Hawaii Offshore Aquaculture Research Project

(HOARP) - Phase II

Final Report

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EXECUTIVE SUMMARY

It is now well recognized that capture harvest of wild fisheries will be unable to meet rising regional and global demands for fish and fishery products in the next millennium. NOAA and the National Sea Grant Office have identified offshore aquaculture as a potential means to alleviate pressures on wild stocks in the United States, while providing new economic opportunities and promoting responsible use of ocean resources. The Hawaii Offshore Aquaculture Research Project (HOARP) is executed and managed by the University of Hawaii (UH) and the Oceanic Institute (OI), in association with the State of Hawaii's Aquaculture Development Program (ADP), and local commercial interests. The purpose of the project is to explore the biological, economic, and environmental suitability of offshore aquaculture in Hawaii and the Pacific region.

HOARP Phase II continued efforts initiated in 1999 under HOARP Phase I to investigate the feasibility of offshore production of Pacific threadfin (*Polydactylus sexfilis*) in a commercial-sized, submersible sea cage in open coastal waters off south Oahu. The overall goal was to improve upon those areas identified during Phase I as critical to move the technology of submerged cage offshore aquaculture closer to commercialization. OI researchers focused on improved biological performance of threadfin and the effects of activities on surrounding water quality and fauna attracted to the cage and an adjacent coral rubble area. OI also worked with a local distributor to sell the byproducts of this research effort, while gaining baseline information essential to marketing of the product. UH researchers focused on the effects of activities on the surrounding benthic biota, and analyses of the economics of an offshore operation. Safety Boats Hawaii, Inc., a local salvage company, provided the vessel for operations and daily cage maintenance. Project participants worked closely with the State of Hawaii's Departments of Health; Land and Natural Resources; Agriculture; Boating and Ocean Recreation; and the U.S. Army Corps of Engineers and Coast Guard.

Results of the 6-month growout of fish in a single 2,600 m^3 bi-conical sea cage yielded final harvest weights (417.7±85.3g) 14% greater and a maximum cage density (12.4 kg/m^3) and harvest (34,850 kg) double that obtained in Phase I. However, overall survival (58%) and feed conversion (2.1) were not improved. An expanded sampling regimen employed improved detection abilities, recording higher than ambient ammonia levels a full cage diameter downstream. Changes in benthic and coral rubble fauna were minimal, while the cage attracted a resident population of an estimated 800 kg of finfish. Economic sensitivity analyses revealed that improvements in biological aspects of the operation were needed to reduce risk and improve the bottom line.

Critical areas identified for subsequent research were to improve nursery cage management to increase survival during this most critical stage, to improve feed conversion and/or reduced cost to minimize overall feeding costs, and to establish a multi-cage effort to better assess the environmental effects of a commercial operation. These issues, as well as research directed at expanding the market characteristics of threadfin and a preliminary assessment of another species for diversification are currently being proposed for HOARP Phase III.

1.0 INTRODUCTION

Great strides have been made in recent years in the technology of offshore containment systems, and several nations have adopted offshore aquaculture at either commercial or experimental levels. Development of offshore capabilities in the U.S. has been hampered by restrictive permitting processes in coastal regions and lack of demonstrated feasibility in critical areas, such as engineering of containment structures to withstand open-ocean conditions, adequate hatchery technologies for target species, and efficient offshore production management and harvesting methods. These broad issues, as well as more regionally specific issues such as marine construction and environmental regulations, need to be addressed before offshore aquaculture production can become feasible.

The ultimate goal of HOARP is to provide a scientific basis for evaluation of the biological, environmental, and economic feasibility of offshore aquaculture in the Pacific region, and ultimately, the entire U.S. HOARP is a joint research effort between the Oceanic Institute and the University of Hawaii Sea Grant College Program in partnership with state governmental agencies, commercial farmers, and seafood processors. Phase I of this project successfully demonstrated the technical feasibility of raising and harvesting large numbers of marine fish in an offshore containment structure under completely submerged conditions. Phase II targeted improvements in biological and operational performance, and better estimates of the environmental and economic impacts of a completely submerged operation.

Section 2.0 outlines the primary objectives targeted in the proposal. It also provides a brief overview of the project organization and responsible work group members for each subcontracted research task. OI was the primary contractor, with other research subcontracts to UH.

Section 3.0 addresses the principal accomplishments under each of the four primary objectives. It outlines the rationale, procedures, priority results, and discussion of each task. Some primary tasks are separated into subtasks for clarity. Accomplishments include efforts to improve biological performance and harvest density of fish, to expand and improve water quality monitoring, to discern effects of activities on surrounding benthic biota, and to describe the fauna attracted to the cage and adjacent coral rubble area. The final task is an assessment of a hypothetical, six-cage offshore production farm that details all capital and operational costs based on results of the research efforts, and a sensitivity analysis to define areas of research and development to improve profitability.

Section 4.0 provides an overall project conclusion from Phases I and II and considerations for future research. HOARP Phase II targeted improvements on results obtained during Phase I and identified key areas for scientific pursuit critical to the advancement of this technology to commercialization. While the suitability of Pacific threadfin to offshore production was demonstrated, several areas of research are critical to establish overall economic viability, environmental capability, and long-term sustainability of a potential offshore industry in Hawaii.

Seven progress reports were submitted for HOARP Phase II: October 1 through June 15, 2000; June 16 through July 15, 2000; July 16 through August 15, 2000; August 16 through September 15, 2000; September 16 through October 15, 2000; October 16 through November 15, 2000;

November 16 through December 15, 2000. Portions of these reports were also submitted by the Sea Grant Director to the Departments of Health (DOH) and Land and Natural Resources (DLNR) in fulfillment of permit requirements. This final report summaries all activities from October 1, 1999 through February 28, 2001. Two appendices include the following: fish health assessments from the State of Hawaii's Aquatic veterinarian; and detailed water quality results.

2.0 OBJECTIVES

This section outlines the primary objectives as stated in the original proposal and responsible work group members. This was a joint research effort between the Oceanic Institute (OI) and University of Hawaii (UH).

1. Determine biological performance of Pacific threadfin (*Polydactylus sexfilis*), locally known as *moi*, in an offshore containment system during the more turbulent Hawaiian winter ocean conditions and stocked at a targeted commercial harvest of 20kg/m^3.
    - Responsible member: A. C. Ostrowski, OI

2. Generate preliminary assessment and evaluation of environmental impacts of the system on surrounding waters and benthic communities.
    - Responsible members: A. C. Ostrowski, OI for water quality
      J. Bailey-Brock, UH for benthic communities

3. Estimate trophic level interactions of resident species and evaluate the influence of the system as a fish aggregation device.
    - Responsible member: A. C. Ostrowski, OI

4. Estimate the production cost structure and profitability of offshore culture of *moi* in Hawaii.
    - Responsible member: P.-S. Leung, UH

3.0 PRINCIPAL ACCOMPLISHMENTS

3.1 Determine biological performance of Pacific threadfin (*Polydactylus sexfilis*) in an offshore containment system during the more turbulent Hawaiian winter ocean conditions and stocked at a targeted commercial harvest density of 20kg/m^3.

3.1.1 Rationale

Overall survival of Pacific threadfin harvested from the 2,600 m^3 Sea Station^{TM} cage during Phase I was 73% compared to 92% of fish raised in onshore, reference tanks. In addition, the feed conversion ratio (FCR) of fish fed both on and offshore was 1.8, and 1.7 respectively. This does not compare favorably to FCRs of 1.3, historically obtained during on-shore growout of this species. Reasons for the poor survival were primarily due to inefficient and stressful transfer methods. Poor FCRs in both on and offshore tanks were suspected due to the feeding method adapted to the behavior of the fish, in which fish were fed almost continuously over the course of the day. The original target objective was to determine biological performance of fish during the winter season in Hawaii, at a target harvest density of 20 kg/m^3. Rather than stocking more fish based on offshore survival rates and feeding in a similar manner as Phase I, the objective for this task was redirected to improve transfer survival and feed fish in discrete feedings to improve FCR. Overall objectives would be achieved in a more efficient manner. It was also decided to repeat the trial over the same season of the year.

3.1.2 Procedure

Pacific threadfin fingerlings were produced using the methods developed by Ostrowski and Molnar (1998). Eggs were collected from a spawning group of wild broodstock held at OI in early April, 1999. Briefly, six 5-ton circular tanks were stocked with an average 150,000 eggs each. F1 generation larvae hatched directly in tanks. Larvae were raised using combinations of enriched rotifers (*Brachionus plicatilis*) and Artemia (*Artemia salina*) through metamorphosis to 25 days of age (D25), and partially trained to accept pelleted feed. Samples of fry were examined for extent of opercular deformity, a malady common in cultured threadfin. Fry were then harvested from tanks and transferred into Nursery Phase I. Approximately 15,000 fish were stocked into each of eight, 5-ton circular tanks (2.5-ton working volume) to D39. On D39, fish were transferred to ten, 30-ton circular (7.3 m diameter) tanks (20-ton working volume) for Nursery Phase II (D40 –D80) to further grow and condition fish for transfer to the cage. Target densities at the end of Nursery Phase II were 6 – 7 kg/m^3.

