HAWAI‘I OPEN OCEAN AQUACULTURE DEMONSTRATION PROGRAM

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ABSTRACT

Although Hawai‘i has been a leader in aquaculture research and development in the Pacific for several decades, no offshore aquaculture activity has been undertaken primarily because our offshore waters tend to be quite rough. The Hawaii Open Ocean Aquaculture Project (HOARP), a joint project between University of Hawai‘i (UH) Sea Grant, Safety Boats Hawai‘i, and the Oceanic Institute, began in 1998. An OceanSpar SeaStation 3000 sea cage was ordered in the fall of 1998 and growout operations commenced in April 1999.

Pacific threadfin *Polydactylus sexfilis,* locally known as *moi*, was chosen as the test species. The brood stock spawned in early February 1999 and 70,000 70-d-post-hatch juveniles (5-7 cm BL) were transferred to the cage in mid April. A special nursery cage was placed inside the main cage to contain the small juvenile fish and was used for approximately 4 wk, until the fish had reached sufficient size that they could no longer escape from the outer net.

Pacific threadfin are surf zone fish and one goal of the demonstration was to determine how these shallow water fish would grow at deeper depths. The top of the cage was at approximately 12 m depth during the growout of the fish. Although the fish are naturally adapted to very shallow water, they performed well at the greater depth.

Feeding was accomplished by means of a tube (10 cm in diameter) connected to the surface. A slurry of water and pelletized feed was introduced for several hr each d. Feed was supplied to the growing fish at a rate of several percent of total fish mass/d. Divers monitored the feeding which was terminated when a slight rain of pellets began to reach the bottom of the cage. Harvesting began in late August of 1999, about 4.5 mo after the fish were introduced into the cage, and continued on an incremental basis until October when the harvest of fish was completed.

The experiment successfully demonstrated the feasibility of growing *moi* at depths of 15 to 30 m and showed that this could be done in an economically viable way with no adverse environmental impact to water column, the sea floor, or the nearby coral reefs.

INTRODUCTION

Hawai‘i, an island state with limited land area but extensive offshore waters, has long viewed aquaculture as a viable means of adding to the economy. Beginning more than 800 yr ago, the ancient Hawaiian culture built fish ponds on the reef flats surrounding most of the islands for the culture of both brackishwater and saltwater fish (Kikuchi, 1976; Tamaru et al. 1998). The species cultivated in these ancient facilities included the grey mullet (*Mugil cephalus)* and the pacific threadfin or *moi* (*Polydactylus sexfilis*) as well as a broad mixture of other wild species.

With the growth of an industrialized society over the past century, most of these fishpond facilities have been allowed to deteriorate or have been filled with rock and soil, given the value of land. Few ponds remain today, and there is question as to whether the low-density culture technique practiced in the fishponds is economically viable given the cost of labor and the regulatory regime under which the operation must function (Tamaru et al. 1998).

However, the past practices can also be looked upon from another perspective. These rock structures constructed on the reef flats were a ‘state-of-the-art’ means of cultivating the ocean many centuries ago. But in today’s culture, modern high-strength materials such as steel and Spectra netting replace the rocks and sticks of yesteryear and thus the modern fishpond becomes a net-enclosed structure supported by a steel frame. And these modern materials permit the utilization of waters further offshore and thus further from the environmentally sensitive coastal region.

RATIONALE AND OPPORTUNITIES

It is well recognized worldwide that capture harvest of wild fisheries has reached critical levels and will not be sustainable in the near future. Aquaculture production of target species has been viewed as a means to supplement increasing demands for fish and fishery products. Seafood demand is projected to nearly double in the next quarter century based upon population growth alone and, as New (1997) has pointed out, aquaculture production must rise to meet this increase in demand.

Great strides have been made in marine aquaculture technologies in the past decade and it is now possible to produce many species of fish in land-based intensive culture systems at costs that are comparable to or below those of harvesting wild stocks. Expanding the use of the ocean to include aquaculture will provide economic opportunities for fish farmers, engineers, commercial fishermen, and seafood processors by enabling the production of aquaculture products at commercially significant levels.

