquaculture and re-introduce them to nature as operators manage systems and learn about nutrient flow and interactions among organisms in an ecosystem. Experience gained from manag-

List 1. Aquatic organisms cultured commercially in Hawaii (HawaiiAquaculture.org, undated; www.hawaii.gov/hdoa/pi/pq/lists, undated)

Abalone (red, *Haliotis rufens* and Japanese, *Haliotis discus hanaï*)
Amberjack (*Seriola rivoliana*)
Aquatic snails (*Pomacea* sp.)
Carp (*Ctenopharyngodon idellus*, *Hypothalmichthys molitrix*)
Catfish (*Clarius fuscus*)
Freshwater ornamental fish and aquatic plants (various species)
Broodstock, juvenile and market-size shrimp (*Litopenaeus vannamei*, *L. monodon*, *L. styliorostris*)
Freshwater prawns (*Macrobrachium rosenbergii*)
Giant clams (*Tridacna* sp.)
Japanese Flounder (*Paralichthys olivaceus*)
Lobster (*Homarus americanus*)
Marine ornamental fish and plants (various species)
Marine ornamental invertebrates (various species)
Marine shrimp for food (*Penaeus vannamei*)
Microalgae (*Spirulina* sp., *Hematococcus* sp.)
Milkfish (*Chanos chanos*)
Mullet (*Mugil cephalus*)
Pacific threadfin (*Polydactylus sexfilis*)
Seahorses (various species)
Seaweed or sea vegetables (*Gracilaria* sp.)
Seed clams (*Mercenaria mercenaria*)
Seed oysters (*Crassostrea gigas*, *Ostrea edulis*)
Seed pearl oysters (*Pinctada fucata*, *P. margaritifera*)
Tilapia (*Oreochromis* spp.)

ing small-scale systems has led to expansion into relatively low intensity commercial production that utilizes cages, tanks and/or ponds. Such commercial operations are usually family-run or employ no more than a half dozen peo-



Fig. 1. Maui Sea Grant Extension Specialist Bob Howerton instructs nearly a dozen schools, families and other groups (e.g., Senior Center, occupational therapy) how to manage backyard aquaculture systems. Pictured from r to l are the fish holding unit, clarifier, biological filter and aquaponic garden operated by students at the Kamehameha School Maui. Water flows from the fish holding unit through the clarifier, to the biological filter and to the aquaponic garden before being returned cleansed of wastes to the fish holding unit. (Photo by J Buttner)



Fig. 2. Cages (background) and net-pens (foreground) used by Ron and Estralita Weidenbach to grow tilapia for local markets in Hawaii. (Photo by J. Buttner)

ple, many part-time, and reflect the traditional, community-based management employed with fishponds.

Cage Culture

Cage culture in protected freshwater and marine environments is pursued globally to produce fish in waters that normally could not support aquaculture, such as deep quarries, rivers, large lakes or estuaries. Additionally, species that normally could not be grown together may be cultured in the same water. For instance, catfish normally prey upon freshwater shrimp, but both species may be cultured in one pond if catfish are housed in cages, while shrimp remain free-swimming. The approach is consistent with Hawai'ian willingness to employ new technologies that promote production without compromising environmental integrity.

In cage culture, small fish are stocked into mesh enclosures, fed and grown until they attain market size. In tropical/subtropical climates, tilapia are frequently farmed. The label “tilapia” is somewhat a misnomer as it references not one type of fish, but more than one hundred species that belong to at least three different taxonomic genera. Tilapia are hardy fish with mild flavor but intolerant of temperatures below $\sim 15^{\circ}\text{C}$. In Hawai'i, many species of tilapia were imported years ago and have established feral populations in fresh, brackish and, to a limited degree, coastal environments where they commonly sustain themselves on algae.