Fish were transferred from the land-based tanks to the Sea Station^{TM} beginning on D50 over three consecutive days. Fish were loaded into a 1-ton hauling container at OI and transported by flatbed truck (1-ton) to Makai Pier directly across the street from OI. Each hauling bin was stocked with approximately 7,000 fish, targeting densities between 14 and 19 kg/m^3. Once at Makai Pier, the hauling bins were transferred by crane to an awaiting 18 x 5.5 m support boat for the 2.5-hour trip to the cage. Each hauling bin was supplied a continuous flow of fresh seawater supplemented with pure oxygen during the entire trip. Fish were gravity fed into a 1,200 m^3 nursery net located inside the Sea Station^{TM} using a 10 cm (4”) flexible hose and water from a 5.5 hp pump to flush the line. The nursery net was constructed of ¼” stretch, nylon mesh and was attached to the center spar of the Sea Station^{TM} creating a bi-conical shape similar to the larger cage. The Sea Station^{TM} was completely submerged under water during the entire transfer process.

In addition to fish in the cage, three land-based, 10 m^3 circular fiberglass growout tanks (working volume = 7 m^3) were stocked to provide a reference for growth and survival of fish offshore. Fish (D50) stocked into the land-based tanks were from the same sibling group as was stocked into the offshore cage. A total 316 fish were stocked into each tank targeting roughly the same operating density (45 fish/m^3) as fish in the cage. Water flows in onshore tanks were adjusted monthly to accommodate increases in biomass to a loading rate of no greater than 1.0 kg/liter/minute.

Fish in the cage and onshore tanks were subjected to the same feeding, maintenance, and sampling protocols. Fish were fed a dry, pelleted feed (Marine Grower, Moore-Clarke, Co., Canada) twice daily to satiation for six months between approximately 0800-1000 and 1400-1530 hours. Feeding onshore was conducted by hand and satiation determined when fish were no longer accepting feed or exhibiting schooling behavior around the center standpipe. Feeding offshore was conducted using a modified version of the venturi-style feeding system designed during HOARP Phase I. Briefly, the system was modified to include a rectangular PVC frame, constructed out of 10 cm internal diameter PVC pipe, placed horizontally in the water column. From this, four different feeding ports were constructed to improve feed distribution. Satiation offshore was determined when fish would break from schooling about the center spar and spread out in the cage. A Feeding Systems Canada U/W video camera with a 120^o field of view connected to a black and white monitor through a 33 m cable was used to assist diver observations of fish behavior during feeding and estimation of satiation.

Weight (g) and fork length (FL) (cm) of fish in the cage and onshore tanks were determined at stocking and then monthly until harvest. One group of approximately 30 fish was taken randomly from each replicate tank. Fish were anesthetized with 90 ppm tricanemethane sulfonate (MS-222), weighed, measured, and returned to tanks after recovery in fresh seawater. Three replicate samples of approximately 100 fish each were taken offshore. Fish were collected by scuba divers with hand held nets, sacrificed onboard with an iced brine bath, and brought back to OI.

In addition, approximately 6-10 live fish from both onshore and offshore were taken monthly to the State of Hawaii’s Aquatic Veterinarian for health assessment. Major organ tissues were blocked and processed by routine histology methods. The slides were stained with hematoxylin and eosin.

The experiment was concluded on October 17, 2000, the first day of fish harvest offshore (D234). All fish onshore were sacrificed, weighed, and measured on D235. Fish offshore were harvested twice weekly through December 2, 2000 for distribution and sale by a local fishmonger to markets outside Hawaii. The same airlift system and corral developed during HOARP I was used to harvest fish from the submerged cage. Thirteen harvests were conducted yielding approximately 2,273 kg of fish each. Approximately 5% of the estimated number of fish in each harvest were individually weighed (gm) and measured (FL), and examined to record any skeletal deformity.

Weight gain, feed conversion (dry feed fed/wet weight gain), specific growth rate (ln final weight – ln initial weight/days x 100), and condition factor (weight of fish/FL^3 x 100), and survival were calculated during the interim periods and at the end of the trial. The feed conversion ratio (FCR = dry feed fed/wet weight gain) of fish onshore was calculated monthly and at the end of the experiment based on the average weight of the fish and the amount of feed fed over time. Monthly FCRs of fish offshore were back calculated after all harvests were completed and the total number of fish recovered was known. All FCR calculations took into account losses due to dead fish recovered. FCRs of fish offshore included losses due to fish not recovered as well, or fish missing as a result of the difference between those stocked and those recovered alive or dead. For calculations, all missing fish were assumed to have been lost during the offshore nursery stage when fish were small enough to be susceptible to either sibling cannibalism or rapid disintegration in the offshore environment.

Percent survival in onshore tanks was calculated by counting the number of fish remaining in each replicate tank minus recorded mortality and any fish missing from the original stocking number at the end of harvest. Survival of fish offshore was calculated from the sub-samples taken during each harvest and the total number of fish harvested that day. Overall survival was determined as the difference between the total number of fish stocked and the sum of all fish estimated from each harvest. An additional check of average weights was conducted during the packaging process for shipment and sale at the fishmonger. Each shipping box was packed with approximately 20 kg of whole fish. Fish were counted individually in randomly selected boxes and the average weight of fish per box recorded.

3.1.3 Results

3.1.3.1 Survival

A total 193,500 twenty-five day old (D25) threadfin were produced from the OI hatchery yielding an average survival from hatching (22.3%), slightly less than historically obtained (Ostrowski and Molnar 1998). Hatch rate from eggs stocked averaged 98.4 ± 11.5%. Each fry produced weighed an average 0.026 ± 0.07 g. Overall deformity rate on D25 was 35.3 ± 16.6%. This percentage consisted of fish exhibiting both wrinkled (23.2 ± 11.0%) and missing (12.2 ± 7.7%) opercula. No other deformities could be discerned at this stage. These figures were within historical ranges.

A total 137,635 fingerlings were produced during the Nursery Phase I run, yielding a survival rate (71.1%) slightly lower than normally obtained (85%). Fish harvested on D39 weighed 0.4 ± 0.1 g. Nursery Phase II yielded 134,094 D50 fish weighing 2.2 ± 0.5g. Survival during Nursery Phase II was 97.4%. There were no indications of any infectious disease in fish prior to stocking.

Transfer time from placing fish into hauling bins at OI to stocking into the nursery cage offshore was approximately 5 hours. Six hauling bins were used on the transfer vessel provided by Safety Boats Hawaii, Inc., the commercial contractor used for vessel support activities. A total 2,619 fish died during the first week, including the 3-day transfer process, for an overall of 98.1% transfer survival.

Harvest of fish offshore started on D234 and continued through D281. A total 34,850 kg was recorded harvested from the cage. The total number harvested based on individual fish weighing was 77,257 and only slightly higher than 72,640 based on box weighing (Table 1). Survival based on the individual weighing estimate was 58%. Of the 134,094 fish stocked on D50, only 5,300 (4%) were recovered as mortality and samples over the course of the experiment and harvest. Approximately 51,537 (38%) fish were unaccounted for and assumed missing. In contrast, survival of fish onshore was 76.5 ± 1.9 %, with 10.1 ± 0.6 % recovered as mortality and 13.4 ± 1.6 % assumed missing or part of counting error.

Table 1 Average weights of harvested fish per sample day as evaluated by Oceanic Institute staff (A) and commercial weighing (B).

Date	AV Wt (g) A	AV Wt (g) B
17-Oct-00	417.7±85.3	401.2
21-Oct-00	445.9±89.1	417.7±23.9
24-Oct-00	412.4±96.0	418±44.3
28-Oct-00	465.8±94.6	435.9±20.5
31-Oct-00	464.8±107.8	434.8±22.8
4-Nov-00	463.8±108.5	441±18.5
7-Nov-00	440.5±107.1	448.4±19.5
11-Nov-00	445.2±111.4	445.9±23.4
14-Nov-00	378.9±134.5	452.5±21.2
21-Nov-00	483.9±129.2	487±19.5
25-Nov-00	485.4±128.9	476±24.6
28-Nov-00	484.6±130.4	436.7±7.9
2-Dec-00	475.0±111.9	447±27.5
Av Wt (g)	**451.1±32.3**	**443.7±22.8**
# Of Fish	**77257**	**72640**
% Survival	**58**	**54**

3.1.3.2 Growth

There appeared to be no diverging patterns of growth between onshore and offshore fish throughout the trial (Fig. 1, Table 2). The average weight of fish at harvest offshore (417.7 ± 85.3 g) was less than 10% greater than fish onshore (380.1 ± 12.7 g). At peak biomass (D234), the average density of fish onshore was 12.6 ± 0.2 kg/m^3. The peak biomass of fish offshore was 12.4 kg/m^3.