The commercial development of offshore aquaculture in the United States has been impeded by the lack of demonstrated feasibility in critical areas, such as engineering of containment structures to withstand open-ocean conditions, adequate information on rate of growth and survivorship in containment structures for interesting species, and efficient offshore production management and harvesting methods. These broad issues, as well as more regionally specific issues such as regulations regarding marine deployment and environmental protection, were addressed by the Hawaii Open Ocean Aquaculture Project (HOARP). This project was the first integrated demonstration of the potential for offshore production in the State of Hawai‘i, and was designed to demonstrate the feasibility and practicality of offshore culture of a high-value, ethnically desirable, locally endemic fish.

The project was funded by the National Sea Grant Office of the National Oceanic and Atmospheric Administration (NOAA) and called for the demonstration of the feasibility of offshore aquaculture in Hawaiian waters as the primary goal. This project made maximum utilization of existing information including the marine finfish culture technologies for *moi* developed by the UH Sea Grant College Program (May 1976) and the Oceanic Institute (Ostrowski 1998) with a commercial offshore containment system supplied by Net Systems (Bainbridge Island, WA, USA). Throughout the project considerable effort was made to assure that the project was conducted in an environmentally acceptable way, for environmental acceptability is a critical factor in the long-term viability of an offshore mariculture industry in the State of Hawai‘i.

Site Location

The primary constraints to conducting offshore aquaculture in Hawai‘i are twofold: environmental compatibility issues, and the physical constraints of weather, oceanographic conditions, and port access. To minimize these constraints, we considered and evaluated several sites along the south and west shores of O‘ahu. In the end we chose to do the initial experiments about 13 km west of Honolulu Harbor at a site about 3 km offshore in water about 30 m deep. A site with a sandy bottom was chosen as ideal for the type of anchors being used and also to minimize the impact on the coral reef ecosystem (an ecosystem perceived to be environmentally sensitive and easily damaged). The nearest reef is about 800 m away. The site for the research project is located to the west of the entrance to Pearl Harbor, approximately 3 km SSE of the coastal community of Ewa Beach and is adjacent to a military testing area.

Project Objectives

Feasibility of offshore culture of finfish is dependent upon several real issues that deal with the biologic performance of the fish and the culture system, several perceived issues that deal with the environmental issues of cage culture in an area that prides itself on scenic beauty and the high water quality in offshore areas, and the general need for the determination of economic costs and benefits of this type of activity. Within these general issues in mind, several specific project objectives were defined to:

- Demonstrate that environmentally compatible, offshore aquaculture can function in Hawai‘i
- Develop a cooperative, effective, and coordinated partnership among the key Hawai‘i contributors to the project, and serve as a test model for offshore aquaculture research and demonstration projects throughout the United States
- Conduct test marketing of aquaculture products derived from project activities both locally and worldwide
- Demonstrate feasibility of submerged growout of *moi*
- Develop means of underwater feeding and harvesting
- Identify and examine issues that might constrain future industrial development

ACCOMPLISHMENTS

A site was identified and research activity was permitted in approximately 30 m of water at a location with a sandy bottom with no nearby coral formation. All offshore waters in Hawai‘i are classified as a conservation district and thus special permits are required for any activity within 5 km of shore (State of Hawai‘i waters). Rather than go through the lengthy full permitting process required by the regulations governing an offshore lease, the project chose to avail itself of the simpler procedure of applying for a permit to do research within the conservation zone. But even this process is cumbersome, for consultations were required with many agencies or divisions of those agencies. These included five divisions of the Department of Land and Natural Resource (DLNR) - (Aquatic Resources, Land, Boating and Recreation, and the Aquaculture Development Program) the Department of Health, the Department of Economic Development and Tourism, the Office of State Planning (particularly its Office of Environmental Quality Control), the United States Coast Guard, the United States Army Corps of Engineers, and the United States Navy. In the end three written permits were required (DLNR Conservation District Use Permit, Army Corps of Engineers, DLNR-Boating and Recreation Mooring Permit) and more than 9 mo elapsed between the start of the process and the issuance of the final permit.