Ron Weidenbach, president of the Hawai'i Aquaculture Association, and his wife, Estralita, operate a cage culture farm on the North Shore of Oahu in an old quarry that filled with groundwater (Figure 2). The 3.3 ha quarry pond is over 30 m deep and water quality is suitable to culture tilapia year round. The property has been leased from the state since 1992, generating tax revenue while ensuring a continuous human presence, which mitigates a not insignificant liability concern. According to Ron “an Idaho strain of tilapia, apparently an *Oreochromis aureus*-based hybrid” are reared in 100 plastic-coated wire mesh cages (with structural support) and 12 larger net pens (without structural support). Both light-colored strains, preferred in Chinese, Japanese and American markets, and natural-colored strains, preferred by Filipinos and Vietnamese, are grown and sold locally. Absence of on-site electricity complicates culture operations inasmuch as supplemental aeration is unavailable. Fish management and health are achieved by observing fish behavior, not unlike management practices employed by *konohiki* of old that were responsible for fishes in traditional fishponds. Both Ron and Estralita have developed a strong “fish sense” after more than 30 years of growing fish in Hawai'i. They were the first and for many years the only growers to culture white spot catfish in Hawai'i. Limited numbers of Russian sturgeon and snake-heads are also produced in tanks to preclude their escape, the former experimentally and the latter for local markets.

Tank Culture

Hawai'i has an abundance of high quality water, appreciated and protected by both early and contemporary Hawaiians, which facilitates tank culture of aquatic organisms. Water from wells or the ocean is filtered to remove living and nonliving particles. Treated water flows continuously into tanks where ornamental fish or algae are farmed. Effluents discharge into seeps where coralline rocks passively filter and purify the water before its eventual return to the groundwater or ocean. Accumulated sediments are collected from freshwater seeps and used as soil enrichment for terrestrial plants, reminiscent of *Loko i'a kalo*, where fish waste was used to fertilize taro plants. In Hawai'i, a substantial industry based on tank culture technology exists, which produces ornamental fish and seaweed.

Ornamental fish support a \$30 million (hobbyist) ornamental fish production industry in the United States, with imports more than 10 times the value of exports (Harvey 2006). Historically, ornamental fish have been harvested from natural systems, often by destructive methods and with

little regard to the long-term survival of harvested fish and their ecosystem. Commercial culture of ornamental fishes not only ensures continuous availability of high quality organisms, but production methods are environmentally friendly unlike the wild harvest in some other areas of the world, which often involves illegally poisoning coral reefs or dynamiting fragile aquatic habitats to stun the fish and make collection easier.

Both Bob Kern and his farm operator, Mark Bornheimer, of Tropical Ponds Hawai'i, view commercial production of ornamental fish as more than a job and source of income. Bob is a special education teacher who operates a 5.3 ha freshwater facility consisting of sixty 50,000 L tanks located outside Hilo on the Big Island. In operation since 1995, Tropical Ponds Hawaii produces mostly swordtails (*Xiphophorus* sp.), destined for California hobbyists, and modest quantities of other fishes, such as platys, *Xiphophorus maculatus*, and gouramis (currently dominated by *Trichogaster trichopterus*, *T. leeri*, *Colisa chuna*, and *C. lalia*).

Ocean Rider, incorporated in 1998 by Carol and Craig Schmarr, who funded the operation with personal resources, targets sustainable culture of seahorses in fiberglass tanks and glass aquaria. Horrified by the indiscriminate overexploitation of wild seahorse populations by harvesters that removed up to one million seahorses annually, Carol and Craig decided to satisfy their dream to make a difference. They and their half dozen employees developed methods to spawn, rear and market seahorses, thereby reducing pressure on wild populations. Finding suitable space and water at the Natural Energy Laboratory of Hawaii Authority (NELHA), they follow rigorous standards that include health inspections and adherence to American Zoological Standards and guidelines established for Commercial International Trade in Endangered Species. Beyond producing more than 10 species of seahorses, they open Ocean Rider to informative, ecologically-based tours (Figure 3) and maintain a dynamic website (www.oceanrider.com). They have and continue to make a positive difference as outlined in their mission statement "to inspire and contribute to saving our planet's oceans by providing the aquarium hobbyist with beautiful and distinctive farm-raised ornamental sea horses." Assisting Carol and Craig with seahorse culture are six technicians. Reflecting a sincere commitment to the environment, neither Tropical Ponds Hawai'i nor Ocean Rider market any ornamental fishes in Hawaii, to preclude accidental release into and subsequent disruption of local ecosystems.

While many people recognize that fish are farmed, far fewer are aware that other organisms such as seaweeds, can be grown. Indeed, over 40 percent of Hawai'i's production in terms of value can be attributed to culture of seaweeds and other algae. Hawaiian Marine Enterprise on Oahu's north shore has commercially farmed seaweed (*Gracilaria* spp.) in tanks for local markets since 1983. Environmental conditions



Fig. 3. Ocean Rider personnel conduct 2-3 tours daily at their facility. Participants not only view seahorses and learn about their biology and ecology; they also get to handle a living seahorse.