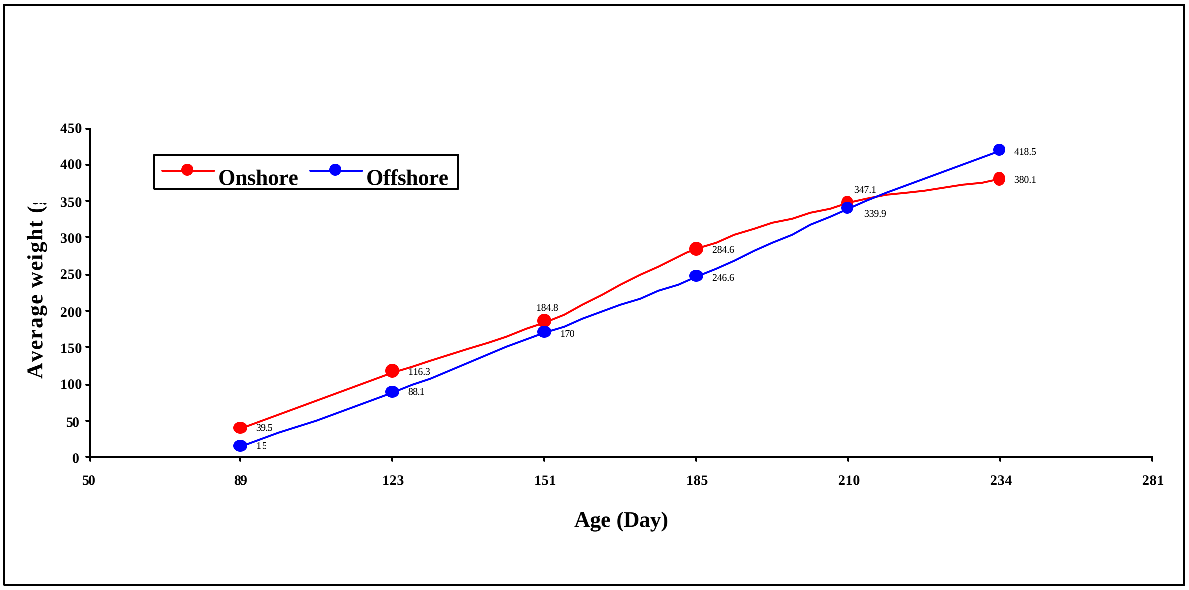


Figure 1. Monthly growth of Pacific threadfin (*Polydactylus sexfilis*) in replicate onshore (10 m^3, 7 m^3 working volume) tanks and in a 2,600 m^3 submerged Sea Station^{TM} 3000 moored 2 miles off the southern coast of Oahu. Fish in both systems were from the same sibling group and stocked in parallel. Water temperature averaged 25 ± 1°C offshore and 26 ± 1°C onshore. Biomass loading rates were 1.0 kg/lpm onshore, and ranged between 7.0 x 10^{-10} – 1.7 x 10^{-10} kg/lpm offshore.

Table 2. Biological performance of Pacific threadfin (*Polydactylus sexfilis*) in duplicate onshore (10m^3, 7m^3 working volume) tanks and in a 2,600m^3 submerged Sea Station^{TM} 3000 moored 2 miles off the southern coast of Oahu. Fish in both systems were from the same sibling group and stocked in parallel. Water temperature averaged 25 ± 1°C offshore and 26 ± 1°C onshore. Biomass loading rates were 1.0 kg/lpm onshore, ranging between 7.0 x 10^{-10} – 1.7 x 10^{-10} kg/lpm offshore.

	ONSHORE				**OFFSHORE**			
	Av Wt (g)	**FCR**	**SGR (%)**	**CFI**	**Av Wt (g)**	**FCR**	**SGR (%)**	**CFI**
D89	**39.5±3.9**	**0.5±0.1**	**10.3±0.4**	**1.6±0.0**	**15.0±5.0**	**1.7**	**6.5**	**1.6±0.1**
D89-123	**116.25±2.7**	**1.0±0.0**	**3.1±0.3**	**2.0±0.1**	**88.0±23.1**	**1.5**	**4.5**	**2.0±0.1**
D123-151	**184.8±7.2**	**1.6±0.1**	**1.7±0.1**	**2.1±0.0**	**170.0±12.7**	**1.2**	**2.3**	**2.0±0.1**
D151-185	**284.6±9.9**	**1.5±0.3**	**1.3±0.2**	**2.1±0.0**	**246.6±8.0**	**2.9**	**1.3**	**2.1±0.0**
D185-210	**347.1±16.8**	**1.5±0.6**	**0.8±0.3**	**2.2±0.0**	**339.9±13.2**	**2.5**	**1.1**	**2.2 ±0.0**
D210-234	**380.1±12.7**	**14.8±22.5**	**0.4±0.3**	**2.1±0.0**	**418.5±83.2**	**2.2**	**0.8**	**2.2±0.0**
cumm 235		**1.3±0.1**	**2.8±0.0**		**418.5±83.2**	**2.1**	**2.8**	

Individual weights of fish harvested from both the onshore and offshore systems were normally distributed (Figure 2 a & b). At first harvest on D234, approximately 63% of fish harvested offshore and 76% of fish harvested onshore fell into the targeted harvest weights between 251g and 450g. By final harvest on D281, 76% of fish harvested offshore fell into the same range. There did not appear to be any difference between the two growout systems on overall size distribution of harvested fish. Only about 1.3% of fish harvested (347 kg) were rejected for sale, averaging 153.9 g each. Informally, the majority of these rejected fish exhibited a combination of mouth and opercular deformity.

Figure 2a

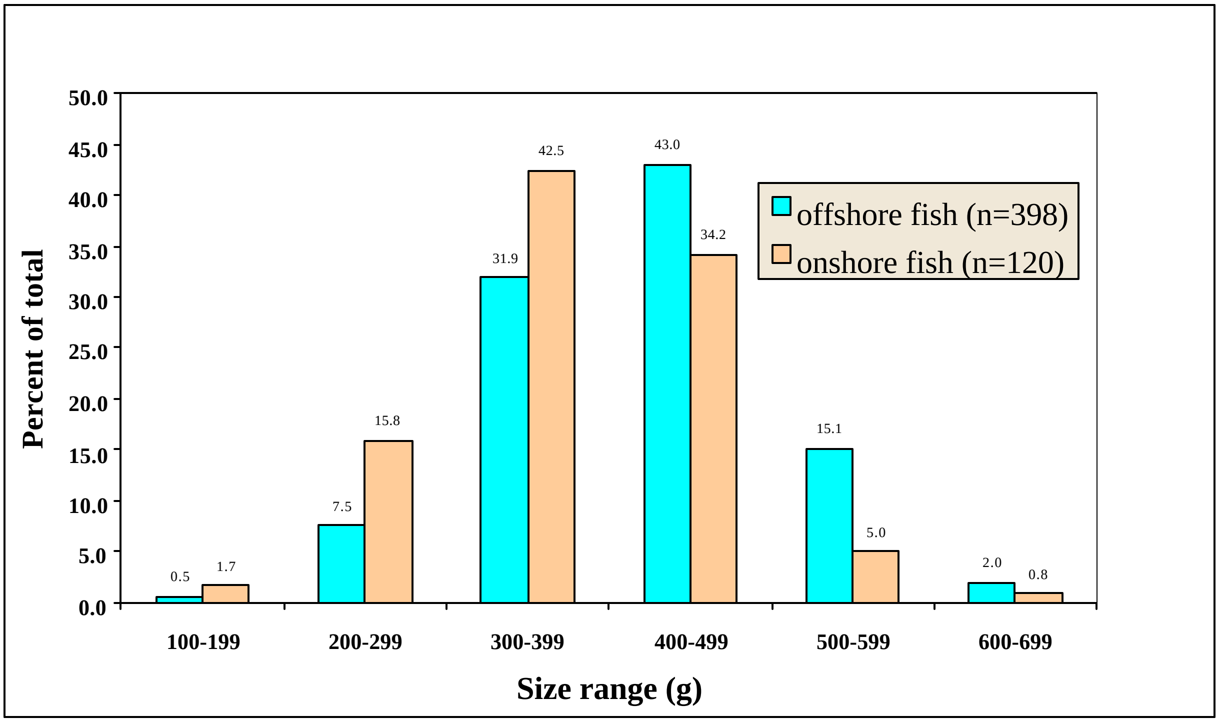


Figure 2b

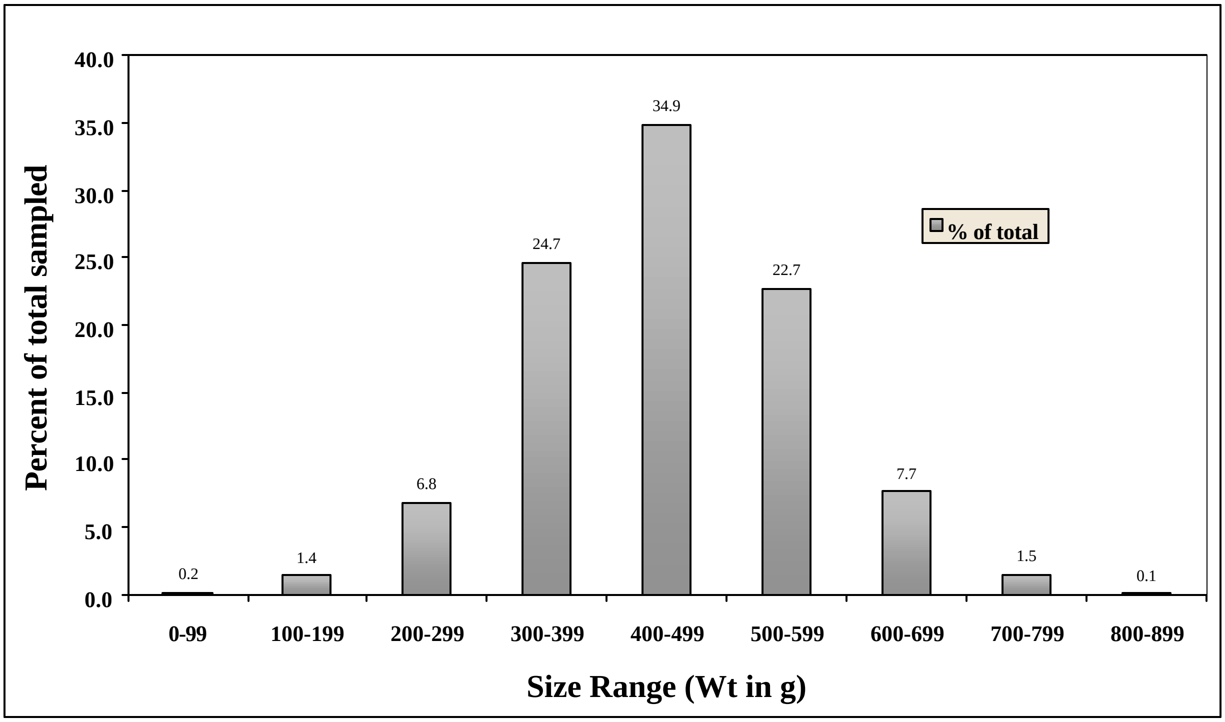


Figure 2 a & b. Size distribution of Pacific threadfin at first harvest (Figure 2a = D234) and final harvest (Figure 2b = D281) from onshore (10m^3; 7m^3 working volume) tanks and a 2600m^3 Sea Station^{TM} during HOARP Phase II.