Once we were fairly confident that the necessary permits would eventually be forthcoming, anchors were placed on the sandy sea floor in the four corners of an imaginary rectangle about 100 by 300 m in extent. Four anchors, with anchor lines five times as long as the water depth, were used and, since bi-directional strong currents were known to exist in the area, safety considerations required that two anchors, each capable of holding the cage in place, be deployed to each side of the cage. Each anchor is 3 t or more in weight (more than needed but the price was right - free) and each line has a subsurface float near the anchor end to hold the line in a constant taut configuration. All anchors and cage deployment activities were constrained to be within 300 m of the permitted location.

Cage System

A totally enclosed, semi-submersible cage produced by Net Systems was chosen for the project. Several types of cages were considered but the perceived need for a cage that could be maintained in a fully-submerged condition was thought to be an important, and perhaps even critical, parameter. Thus an OceanSpar Sea Station 3000 was purchased.

The cage is bi-conical in shape, approximately 25 m in diameter and 15 m in depth with a working volume of about 2,600 cubic m (see Fig. 1). The cage was moored on a four-point anchor system with a working anchor scope in excess of 5:1. Each anchor was larger than required since they were from a stock of surplus anchors and the smallest had a mass of greater than 3 t. Each anchor was attached to the cage with Spectra mooring line and a short piece of heavy anchor chain. Subsurface floats were attached to the Spectra line approximately 20 m from the chain to provide a compensation system that assures that the anchor lines remain taut, yet shock absorbing, at all times.

The skin of the cage consists of a hexagonal mesh of Spectra netting with an opening of 2 cm. The netting is stretched taut between 12 guy lines that attach the ring to the spar. For purposes of regulation, the Coast Guard

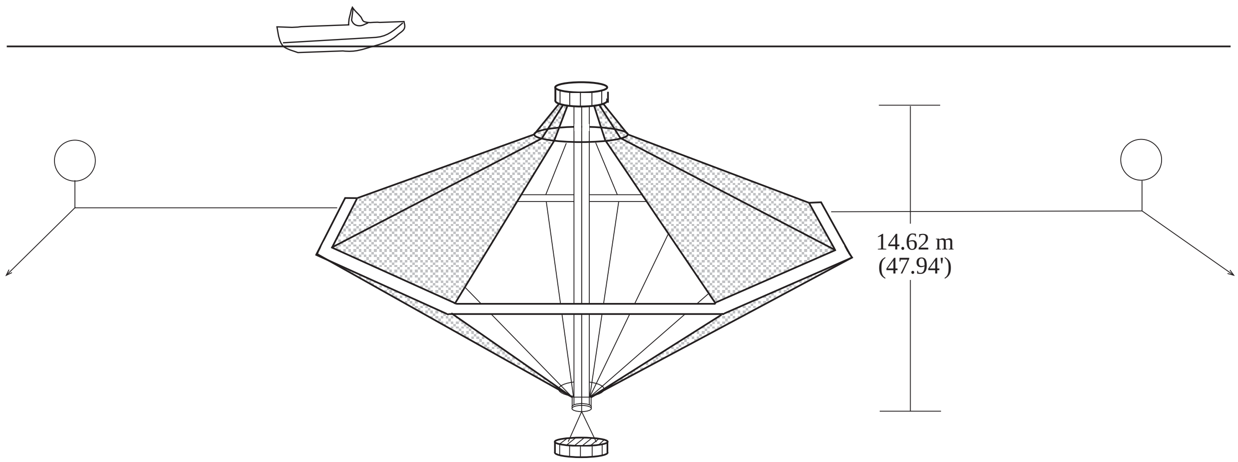

Figure 1. Schematic presentation of the sea cage used in this project.

has defined the cage structure as a moored vessel, a barge, when it is at the surface.

The cage was constructed at the surface of the sea. Once construction was completed, half of the spar was flooded and the cages settled until its ballast weight contacted the sea floor. The cage remained fully submerged, with the very top of the cage about 12 m below the surface, for the duration of the experiment. All stock introduction, feeding, and harvesting was done from this fully-submerged location.