Fig. 4. Rick Spencer, co-owner of Hawaiian Marine Enterprises, admires a hand-full of farmed *Gracilaria*. (Photo by J. Buttner)

are nearly perfect for continuous growth: plenty of sunshine, water temperature between 25-30°C and water of the highest quality with just enough dissolved nutrients to promote rapid growth. Operated by Rick Spencer and his business partner, Fred Mencher, 50 tanks are managed for seaweed production. A tank typically produces a biomass increase of 7-8 kg/day and increases in excess of 20 kg/day are not uncommon (Figure 4). Rick is intensely proud of his operation, which has "never missed an employee payroll" and has spawned at least a "dozen copy-cat firms." Ever resilient, Rick and Fred are currently looking for a new site as they recently learned their lease will not be renewed. Seaweed production requires little more than water, dissolved minerals and sunlight; it is arguably the most "green" form of aquaculture.

Pond Culture

More aquaculture production occurs in freshwater ponds than any other system, both in the United States and globally. Romy Aquinaldo and his family have leased land from the Campbell Estate for more than 20 years to grow freshwater and marine shrimp in over 65 ha of water managed by the family. As embraced by ancestral Hawai'ians, the Aquinaldo's culture methods differ little from those employed long ago; ponds are filled and supplemental food added. However, management methods are enhanced by a relatively new technology unavailable to *konohiki* or managers of traditional fishponds; ponds are aerated by paddlewheels that



Fig. 5. Romy's restaurant or shack attracts shrimp hungry tourist from Honolulu and Waikiki, 40 miles distant. (Photo by J. Buttner)



Fig. 6. Fee-fishing for prawns in a pond involves the entire family and provide a most unusual picnic experience. (Photo by J. Buttner)



Fig. 7. Cyanotech Director of Business Development Valerie Harmon, adjacent to pond circulated by paddle-wheel and lined with food-grade plastic used to culture spirulina. (Photo by J. Buttner)

splash and circulate water to promote health and growth of farmed crustaceans. As observed by his daughter, Kaylene: "Working with my father and family's business is a privilege that brings much happiness," an assertion that could have been made by siblings of *konohiki*.

A modest number of part-time and full-time employees assist Romy with farm operations. Several similarly managed shrimp farms exist throughout Hawaii, but none have been as creatively integrated as Romy's. While growing the highest quality organisms remains the primary focus, Romy's restaurant adjacent to his ponds has become an Oahu landmark and tourist attraction (Figure 5). Unlike other growers and restaurant operators, Romy sells only Hawai'i-reared products without any supplementation by imported shrimp. Recently, his entrepreneurial tendencies catapulted him into a new arena, fee-fishing for shrimp (Figure 6). Fee-fishing expands upon traditional production by opening and managing a site, commonly one or more ponds for recreational angling that affords individuals or families an opportunity to catch and retain fish, or as at Romy's, freshwater shrimp, from a heavily stocked pond. All equipment, processing and amenities are provided to ensure fast action and angling success in an aesthetically pleasing atmosphere, which excites youth and adults alike. Romy and his operation emulate a commitment to traditional Hawai'ian values as well as a willingness to pursue and employ new approaches.

High Intensity Aquaculture

While relatively small-scale aquaculture can provide a respectable income for a family or limited number of people and service local or niche markets, to produce aquatic organisms in large quantities for export or global markets requires expansion upon the basic aquaculture approach illustrated by backyard, cage, tank and pond culture. Guiding principles and production systems remain unchanged, but the magnitude of scale increases explosively in terms of cost, personnel, size, production and potential impact. Given the long aquaculture tradition and entrenched commitment to preserving environmental integrity, large-scale production in Hawai'i has been pursued cautiously, employing sophisticated technology and adhering to high standards of sustainability. High intensity, large-scale commercial aquaculture has occurred and is growing in two arenas: land-based systems with little or no discharge of water, particulate waste and metabolites; and open-ocean aquaculture at carefully selected and managed sites with state-of-the-art sea cages.