3.1.3.3 Feed Utilization

The overall FCR of fish onshore to D235 was much lower (1.3 ± 0.1) than that calculated for fish offshore (2.1) at the end of the trial (Table 2). The interim measurements for fish offshore should be viewed with caution since actual numbers of fish used to calculate the value were not known, and only back calculated at the end of the trial. The total amount of feed presented to fish offshore was 70,590 kg (Table 3).

Table 3. Total amount of feed fed to offshore fish.

Age (Fish)	**Total feed (kg)**
D84	1,775
D85-123	8,635
D124-152	12,380
D153-180	17,020
D181-209	18,180
D210-235	12,600
Total	**70,590**

3.1.3.4 Fish Condition & Health

Condition factors of fish grown onshore and offshore did not differ (P>0.20) throughout the trial indicating a similar degree of general robustness (Table 2). Condition factor reached a maximum of 2.0 in both groups by D123. There were also no differences (P>0.20) in gutted weight (93.8 ± 0.7% vs. 92.2 ± 1.0%) and total fillet ratio with skin on (63.6 ± 0.0% vs. 63.6 ± 1.4%) of fish raised onshore and offshore, respectively. The fillet ratio without skin was 49.7 ± 0.0% for fish raised onshore and 49.4 ± 2.4 % for fish raised offshore.

Fish appeared outwardly healthy with no signs of disease or lethargy throughout the trial. Routine veterinary inspection, however, raised questions about the general safety of fish for human consumption (see Appendix A). Histology revealed (beginning at D110) cytoplasmic vacuolation in livers of several fish sampled offshore. Differential diagnosis required by inspection included possibilities of toxic insult, either due to feed spoilage or water-borne pollution. A series of tests conducted (Appendix A) on feed and water samples about the cage excluded these possibilities.

Approximately 2,725 fish raised offshore were individually examined for deformity during the thirteen harvests (Figure 3). Approximately 69.5 ± 0.1% of fish had no deformities. Total deformity recorded was 30.5 ± 0.1%, consisting of shortened or missing opercula (21.9 ±3.8%), jaw skewness (8.1 ± 0.0%) and scoliosis (0.6 ± 0.0 %).

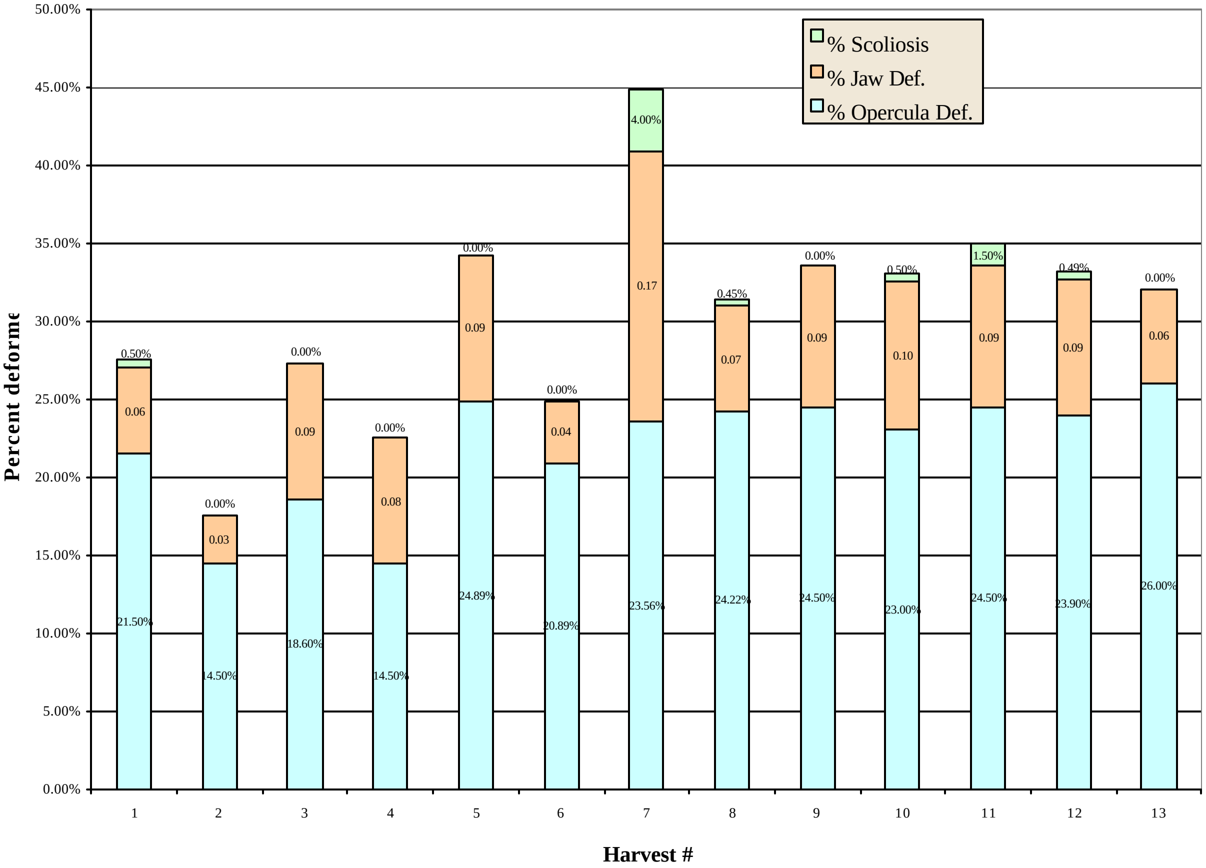


Figure 3. Relative distribution of skeletal deformities of Pacific threadfin (*Polydactylus sexfilis*) harvested from a 2,600 m^3 SeaStation^{TM} during HOARP II.

3.1.4 Discussion

HOARP Phase II achieved the goals of improving growth of threadfin (0.41-0.48 kg fish harvested) and doubling harvest density (12.4 kg/m^3, with over 34,850 kg harvested), but with little change in FCR (2.1) and overall harvest survival (58%) compared to Phase I. The first and most compelling issue that arises is the unaccounted losses of over a third (38%) of fish stocked that was missing at the end of the trial. This was a much higher figure than the 10% missing fish reported for HOARP Phase I (Ostrowski 2000) when larger, 10g (D69) fish were stocked. During Phase I only 74% of fish stocked survived during and shortly after transfer to the nursery cage due to both human error and the stress of transport in closed-system transfer containers. A remaining 3% were recovered as mortality, yielding an overall recovery or survival rate of fish at the end of harvest at 61%. At least a portion of the unaccounted losses could have been due to counting error at stocking. To reduce mortality due to stress and length of the transfer process, 2g (D50) fish were stocked during Phase II, using an improved flow-through transfer container system. Although transfer survival of these fish (98%) was much better than that of fish during

Phase I, final recovery represented only 58% of total fish stocked. Dead fish recovered was less than 4%. It is suspected that the majority of the unaccounted losses (38%) in Phase II occurred during the nursery stage. It is at this stage when cannibalism is prevalent (Ostrowski *et al*. 1996), and where natural settling behaviors of juvenile threadfin (Ostrowski and Molnar 1998) expose them to the risks of crowding at the bottom of a bio-conical nursery cage design. An appropriate stocking size of threadfin to reduce cannibalism in an offshore nursery cage appears to be between 2 and 10g, and it is unclear whether a better nursery cage design can be used, at least for this species.

The second issue that arises from these results is the general health of fish and fitness for human consumption. High liver lipid levels are common in intensively cultured fish, and the effects on fish (Woods *et al*. 1995; Craig *et al*. 1999) and human (Ackman and Polvi 1988; Singh and Chandra 1988) health have received increased attention. It is not clear what effects high liver lipid levels and cytoplasmic vacuolation has on aquacultured Pacific threadfin. After rigorous analyses of feed and water samples about the cage to exclude toxic insult, the most probable explanations for the changes are improper dietary formulation for this species or overfeeding. During Phase I, a continuous feeding regimen employed throughout the day resulted in a 1.8 FCR, similar to that of fish in onshore tanks (1.7) fed similarly. The discrete feeding regimen employed during Phase II did not improve FCR of fish offshore (i.e. 2.1), but did bring the FCR of fish onshore (1.3) to levels normally recorded in onshore systems with this species (Ostrowski 2000). It is important to address this issue and prevent excessive accumulation of lipid in the liver and to avoid questions of adverse effects on human health that might prevent sale of fish raised offshore in the marketplace. It may be possible to improve liver histology, function and overall feed utilization, without affecting growth or body composition of threadfin with changes in dietary formulation or feeding regimen.