Species of Culture

The species of fish chosen for culture is the indigenous Pacific threadfin (*Polydactylus sexfilis*), known locally as *moi*. This fish has been highly regarded in Hawai‘i since ancient times when it was known as the food of the *ali‘i*, only to be consumed by members of Hawaiian royalty. *Moi* was commercially fished in the past but over-fishing and over-regulation effectively removed it as a commercially exploitable stock (see Fig. 2). Today, annual commercial catch from the wild averages less than 1,000 kg, although considerably more is thought to be caught for individual consumption.

In the 1970s the UH Sea Grant College Program supported research into the life cycle of *moi* and over the last 5 yr the Oceanic Institute has developed culture technologies appropriate for the threadfin making it the newest commercially grown species in Hawai‘i. The species grows well in captivity, reaches a market size (350 g) in 6 mo and sells in the round for about US$10/kg at the farm gate.

Moi is the only marine species currently being cultured in Hawai‘i in numbers sufficient for the demonstration project. Methods for the hatchery production of fry have been described by Ostrowski and Molnar (1998). The parents of the cultured *moi* are captured from the indigenous wild stock of Hawai‘i and genetic mapping has indicated that fish are of one genetic stock. *Moi* from the same parents are currently being grown for release for stock enhancement purposes. Thus an accidental release of fish from the cage would have no adverse genetic impacts on wild populations. A cooperative export marketing plan was devised to ensure that local farm producers would not be adversely affected by our test offshore production efforts.

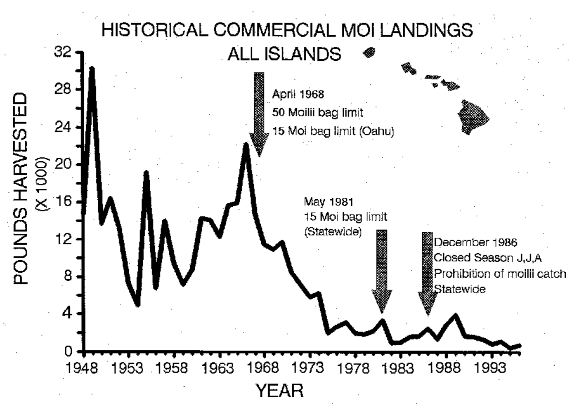

Figure 2. Commercial landings of the *moi* in Hawai‘i between 1948 and 1996. Arrows indicate implementation of fishing restrictions. Source: Division of Aquatic Resources, State of Hawai‘i.

Operations

The cage was deployed in March 1999 and is expected to remain in the water 18-24 mo. It was constructed and deployed approximately 1 mo prior to fish delivery to assure it was sea worthy. A few days prior to the introduction of the juvenile fish to the cage, an inner nursery net (0.5 cm mesh) was deployed around the central spar inside the main net. This nursery net has about one-tenth the volume of the main net. The nursery net within the main cage was stocked in mid-April 1999 with approximately 70,000 fingerlings of two cohort classes: 70-d-old Pacific threadfin (approximately 10 cm long and 12 g in weight) and 50-d-old fish weighing 4 g. The fish were fed to satiation each morning with a commercially pelleted feed (initially 2 mm pellets and later 5 mm pellets) for the duration of the project (6 mo). After about 1 mo, the inner nursery net was removed giving the young fish access to the entire main cage.

Harvest commenced in early September when fish reached 180 d of age (350 g in weight) and continued for approximately 2 mo until all the fish were harvested. At the end of the experiment, the cage and its associated mooring system was secured and left at the site to await a second experiment that was planned for the following year.

Fish were sampled once every month for weight and length and compared with growth studies conducted in tanks on shore. Growth was comparable in the tanks and in the cage although those in the cage grew slightly less rapidly and they appear to have had a wider size spread. Samples of fish were provided to the State Fish Pathologist (Dr. James Brock) on a more or less monthly basis and no disease was noted. The health of the fish was examined daily and any dead fish were removed and examined for parasites, bacteria, and other indicators of disease. None were noted. Mortality was generally low once the pulse of stress-induced mortality associated with the transfer operations ended. At harvest, 52,000 fish were taken from the cage with a total harvest weight of slightly more than 18,000 kg.