High-tech Algal Production

Cyanotech is the largest single aqua business in Hawai'i. Attracted to NELHA in 1984 by Hawai'i's political climate, abundant sunlight, optimal temperatures and NELHA's unique supply of deep and surface oceanic waters, Cyanotech employs over five dozen people to rear microscopic algae. Two microalgae, *Arthrospira platensis* and *Haematococcus pluvialis*, are cultured in over 36 ha of shallow, circulated ponds (Figure 7). Both algae are produced as human nutritional supplements and health foods.

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Fig. 8. *Spirulina* as a finished product, in tablet form and ready for retail to health conscious consumers. (Photo by J. Buttner)



Fig. 9. Hai Yuan, Vice President of Operations at KBMR, proudly, acknowledges Exporter of the Year award. (Photo by J. Buttner)



Fig. 10. Large uncovered tanks are used to grow juvenile shrimp to broodstock size. Tanks in center of image are linked to raceways that contain clams which filter suspended solids from water pumped from shrimp culture tanks before cleansed water is returned to the tanks. (Photo by J. Buttner)

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Arthrospira platensis is a unique and hardy organism that thrives under environmental conditions that challenge or preclude most life: pH \geq 9.5, salinity = 15 ppt, alkalinity = 16,800 mg/L. Freshwater mixed with deep seawater provided by NELHA and supplemented with sodium bicarbonate, carbon dioxide, and food grade fertilizer creates aquatic conditions conducive to rapid growth of spirulina. Efficacy of Cyanotech's approach is validated by its spirulina being the oldest continuously cultured strain in the world, with a production of 300-400 t annually and a quality product that has yet to be replicated elsewhere. Under optimal conditions, ponds may be harvested weekly.

Culture methods for *H. pluvialis* differ from those employed for *A. platensis*. Most notably, *H. pluvialis* is a freshwater alga relocated from indoor culture systems into ponds filled with freshwater, where conditions are manipulated to promote increased production of astaxanthin by the alga.

At harvest, both *A. platensis* and *H. pluvialis* are separated from their aquatic culture medium. Algal cells are cleansed, processed and prepared for market (Figure 8), and water is diverted to a retention pond where it is stored and used to refill drained ponds. There is no discharge from the site. Nutrients that precipitate in the retention pond are removed twice annually and applied locally as a soil enhancer. A Hazard Analysis Critical Control Point plan has been developed and all phases of production are carefully monitored to ensure that state, federal and European criteria are met so the final product can be widely marketed. Production of the highest quality product with negligible environmental impact is essential for commercial survival and facilitated by traditional Hawaiian respect for environmental integrity.

Pathogen-free Organisms

Evolving on islands of volcanic origin distant from other land masses, Hawai'ian flora and fauna have, until recently, developed in isolation. Isolation has produced an environment where parasites and pathogens that plague commercially important aquatic organisms elsewhere are not found. Capitalizing on Hawai'i's isolation and pathogen/parasite-free status, Kona Bay Marine Resources, Inc. (now, Sunrise Capital, Inc – Limaloa Farm for growout and Waimea Aquatic Laboratory for broodstock), based for 11 years at NELHA, developed its technical and commercial niche. Employing two dozen technicians from around the world, two exotic organisms are cultured for export: "Specific Pathogen Free" broodstock shrimp and "clean" juvenile hard clams. Utilizing Hawai'i's isolation and high water quality, "clean" organisms can be produced for distant markets. Indicative of their success at targeting and capitalizing foreign markets. In 2004, the company was acknowledged as Exporter of the Year for its environmentally-friendly track record and application of technology developed in Hawai'i (Figure 9).

Housed on somewhat more than 2.6 ha, 20 million juvenile clams (2-4 mm shell length) are produced and marketed per month. Clams are spawned and spat are reared on-site to approximately 0.85 mm before most are transferred to an off-site location where they are grown to market-size juve-

niles that are sold to farmers outside Hawai'i and then reared to a size suitable for human consumption. Many clams are retained at the NELHA site to assist with shrimp culture. Shrimp are spawned on-site and grown for 7-9 weeks in restricted and quarantined spawning/nursery systems, until they average 1-2 g. Juvenile shrimp are transferred to recirculating aquaculture systems where they are fed and grown until mature, an additional 9-12 months. While in the recirculating aquaculture systems, water carrying suspended solids, such as uneaten food, algae and shrimp waste is diverted over a bed of hard clams, which ingest the particles, obtaining sustenance from the effluent while restoring water quality (Figure 10). The operation replaces only five percent of its water daily. Part of the water is lost through a 5-10 minute daily discharge that removes settled solids from culture tanks and part is lost by evaporation. Discharged water is filtered and settleable solids concentrated on-site before cleansed water leaves the site. A commitment to environmental preservation as well as employing an integrated production system, where clams feed on shrimp waste and improve water quality passively for shrimp, are direct links to management practices employed in traditional fishponds.