3.2 Preliminary evaluation of environmental impacts of the cage system on surrounding waters and benthic communities.

3.2.1 Effects on Water Quality

3.2.1.1 Rationale

Probably one of the most prominent issues facing all animal agriculture production systems worldwide today is the effect of feeds and animal wastes on degradation of environmental quality (Blake *et al*. 1991, Fuentes-Quezada 1996, Stillborn 1996). Several studies from around the world have indicated that intensive aquaculture practices can cause detrimental environmental effects to regional coastal areas, enclosed bays, and estuaries (Aure and Stigebrandt 1990, EPA 1991, Hirata *et al*. 1994). Salmon net pen farms in British Columbia have been heavily criticized for their potential environmental and social costs (Ellis and Wier 1996). In the U.S., new technologies for land-based marine shrimp farming are being developed in direct response to concerns about degradation of sensitive coastal resources, biosecurity for the aquaculture production and coastal shrimp stocks, and user conflicts for scarce resources (Moss *et al*. 1998). Offshore aquaculture is thought to reduce environmental effects because of presence of currents and sufficient depths to distribute and dilute mariculture wastes to the surrounding environment (Gowen *et al*. 1989, Penchang and Newell 1997).

The main pollutants arising from feed, fecal, and excretory waste, are organic carbon, organic nitrogen, and soluble nitrogenous compounds. About 60–90% of the nitrogen waste is excreted in the form of soluble ammonia through the gills (Lovell 1989). Dissolution of uneaten feed also releases carbon and nitrogen from the protein, fat and carbohydrate components. Decomposition of feeds, dissolution of unconsumed feed, and fish respiration might also significantly lower the dissolved oxygen in the water column surrounding the cage and also down current from the cage.

3.2.1.2 Procedure

The plan adopted for measuring water quality during HOARP Phase II was modified to improve detection levels and overall efficiency of the monitoring plan. It focused to closely examine two key aspects, total ammonia and total suspended solids (TSS). These two parameters were measured routinely, while measurements of other nutrient parameters falling under National Pollution Discharge Elimination System (NPDES) permit requirements occurring only at peak biomass periods.

Initial water samples were taken in March of 2000, three months after fish from the Phase I project were harvested from the cage and just prior to stocking fish for Phase II. These samples included analysis of all water quality parameters for a NPDES permit from nine sites designated on the original CDUA permit for Phase I.

Beginning on May 9, 2000 duplicate water samples were collected by SCUBA (Self Contained Underwater Breathing Apparatus) on a weekly, monthly, and quarterly basis. All samples were collected approximately four hours after the first feeding of the day, just prior to second feeding. Initial techniques employed use of zip-lock bags to collect water at depth, one bag at a time. Samples were transferred into 200 ml plastic sample bottles that were previously acid washed with 10 % Hydrogen Chloride (HCl) and distilled water. Revised collection techniques were implemented on July 14, 2000 to eliminate differences observed in analysis of replicate samples. Revised procedures for ammonia included use of a 60 cc plastic syringe (HCl 10% solution acid washed and distilled water rinsed prior to collection) with replicate syringes taped together for simultaneously collection. Each set of syringes were taken to the appropriate sampling site and rinsed three to five times with seawater at depth before collection of sample. Samples were brought to the surface and placed into 60 ml Nalgene bottles (acid washed and rinsed with distilled water) on the boat. Samples were stored on ice and brought back to OI and frozen until taken to the SOEST Analytical Services Lab at University of Hawaii for analysis. Special care was taken for the ammonia samples due to low sensitivity of the equipment used to detect levels of ammonia. All samples were analyzed using an auto-analyzer suing to standard methods for automated nutrient analysis. The practical detection limit was 0.03 µm.

Water samples for TSS and nutrients were collected in a 1 liter plastic bottle. Bottles were acid washed with 10% HCl and rinsed with distilled water. The bottles were further rinsed (three to five rinses with surface salt water) before taken to depth and opened. Samples were returned to the surface, stored on ice, and brought back to the lab at OI for analysis. Nutrients were analyzed using a Zellweger Analytics, Lachat Instruments QuikChem FIA+ 8000 Series instrument using the following methods: Nitrate+Nitrite, method #31-107-04-1-C, nitrite method # 10-107-05-1-A, ortho-phosphate method #31-115-01-3-C, total nitrogen method # 31-107-04-1-B and total phosphorous method # 30-115-01-1-B.

The sampling regimen employed included weekly, monthly, and quarterly estimates:

Weekly:

Ammonia and TSS were measured weekly. Initially, replicate samples were taken from only the upstream and downstream locations of the rim of the cage at 18m depth (Fig. 4). Additional samples were included 15 meters downstream from the rim of the cage (18 m depth) on June 2, 2000, and 30 m downstream from the rim of the cage (18 m depth) on August 10, 2000.

Monthly:

A broader range of sampling sites for ammonia and TSS were taken monthly during the last four months of the project when biomass in the cage reached significant levels (Fig. 4). The additional sites included: 15m downstream to the north lateral edge of the rim of the cage (18m depth); 15m downstream to the south lateral edge of the rim of the cage (18m depth); and at the reef approximately 0.5 m from the cage (18 m depth).

Quarterly:

Quarterly samples for July 6, and November 27 consisted of all samples included in weekly and monthly listed above in addition to the following: 30 m downstream water depth 30 m; and 30 m downstream water depth 13.2 m (Fig. 4). All quarterly replicate samples were analyzed for the following: ammonia, nitrate+nitrite, total nitrogen, soluble reactive phosphate, total phosphate, turbidity, total suspended solids and chlorophyll A.

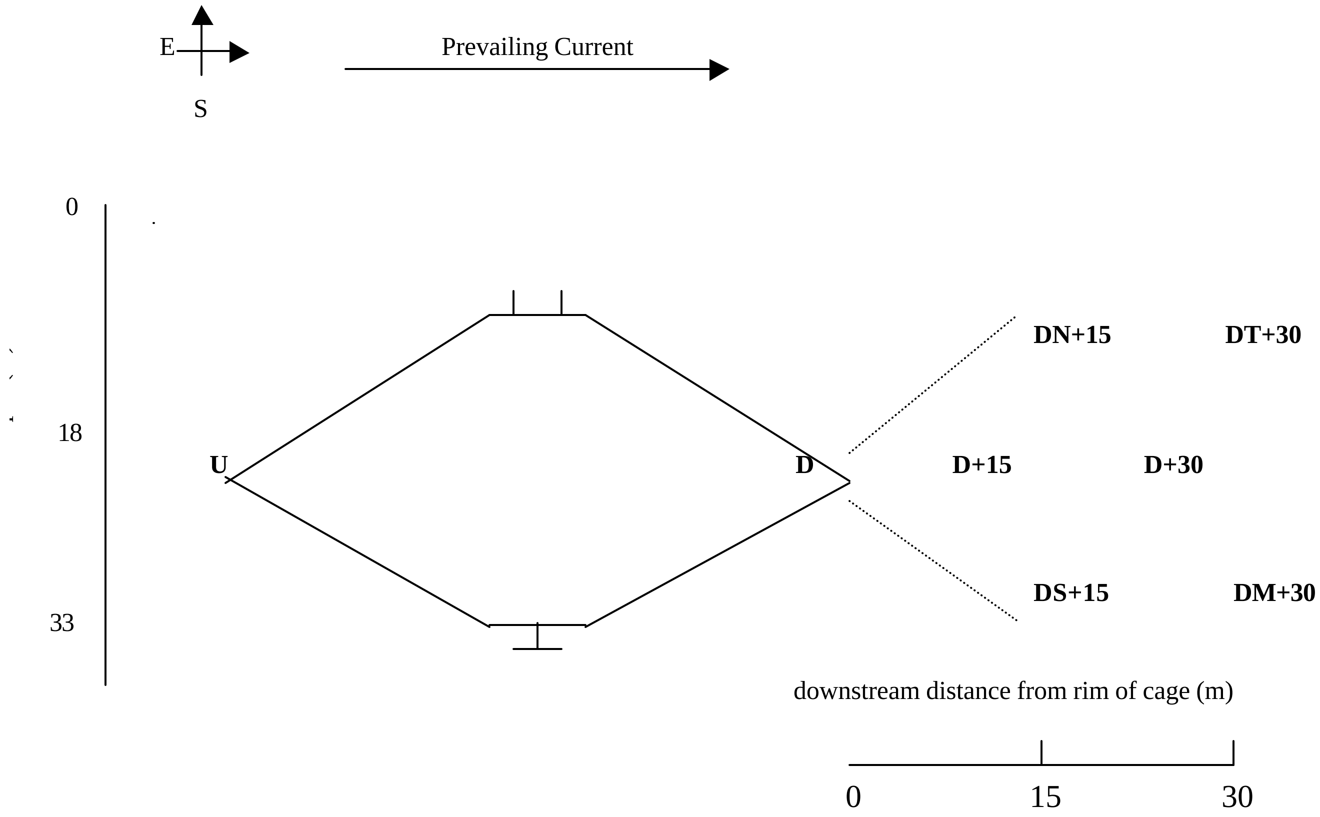


Figure 4. Diagram of Weekly and Monthly Water Sampling Sites. Lateral View: (U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of cage, (D+30) 30m downstream from the rim of cage, (DAR) reef approximately 0.5 m from cage not pictured, (DM +30) 30m downstream at midway between midline of cage and bottom of cage (depth 30m), (DT + 30) 30 m downstream at the top of the cage (depth 13.2 m). Top view: (DN+15) 15m downstream north lateral edge from rim of cage, (DS+15) 15m downstream south lateral edge from rim of cage.