Feed conversion efficiency was less than expected and the feed conversion ratio (FCR) was 1.8 kg dry food/kg fish. Based upon previous tank experiments we had expected an FCR of 1.3 to 1.5. The fish fed in tanks on land, however, had a similar low FCR of 1.7 when fed under the same one-feeding-per-day regime. Thus, the relatively poor FCR performance for the cage at sea was probably due to the once-a-day feeding strategy. This strategy has been modified for the second experiment currently underway.

Environmental Analysis

Quantitative and qualitative assessments of pelagic and benthic animal and plant communities around the cage was conducted prior to cage deployment, during growout, and after fish harvest. Bottom samples taken from points around the cage showed little systematic change except during a period of overfeeding. During this period, feed was allowed to fall through the cage and this abundant source of food produced a change in the ratio of indicator organisms under the cage (Dave Bybee, personal communication). Once the extra feed was removed, the bottom biota rapidly returned to its pre-cage ratios.

Fish and algal communities on the outside of the cage were also monitored. Initially, algae rapidly accumulated on the mesh of the net and the divers were barely able to remove it by scrubbing as rapidly as it grew. But during the summer, an equilibrium was established between the growth rate of the algae and the foraging rate of the herbivores external to the cage. This community of fish, our 'worker fish', took about 3 mo to accumulate to an extent that they grazed off the algae as rapidly as it grew. The primary components of this fish community were broomtail filefish or *loulu* (*Alutera scripta*) and various surgeonfish or *palani* (*Acanthurus dussumieri)*, *pualo* (*Acanthurus blochii* and *Acanthurus xanthopterus*). *K hala* (*Seriola dumerilii)*, a carangid, also took up residence beneath the cage. Other fish that were observed from time to time include, Sandbar sharks (*Carcharinus milberti)*, *'opelu* (*Decapterus macarellus)*, *akule* (*Selar crumenophthalmus)*, *kawakawa* (*Euthynus affinis)* and *ono* (*Acanthocybium solandri)*.

Hydrological data also was collected three times during the experiment: once at the start, once near the time of maximum biomass, and again at the end of the experiment shortly after harvest. Observations made included temperature, velocity and direction of the current, wave height, and turbidity. All parameters were within the range expected for Hawai‘i waters although the current was generally less than that anticipated (it was rarely above one knot). Water samples also were taken down current and up current from the cage to determine water chemistry and total suspended solids. Unfortunately, the sampling frequency was too infrequent to establish a clear correlation with feeding rate or biomass. In fact, the data on water chemistry showed essentially no signal from the presence of the fish except for a slight elevation in the NH_4 level just downstream of the cage. The site is located in Class A waters between two point source high nutrient discharges (sewage discharge diffusers) and this, and the natural but variable outflow of nutrients from Pearl Harbor, produced high variability in the background water quality readings in the same range as those produced by the fish in the cage.

Prior to the experiment a number of UH scientists at both the M noa and Hilo campuses participated in several offshore aquaculture planning and advisory sessions. In general, the assessments and projections this group made prior to the experiment were born out by the observations made during the experiment. Assessment of the feeding levels proposed indicated that the nutrients from the cage would have no detrimental impact on the water column or the benthic communities surrounding the cage due to the large volumes of water involved. This was verified by observations during and after the experiment, for only temporary transitory effects were noted or no effect could be found. The advisory group also stated that given the currents present at the site and the rapid exchange of offshore waters and the immense expanse of the seas surrounding the islands, it is unlikely the small addition of organic carbon and nutrients to nearshore waters would have a measurable effect on water quality. Again, no effects were noted.

Retrospective Analysis

Looking back on the experiment, we can see that we learned may things. We established that a locally desirable fish, *moi*, can be grown in a totally submerged offshore cage. We also established a baseline protocol for the feeding and harvesting of the fish in the submerged cage and we established that no lasting negative environmental impact would result from the deployment of an offshore fish farm stocked with a limited number of fish.