Open Ocean Aquaculture

“Offshore aquaculture is a sector where Hawai'i leads the nation in commercial application of technologies” (Corbin 2007). Acknowledging both the necessity of aquaculture and the competing uses of coastal waters, global interest has recently shifted to aquaculture in offshore environments (Nash *et al.* 2005, Marine Aquaculture Task Force 2007). Many such operations exist in Asia, Europe and South America, but only four are located in deep waters of the United States. Two of the four U.S. operations produce fish commercially and both of these are based in Hawai'i. Located off Honolulu Harbor in waters surrounding O'ahu, is the 11.4 ha growout site of Hukilau Foods, Inc., formerly Cates International. The approximately 36.5 ha growout site of Kona Blue Water Farms lies off Kona, in waters surrounding the Big Island (Figure 11). Site selection and permitting were involved several agencies and the local community. The approach avoided potential conflicts, identified sites of suitable current and depth, and enlisted broad-based community support, reflective of community involvement employed in the past in construction, management and harvest of traditional fishponds.

By its nature, open ocean aquaculture is a technologically sophisticated and expensive endeavor that pushes aquaculture literally into new and only partially understood waters. Both Hukilau Foods, Inc. and Kona Blue Water Farms spawn and grow fish at land-based culture sites. Large-scale tank culture is pursued on land to produce hundreds of thousands of fingerling fish that are transferred to sea cages and grown to market size. Submersible sea cages (3,000 m³ each) are moored in 45-65 m of water by multiple anchors that weigh several tons each. Tons of feed are transported from shore to growout sites weekly. Certified divers inspect and maintain cages weekly. Sustainability and maintenance of environmental integrity are fundamental, both operations monitor water and benthic quality through indepen-



Fig. 11. Submersible sea cages managed by Kona Blue Water Farms partially exposed for routine maintenance and weekly harvest. (Photo by J. Buttner)



Fig. 12. Randy Cates (lt) and Jeff Barbieto prepare to transfer bagged fish food, in right foreground, to hydraulic feeder. (Image: J. Buttner)

dent contractors. These open ocean aquaculture operations have the potential to produce many tons of high quality fish per week, a potential being approximated today with realized harvests of 2.5-6 t per week. Both firms plan to expand production in the near future by adding more cages and additional sites.

Hukilau Foods, Inc. was developed by Randy Cates with final permits acquired in May 2001. Pacific threadfin was selected as the preferred species for culture. Fingerlings have been spawned and reared at the Oceanic Institute through a cooperative arrangement with the Waimanalo, HI based research facility. A \$6 million hatchery is being built to facilitate vertical integration of production. When fingerlings attain 5 g they are harvested, transported and stocked into one or more of the four 3,000 m³ sea cages anchored on-site (Figure 11). Fish are fed a prepared ration daily, delivered by a patented hydraulic feeder designed by Randy (Figure 12). When Pacific threadfin attain a target weight of 450 g, they are harvested and marketed locally. Randy is a very “hands-on” manager, having personally assisted with every fish transfer since cage installation.

Kona Blue Water Farms represents the culmination of efforts by Neil Sims, an Australian who arrived in Hawai'i



Fig. 13. Kona Kampachi™ start life as fertilized eggs, ~1 mm in diameter. Fish spawn continuously, providing a dependable and continuous supply of young fish. (Photo by J. Buttner)



Fig. 14. Community members helped restore the mākāhā (fish gate) of He'eia fishpond. Mākāhā permit passage of water and small fish, but restrict escapement of larger fish. (Photo by J. Buttner)

in 1991 “with a passion for finfish” and Dale Sarver (Ph.D. University of Hawaii), a local resident with international experience in aquaculture. They met at a Christmas party and started “to kick ideas around.” Ultimately, they formed their own aquaculture company focusing on environmental and economic imperatives. Kona Blue assisted with revisions to the ocean leasing legislation in Hawai‘i that were passed in 1998, which made open ocean aquaculture feasible. Dale and Neil held their first of many exploratory public meetings with the community in 2000. A multi-year information exchange ensued, which utilized the Internet and a company website. Complete transparency was a high priority as dialogue, impact assessments and concerns generated by the public were addressed by comprehensive and often personal responses. By 2004, permits had been secured and the first cage was deployed in 2005. Hawaiian amberjack (*Seriola rivoliana*), trademarked by the company as Kona Kampachi™ was selected as the preferred culture species, after exploring nearly a dozen, high-value candidate fishes. “Kampachi” is the Japanese name for *S. rivoliana*.