The first quarterly sample for Phase II was conducted on March 9, 2000, the end of the Phase I project with the cage completely empty of fish. Replicate samples were taken at each of eleven sites including two upstream locations, five downstream locations, three control locations and one location inside the cage (Fig. 5). This sampling protocol was slightly different than subsequent sample dates due to the improved methods and site selection that occurred later.

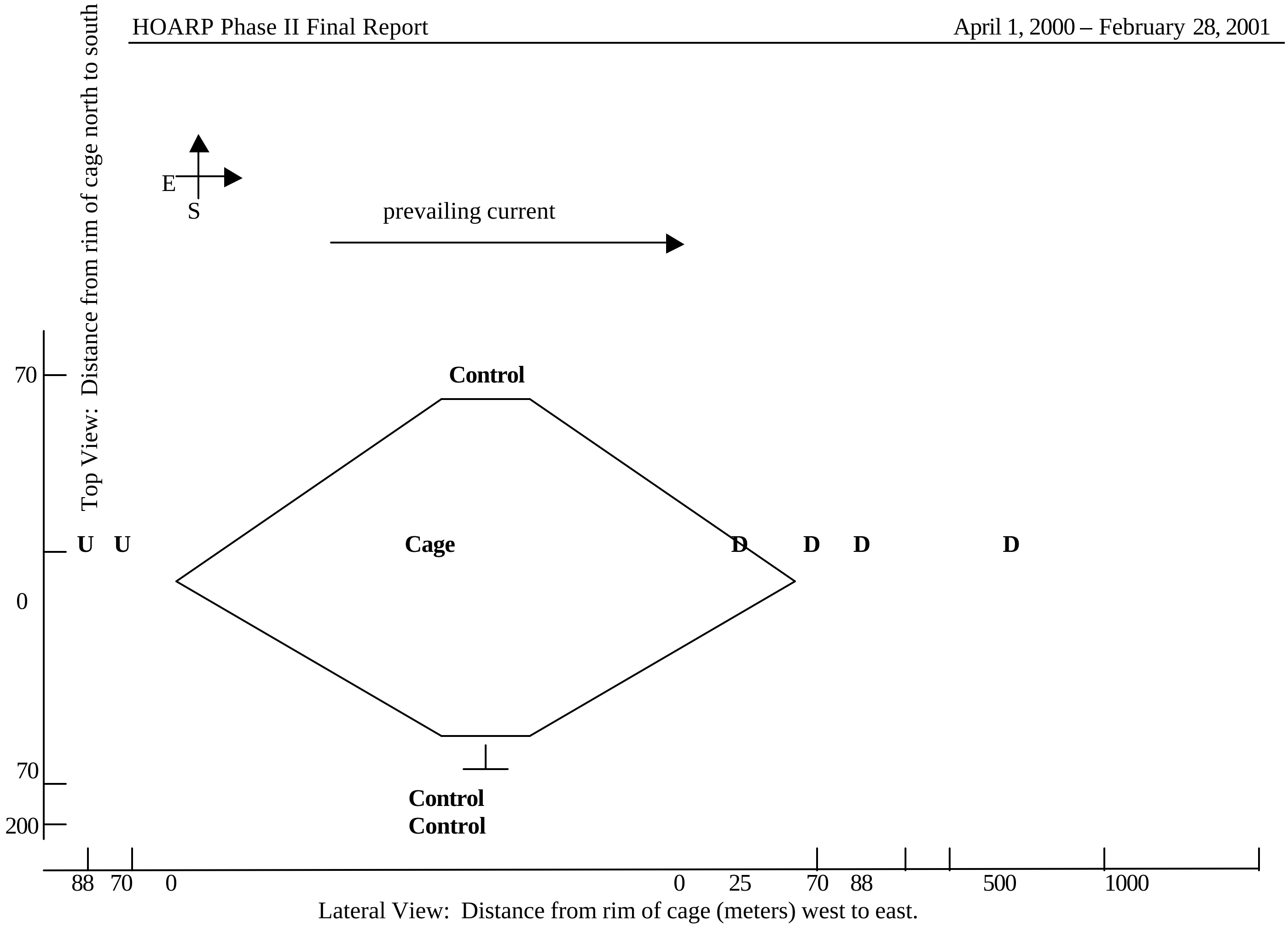


Figure 5. Diagram of Quarterly Water Sample at 18m depths March 9, 2000.
(U) Upstream, (D) Downstream, "Cage" inside cage and "Control" sites.

Water Quality Comparisons

The geometric mean of all water quality determinations were calculated and compared with published values in the "Department of Health (DOH) Water Quality Standards for 2000." All sample values were used to calculate the mean. The cage was considered located in open coastal waters defined by Section 342D-1, and in the "dry" criterion, receiving less than 3 million gallons of fresh water discharge per shoreline mile per day.

3.2.1.3 Results

Total Suspended Solids (TSS)

Summary results from weekly, monthly and quarterly monitoring for TSS from May 17–December 20 are in Table 4. There appeared to be no discernable trend or changes in TSS values throughout the project. There was occasional high surf and strong currents that could account for fluctuations in TSS according to the date sampled, but no apparent trend was observed with relation to upstream versus downstream sites. Values ranged from 0.9 – 7.0 mg/l depending upon date and sample site. For convenience, replicate samples corresponding to the summary values are included in Appendix B.

Table 4. Weekly, monthly & quarterly total suspended solids from March 9, 2000 – December 20, 2000.

Date	U mg/L	D mg/L	D+15 mg/L	D+30 mg/L	DN+15 mg/L	DS+15 mg/L	DAR mg/L
09-Mar-00	1.3 ± 0.3	1.1 ± 0.4	*	*	*	*	*
17-May-00	1.4 ± 0.1	1.0 ± 0.3	*	*	*	*	*
24-May-00	1.8 ± 0.7	1.2 ± 0.4	1.4 ± 0.6	*	*	*	*
05-Jun-00	2.7 ± 1.7	1.7 ± 1.1	1.7 ± 0.6	*	*	*	*
09-Jun-00	3.1 ± 1.1	3.1 ± 0.6	4.7 ± 5.3	*	*	*	*
16-Jun-00	5.3 ± 5.2	3.2 ± 0.7	2.7 ± 2.3	*	*	*	*
22-Jun-00	1.6 ± 0.6	2.3 ± 0.4	2.9 ± 0.7	*	*	*	*
29-Jun-00	2.8 ± 0.8	2.5 ± 1.5	3.0 ± 2.2	*	*	*	*
06-Jul-00	2.8 ± 1.0	2.0 ± 0.2	2.1 ± 2.1	*	*	*	*
14-Jul-00	4.0 ± 1.9	4.3 ± 2.3	2.1 ± 1.4	*	*	*	*
21-Jul-00	1.4 ± 0.3	1.3 ± 0.3	2.0 ± 1.1	*	*	*	*
26-Jul-00	1.0 ± 0.2	1.1 ± 0.4	1.4 ± 0.6	*	*	*	*
03-Aug-00	0.8 ± 0.4	0.5 ± 0.5	1.3 ± 0.3	*	*	*	*
10-Aug-00	1.5 ± 0.7	1.9± 0.2	1.2 ± 1.4	3.7 ± 4.3	*	*	*
17-Aug-00	1.3 ± 0.6	1.7 ± 0.5	2.1 ± 1.0	2.9 ± 2.0	2.0 ± 0.5	2.0 ± 1.3	1.3 ± 1.0
23-Aug-00	3.2 ± 1.4	2.0 ± 1.0	1.6 ± 0.5	1.8 ± 2.1	*	*	*
31-Aug-00	1.9 ± 1.3	1.7 ± 0.9	1.7 ± 0.8	1.9 ± 0.4	*	*	*
07-Sep-00	4.1 ± 2.6	1.7 ± 1.8	2.5 ± 0.7	2.3 ± 0.5	*	*	*
14-Sep-00	0.8 ± 0.6	1.3 ± 0.3	1.2 ± 1.1	1.4 ± 0.9	1.4 ± 0.7	1.2 ± 0.7	1.2 ± 0.9
21-Sep-00	1.1 ± 0.6	1.3 ± 0.4	1.1 ± 0.7	1.1 ± 0.6	*	*	*
28-Sep-00	1.9 ± 1.0	1.9 ± 0.7	1.2 ± 0.5	1.2 ± 0.8	*	*	*
05-Oct-00	1.7 ± 0.7	1.6± 1.3	1.7 ± 1.0	1.6 ± 1.2	*	*	*
12-Oct-00	2.2 ± 0.8	1.5 ± 1.4	1.3 ± 1.1	1.9 ± 1.6	*	*	*
19-Oct-00	2.9 ± 1.6	2.4 ± 0.9	1.3 ± 0.6	1.8 ± 1.4	*	*	*
26-Oct-00	1.9 ± 1.2	7.0 ± 10.8	2.1 ± 2.1	1.7 ± 1.6	1.4 ± 0.8	1.1 ± 0.6	1.5 ± 1.0
03-Nov-00	3.0 ± 2.3	2.3 ± 1.1	1.1 ± 0.5	0.9 ± 0.5	*	*	*
09-Nov-00	3.8 ± 2.2	1.7 ± 0.7	1.9 ± 0.9	1.7 ± 0.2	*	*	*
16-Nov-00	2.6 ± 0.3	3.0 ± 1.5	1.8 ± 1.5	1.2 ± 0.5	*	*	*
27-Nov-00	4.0 ± 1.0	4.0 ± 2.0	4.9 ± 1.0	1.4 ± 0.1	1.7 ± 0.1	2.0 ± 0.1	1.7 ± 1.7
01-Dec-00	4.0 ± 0.9	3.2 ± 2.5	1.6 ± 0.4	1.9 ± 0.9	*	*	*
08-Dec-00	0.9 ± 0.6	3.5 ± 0.4	1.3 ± 0.4	1.7 ± 0.2	*	*	*
20-Dec-00	3.8 ± 0.8	3.1 ± 2.8	1.9 ± 1.2	2.2 ± 0.4	1.5 ± 0.7	1.9 ± 0.6	1.2 ± 0.5