But we also learned that the experiment had many shortcomings. We did not succeed in stocking the cage at a commercial density and our number of fish at harvest was far too low for the cost and effort it took to raise them. The cost of feeding the fish was between US$100,000 and $160,000 for labor and operations and US$60,000 in feed and supplies. This suggests our cost, without amortization of the cage or the consideration of maintenance and management costs, was about US$9/kg. In other words, the experiment was sub-economic and the number of fish would have to be increased by at least a factor of three to begin to have an economically viable growout effort. Moreover, many of the environmental effects were too small to be noticed due to the relatively small number of fish. Thus, in order to examine the economic viability and the potential environmental impacts on the ocean immediately outside the cage, the experiment should be repeated using between 100,000 and 150,000 fish.

Several technical issues must be addressed as well. First, a more efficient feeding methodology must be developed to include multiple feeding stations as well as a means for more continuous feeding. This may mean more time on station by those overseeing the feeding or it may require the development of an underwater feeding system that can provide one or more supplemental feedings each day.

A second technical issue is the method of harvesting. The OceanSpar SeaStation 3000 is designed to be bulk-harvested all at one time. A means to undertake a progressive harvest is needed for the market has yet to be developed for large quantities of *moi* at any given time. The project developed a rudimentary progressive harvest technique using a fish pump methodology. This worked, but it required a large expenditure of manpower, three or four divers, on harvest days.

Thus, a more efficient progressive harvest system is necessary.

The size of fish in any one harvest was quite variable. Initially this ranged from 250 g to 500 g and by the last harvest the range had increased to 300 g to 750 g. Since the market prefers fish of more uniform size, a means of grading the fish prior to harvest is desirable. This issue was not addressed during this experiment.

Marketing was not addressed in a systematic way. Naively, we thought we only had to call a wholesaler when the fish would be ready to harvest. It was a surprise to find that there was no market for these highly-prized fish outside of Hawai‘i. Thus, if this fish is going to be used for a culture industry, much effort has to be spent on the development of markets outside the state.

Transfer of the fish to the cage proved to be more difficult than envisaged. This was in part due to the size of the fish. The large 10 to 12 g fish proved to be much more susceptible to stress from handling than anticipated. We deliberately chose to raise the fish to 70-d-post-hatch on land rather than transferring them at the usual 30 to 50 d so as to reduce the stress of placing the fish in a high current environment when they were still small. But this almost proved to be our undoing for nearly 30% of the fish died during the transfer operation. Lack of oxygen, poor water quality, possible elevated temperatures, and surface abrasions and the resulting secondary infections proved to be the primary causes of mortality. It is felt that a more rapid transfer, and a transfer at a younger age, could have avoided most of these problems. (This surmise was proven in the second experiment currently underway were younger fish (50-d-old) were transferred successfully with very low mortality).

Local sales were conducted at the UH M noa campus where we found good market demand when fish were sold at US$5-$6/lb (US$12-$14/kg.). Clearly there is a fairly large and untapped local market for this fish. International sales were primarily to Mexico where this unknown fish was readily accepted at a rate of about 3 mt/wk. The price was low for this introductory effort but it is thought that future international sales could be substantial if a market is properly promoted.

CONCLUSIONS

The Hawaii Open Ocean Demonstration Program successfully grew and marketed more than 50,000 fish (*moi* or *Polydactylus sexfilis*) in a subsurface offshore cage in an effort to define the constraints and impediments an offshore aquaculture industry in Hawai‘i might face. For the most part, the operation went very smoothly and no insurmountable problems were found in the culture, operation, or marketing of the fish. The most difficult part of the project was acquiring the required permits. The project used a research permit approach, which required a minimum of permits, but even so, the permitting problem is probably the most significant issue to be overcome. Public acceptance of the project was high and the results suggest that offshore aquaculture, conducted with an appreciation for minimizing the real and perceived impacts on the environment, can be a viable business opportunity in Hawai‘i.

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