Kona Kampachi™ are spawned and reared to fingerling-size at Kona Blue’s land-based operation located at NELHA (Figure 13). When fingerlings reach a minimum of 5 g, they are transferred to sea cages for 10-11 months, until they have grown to market-size of 1.8-2.5 kg each. Harvested fish are of sushi quality and marketed internationally.

What about Fishponds?

Since 1900, desires to restore and maintain fishponds have been expressed and pursued by each generation, to no avail. Between 1900 and 1994 the number of fishponds in commercial production decreased from 99 to 6 (Farber 1997). In 1989, DHM *et al.* (1989) surveyed nearly 380 identifiable fishponds and found 30 in very good to excellent condition as defined by the seawall (*kuapā*) being in generally good to excellent condition, retaining much of the traditional construction technique and minimal siltation. Bureaucratic slothfulness, fishpond uniqueness and unrealistic expectations regarding economic viability all contributed to failed preservation efforts, despite the sincere desires and efforts of local communities. As contemporary aquaculture has been embraced and grown in Hawai‘i, interest in fishponds revived, stimulated by the Governor’s Molokai Fishpond Restoration Task Force in 1990 that brought ADP in partnership with the Molokai Community and Farber’s (1997) poignant examination of the challenges. Farber (1997) chronicled the ADP and Molokai Community initiative that culminated with restoration of two fishponds, requiring nearly five years from identification to completion. Farber argued strongly and convincingly that restoration efforts shouldn’t be determined solely by economic gain realized through fish production. Spiritual and cultural elements were co-equally important, but characteristically under-appreciated in permitting and decision making processes.

On-going renovation of He’eia fishpond on Oahu, characterized as in good condition by DHM *et al.* (1989), illustrates efficacy of the new, cooperative approach to restoration (Figure 14). He’eia fishpond is owned by Kamehameha Schools and preservation efforts are coordinated by Paepae O He’eia, a private non-profit organization dedicated to caring for He’eia Fishpond (www.paepaeohe'eia.org). The pond encompasses 40 ha enclosed by a 2.1 km seawall; pond depth is tidally influenced and ranges between 0.61 and 1.5 m. Natural fauna and flora include: surgeonfish (*Acanthurus* sp.), Pacific threadfin (*Polydactylus sexfilis*), milkfish (*Chanos chanos*), barracuda (*Sphyraena barracuda*), blennies (Blenniidae), mullet (*Mugil cephalus*), crabs, and algae (*Gracilaria salicornia*, *Acantophora spicifera*). Volunteers have replaced portions of the *kuapā* damaged during storms and removed a 76 m length of exotic, invasive mangroves from the fishpond that undermine the seawall’s integrity.

Opinions vary among Hawaiians as to how fishponds should be restored and managed. Some believe that only traditional materials and techniques should be employed, while others observe that their Polynesian ancestors were adaptable and embraced new techniques and technologies. Most likely, a composite approach that reflects desires of indi-

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Fig. 15. Wally Ito feeds Pacific threadfin farmed in one of five net-pens installed in He'eia fishpond. (Photo by J. Buttner)



Fig. 16. Hawaiian youth rediscover and embrace their cultural and aquatic roots. (Photo by J. Buttner)

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vidual communities will morph, with some ponds preserved and maintained in traditional ways and others hybridized to include more recent advances (Figure 15).