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of cage, (D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage, (DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage. All samples taken at 18m depths.
* No data required for sample site.

Ammonia nitrogen

Ammonia levels fluctuated greatly with the initial sample regimen, but improved once the simultaneous sample technique was employed (Table 5). There was one exception of obvious contamination during August 3, 2000. In contrast to TSS, ammonia levels during peak biomass months generally increased slightly downstream from the cage, and were diluted to upstream levels, in most cases, at the downstream + 30 m site (Fig. 6). All sample dates from August 31 – November 3 during peak biomass, indicate downstream values higher than the upstream values. The downstream + 15m values for 6 of 10 sample dates (60%) were lower than the downstream values at the rim of the cage indicating the start of the dilution effect. For convenience, replicate samples corresponding to the summary values are included in Appendix C.

Table 5. Weekly, monthly & quarterly ammonia results from March 2000-December 2000.

Date	U (µg/l)	D (µg/l)	D+15 (µg/l)	D+30 (µg/l)	DN+15 (µg/l)	DS+15 (µg/l)	DAR (µg/l)
09-Mar-00	N/D	N/D	*	*	*	*	*
09-May-00	0.7 ± 0.40	11.4 ± 3.30	*	*	*	*	*
17-May-00	33.9 ± 46.1	10.9 ± 2.80	*	*	*	*	*
23-May-00	35.1 ± 29.9	35.5 ± 34.60	24.4 ± 0.00	*	*	*	*
05-Jun-00	0.7 ± 0.00	0.8 ± 0.10	0.5 ± 0.70	*	*	*	*
09-Jun-00	16.2 ± 1.20	46.6 ± 0.00	9.9 ± 1.30	*	*	*	*
16-Jun-00	0.8 ± 0.20	3.5 ± 0.60	2.3 ± 0.90	*	*	*	*
22-Jun-00	1.1 ± 0.60	11.3 ± 1.90	7.1 ± 2.10	*	*	*	*
29-Jun-00	0.8 ± 0.50	1.7 ± 0.20	1.4 ± 0.00	*	*	*	*
06-Jul-00	1.2 ± 0.10	2.6 ± 0.10	35.2 ± 41.7	*	1.9 ± 0.3	6.5 ± 6.0	1.3 ± 0.4
14-Jul-00	5.0 ± 5.50	9.5 ± 3.90	3.8 ± 0.00	*	*	*	*
21-Jul-00	1.4 ± 1.40	4.3 ± 1.40	11.5 ± 0.60	*	*	*	*
26-Jul-00	6.0 ± 0.30	7.1 ± 9.30	37.9 ± 50.20	*	*	*	*
03-Aug-00	**66.08 ± 0.00**	**42.56 ± 16.83**	**77.49 ± 65.63**	*	*	*	*
10-Aug-00	2.24 ± 0.20	1.19 ± 0.10	0.84 ± 0.59	0.14 ± 0.20	*	*	*
17-Aug-00	0.70 ± 0.20	50.89 ± 0.30	23.80 ± 0.79	7.07 ± 0.69	1.47 ± 0.10	7.35 ± 2.87	0.91 ± 0.89
23-Aug-00	2.45 ± 0.89	2.03 ± 0.10	3.15 ± 0.69	1.33 ± 0.69	*	*	*
31-Aug-00	0.56 ± 0.40	3.29 ± 0.30	0.91 ± 0.10	1.68 ± 0.00	*	*	*
07-Sep-00	1.47 ± 0.30	2.03 ± 0.49	6.44 ± 3.96	8.54 ± 0.99	*	*	*
14-Sep-00	8.89 ± 0.10	45.99 ± 1.29	18.83 ± 2.67	1.89 ± 0.30	19.39 ± 0.30	22.26 ± 5.15	1.75 ± 0.49
21-Sep-00	1.61 ± 0.89	19.39 ± 0.89	14.07 ± 0.49	21.07 ± 0.89	*	*	*
28-Sep-00	0.77 ± 0.10	2.17 ± 0.10	1.96 ± 0.20	1.61 ± 0.10	*	*	*
05-Oct-00	1.47 ± 0.10	2.52 ± 0.90	9.17 ± 11.58	6.37 ± 1.68	*	*	*
12-Oct-00	0.98 ± 0.20	2.03 ± 0.10	9.17 ± 2.10	1.89 ± 1.10	*	*	*
19-Oct-00	1.05 ± 0.30	1.89 ± 0.10	1.19 ± 0.50	1.96 ± 0.20	*	*	*
26-Oct-00	2.03 ± 0.10	11.69 ± 0.10	2.80 ± 0.00	3.08 ± 0.59	2.59 ± 0.10	0.49 ± 0.30	0.84 ± 0.20
03-Nov-00	6.93 ± 0.89	7.98 ± 0.28	15.89 ± 1.09	17.36 ± 0.79	*	*	*
09-Nov-00	6.65 ± 0.10	4.55 ± 0.30	3.71 ± 0.69	5.95 ± 0.89	*	*	*
16-Nov-00	3.78 ± 0.20	5.60 ± 0.79	3.22 ± 0.59	3.64 ± 0.89	*	*	*
27-Nov-00	4.06 ± 0.00	4.13 ± 0.10	2.87 ± 0.10	1.54 ± 0.40	0.77 ± 0.10	1.19 ± 0.49	1.26 ± 0.20
01-Dec-00	3.50 ± 0.20	2.80 ± 0.24	1.40 ± 0.20	1.54 ± 0.00	*	*	*
08-Dec-00	2.59 ± 1.48	1.75 ± 0.10	2.59 ± 0.10	1.26 ± 0.20	*	*	*
20-Dec-00	0.91 ± 0.10	2.17 ± 0.10	1.54 ± 0.40	0.42 ± 0.00	1.05 ± 0.30	0.63 ± 0.10	0.63 ± 0.10

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of cage, (D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage, (DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5m from cage. All samples taken at 18m depths.

Value of "0" = Below detection, 0.01µM = lowest limit, but not significant,0.03µM = Practical Detection Limit

N/D = none detected, * no data required

bold = contamination

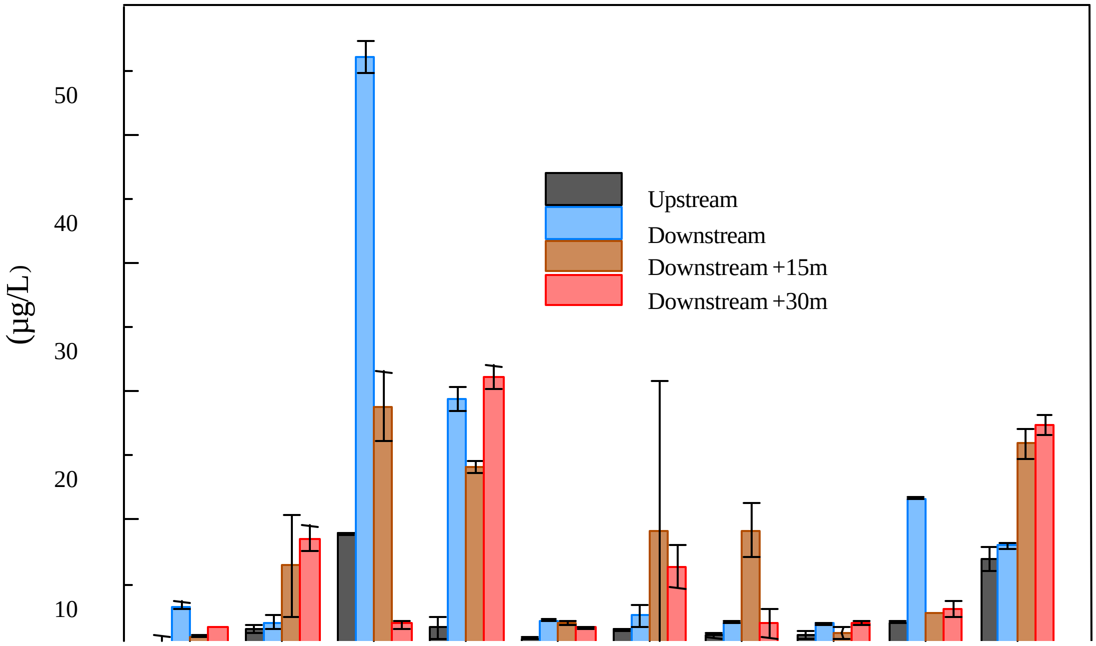


Figure 6. Ammonia levels during peak biomass of HOARP Phase II.