The Future

Hawaiians are justifiably proud of their heritage, whether they were born in Hawai'i (*kama' āina*) or relocated from elsewhere (*haole*). Fishponds and sustainable aquaculture are part of this heritage. Bus drivers, store clerks, waitresses, students and the public generally are largely familiar with and supportive of aquaculture, reflecting a shared culture and efficacy of the state's forty-year investment to the Blue Revolution and to sustainable aquaculture. Fishponds provide a tangible link with historic Polynesian roots, while sustainable aquaculture as variously pursued on or adjacent to islands keeps the heritage alive. Living with and on the

ocean remains relevant and vibrant today as young Hawaiians sustain their traditional roots, while embracing contemporary aquaculture as a means to ensure food and job security (Figure 16). A holistic approach built upon traditional cultural and environmental values augmented with scientific knowledge and appropriate technology has been pursued enthusiastically in Hawai'i. Commercial aquaculture has developed in a sustainable manner, creating jobs, perpetuating a fishing tradition and generating high quality products for local consumption and export.

The Lesson – A Global Perspective

In the 1970s modern aquaculture, the Blue Revolution, emerged globally, promising reliable supplies of high quality protein to eradicate human hunger while generating negligible environmental impact. To some degree this lofty aspiration has been realized; aquaculture production has greatly outpaced human population growth, with per capita supply increasing from 0.1 kg in 1970 to 7.1 kg in 2004 (FAO 2007). Salmon, once a seasonally available gourmet item or a canned product and mainstay for the common person, has become a universally available commodity as fresh or frozen fillets from fish increasingly raised under carefully and sustainably controlled conditions (Knapp *et al.* 2007). Shrimp prices have diminished and availability has increased due to aquaculture (Harvey 2006), increasingly pursued with ecological conscientiousness (FAO 1998, Barg *et al.* 1999, FAO 2003). Tilapia, a fish unknown to most consumers in the United States only one generation ago, is now the sixth most commonly consumed seafood in the United States, most of it imported (Harvey 2006, Johnson *et al.* 2006). While aquaculture globally has experienced dramatic growth and success, the United States has lagged in embracing and realizing the benefits of a sustainable aquaculture industry (Harvey 2006).

Hawai'i, with its long tradition of sustainable aquaculture, year-round warm temperatures, solar intensity among the highest of any state, abundance of high quality fresh and seawater, extensive coastline, aquaculture-friendly lease options, and a wealth of resident aquaculture expertise, represents a notable exception. Additionally, seafood consumption in Hawai'i is more than three times the national per capita average (www.hawaii.aquaculture.org). Fish is a large part of the traditional Hawaiian diet and a preferred food among Asians, an ethnic group that constitutes over 40 percent of the current Hawaiian population. Consumption is also enhanced by the millions of annual visitors that anticipate and seek high quality, fresh and tasty seafood dishes during their Hawaiian visit.

All forms of aquaculture practiced in the United States are pursued commercially in Hawai'i: finfish and shellfish; freshwater, saltwater and brackish water; minimal investment backyard and large-scale technologically sophisticated systems; and cold, cool and warmwater species. The Hawaiian approach and success can serve as a catalyst and template for expanded production in the United States. As the human population continues to grow in the United States and globally, securing a greater proportion of our food supply from the ocean becomes increasingly necessary. Commercial fish-

eries globally have stagnated at 90.4-95.6 million t between 1996 and 2005 inclusive, while world aquaculture has grown from 26.6 to 48.1 million t during the same time (Pritchard 2007). Aquaculture is not a luxury to be relegated off American shores, generating an \$8.8 billion dollar trade deficit in 2005.³ The United States possesses the technology, a willing workforce and one of the greatest reservoirs of aquatic resources globally. Certainly, locations on our Pacific, Atlantic and Gulf coasts as well as the Great Lakes and St. Lawrence River shared with Canada can prove amenable to sustainable aquaculture as a complement with other uses. While sustainability of aquaculture has been extensively debated from multiple perspectives (Goldburg *et al.* 2001, Anonymous 2003, Lubchenco 2003, Shumway *et al.* 2003, Weber 2003, White *et al.* 2004, Stickney *et al.* 2006, Knapp *et al.* 2007, Report of the Marine Aquaculture 2007, Sachs 2007, Weeks 2007), the Hawai'iian experience demonstrates concretely that aquaculture can be pursued with commercial success and with benign environmental impact, if appropriately located and managed. As we explore as a Nation and people, the potential role of commercial aquaculture in our Exclusive Economic Zone, including a pending bill HR2010 in the House and S1609 in the Senate, and elsewhere, we would do well to follow in the paths of the early Polynesians that colonized the Hawaiian Islands and assimilated new ways to perpetuate not only their own food security, but the quality of their island home.

Notes

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