Nutrients

The sample conducted during March 9, 2000 with the cage empty gave a good approximation of ambient nutrient levels about the offshore site (Table 6). Ammonia was not detected in this sample, while ambient total nitrogen levels were between 55 and 81 µg/L (control site was 59.59 ± 9.57 µg/L). Total nitrogen levels did increase nearly 7-fold once fish were inside the cage, but there were no discernable trends between upstream and downstream sites. Nitrate + nitrite, total phosphorus, and soluble reactive phosphorus were not detected until November, but again, no trends were evident. Chlorophyll A and turbidity levels during all quarterly sample periods were all within the March 9, 2000 ranges, and no trends between upstream and downstream values evident. For convenience, replicate samples corresponding to the summary values are included in Appendix D.

Table 6. Quarterly Water Sampling for HOARP Phase II.

[a] 09-Mar-00	Mean Detection Limit (MDL)	U	D	Cage	Control
Ammonia (µg/L)	5.04	N/D	N/D	N/D	N/D
TSS (mg/L)	N/A	1.3 ± 0.3	1.1 ± 0.4	1.1 ± 0.4	1.3 ± 0.3
Nitrate+Nitrite (µg/L)	2.66	N/D	N/D	N/D	N/D
Total Nitrogen (µg/L)	3.6	80.77 ± 9.57	54.7 ± 10.6	75.4 ± 41.5	59.59 ± 9.57
Soluble reactive phosphate (µg/L)	4.03	N/D	N/D	N/D	N/D
Total Phosphate (µg/L)	4.5	64.58 ± 12.11	58.5 ± 10.5	54.6 ± 18.2	64.6 ± 12.11
Turbidity (NTU)	N/A	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0
Chlorophyll (µg/L)	N/A	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0

[b] 06-Jul-00	Mean Detection Limit (MDL)	U	D	D+15	D+30	DN+15	DS+15	DAR	DM + 30	DT + 30
Ammonia (µg/L)	0.03uM	1.19 ± 0.10	2.59 ± 0.10	35.21 ± 41.68	*	1.89 ± 0.30	6.51 ± 6.01	1.26 ± 0.40	11.27 ± 13.76	1.54 ± 0.20
TSS (mg/L)	N/A	2.8 ± 1.0	1.9 ± 0.2	2.1 ± 2.1	*	1.8 ± 1.8	3.7 ± 1.0	7.3 ± 6.0	3.1 ± 0.9	1.2 ± 0.0
Nitrate+Nitrite (µg/L)	2.24	N/D	N/D	N/D	*	N/D	N/D	N/D	N/D	N/D
Total Nitrogen (µg/L)	1.4	345.8 ± 1.2	333.7 ± 0.8	384.5 ± 73.5	*	365.6 ± 26.9	354.5 ± 23.3	342.0 ± 5.9	345.2 ± 23.6	349.3 ± 2.5
Soluble reactive phosphate (µg/L)	11.8	N/D	N/D	N/D	*	N/D	N/D	N/D	N/D	N/D
Total Phosphate (µg/L)	11.8	N/D	N/D	N/D	*	N/D	N/D	N/D	N/D	N/D
Turbidity (NTU)	N/A	0.3 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	*	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Chlorophyll (µg/L)	N/A	0.2 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	*	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0

Table 5 continued

[b] 27-Nov-00	Mean Detection Limit (MDL)	U	D	D+15	D+30	DN+15	DS+15	DAR	DM + 30	DT + 30
Ammonia (µg/L)	0.03uM	4.06 ± 0.00	4.13 ± 0.10	2.87 ± 0.10	1.54 ± 0.40	0.77 ± 0.10	1.19 ± 0.49	1.26 ± 0.20	1.82 ± 0.59	0.77 ± 0.10

Table 6 cont.

TSS (mg/L)	N/A	4.0 ± 0.9	4.1 ± 2.0	5.0 ± 1.1	0.6 ± 0.1	1.7 ± 0.1	3.7 ± 1.0	7.3 ± 6.0	3.1 ± 0.9	1.2 ± 0.0
Nitrate+Nitrite (µg/L)	1.0	5.9 ± 0.4	5.1 ± 0.2	5.1± 0.2	5.1 ± 0.6	1.7 ± 0.1	2.0 ± 0.1	1.7 ± 1.6	1.7 ± 1.8	0.8 ± 0.6
Total Nitrogen (µg/L)	1.4	380.0 ± 79.2	281.0 ± 28.3	243.5 ± 7.8	270.0 ± 9.9	255.5 ± 2.1	291.5 ± 38.9	296.0 ± 2.8	308.0 ± 9.9	243.5 ± 3.5
Soluble reactive phosphate (µg/L)	0.1	11.0 ± 3.3	7.8 ± 0.0	6.8 ± 0.4	6.7 ± 0.2	7.0 ± 0.2	6.8 ± 0.0	7.3 ± 0.2	7.6 ± 0.3	7.0 ± 0.2
Total Phosphate (µg/L)	6.9	100.0 ± 2.8	77.2 ± 18.0	75.5 ± 7.6	62.2 ± 17.7	7.0 ± 0.2	89.9 ± 0.8	96.3 ± 22.2	62.6 ± 8.3	78.9 ± 39.7
Turbidity (NTU)	N/A	0.5 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Chlorophyll (µg/L)	N/A	1.8 ± 1.5	0.4 ± 0.3	0.1 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0

[a] (U) upstream values at rim of cage, (D) downstream values at rim of cage, "Cage" inside cage, and "Control" 70m south of cage.

[b] (U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage, (D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage, (DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage .

All samples taken at 18m depth. (DM +30) 30 m downstream at midway between midline of cage and bottom of cage (depth 30m), (DT + 30) 30 m downstream at the top of the cage (depth 13.2 m).

* no data required for sample site, N/A = not applicable, N/D = non detectable

Water Quality Comparisons

Comparisons of geometric means for all water quality parameters measured with that of DOH standards are in Table 7. Geometric means for nitrate + nitrite, chlorophyll a, and turbidity were all below allowable levels. Means for total nitrogen and ammonia both exceeded DOH standards slightly, while total phosphorus was more than twice the allowable level.

Table 7. Geometric means for water quality parameters of Water Quality Standards for 2000 for open coastal waters ("dry") compared to the geometric means for water quality.

Parameter	Geometric mean not to exceed given value	Geometric mean of HOARP II monitoring
Total Nitrogen (µg N/L)	110.0	139.1
Ammonia Nitrogen ((µg NH4-N/L)	2.00	3.03
Nitrate + Nitrite (µg [NO3+NO2]-N/L)	3.50	0.20
Total Phosphorus (µg P/L)	16.00	36.80
Chlorophyll A (µg/L)	0.15	0.10
Turbidity (N.T.U.)	0.20	0.10

3.2.1.4 Discussion

The results of water quality analysis indicated the difficulty in accurately discerning the effects from a single cage operation. The comparisons of water quality between DOH allowable and actual HOARP II levels must be viewed with caution since its does not take into account unexplained fluctuations in ambient water quality levels. In most instances and with most parameters measured, upstream and control site measurements were no different than downstream sites from the cage. Occasional high surf action and strong currents may have also accounted for fluctuations from one sample date to another. Installation of a current meter would have assisted in determining any relation between changing values and changing weather and surf conditions. Multiple cages would also increase biomass and presumably increase effluents to better discern between actual effects and background water quality levels.

Although trends were not always consistent, ammonia was the only water quality parameter that appeared to be affected by activities of the HOARP II project. In broad terms, there was an increase in ammonia directly downstream from the cage four hours after the first feeding of the day, which would become diluted approximately 15m downstream. In most instances, ammonia reached ambient, upstream levels, 30m downstream from the cage. Improved methods of collection together with the more intensive, weekly sample regimen allowed a better estimate of these effects compared to the monthly ammonia samples taken during Phase I. This provides the first estimate of an appropriate monitoring regimen for offshore activities in Hawaii for establishment of zone of mixing requirements for an NPDES permit.

3.2.2 Effects on Benthic Biota

3.2.2.1 Rationale

Fecal matter and feed decaying on the bottom may alter the benthic ecology since bacteria that facilitate the decaying process lower the oxygen levels in the epibenthic layer, and mixing makes the sediment surface layer anoxic. Toxic byproducts of decay (methane and hydrogen sulfide) are also released in the water column (Aure and Stigebrandt 1990). Organic nitrogen contained within the feed may cause nuisance plankton blooms (Dortch *et al*. 1998).

The bi-conical cage was anchored on the west side of the Pearl Harbor entrance channel in waters 30m deep, 3-5m off the bottom in a sand habitat. Potential invertebrate consumers of fish wastes and feed residues occupy habitats in sand (infaunal) and attach to firm substrates (epifaunal). Opportunistic benthic species benefiting from feed residues may increase abundance and serve as indicators of change in this section of the reef. Documentation of impacts to the benthos may be required for permit and/or project expansion purposes. For mitigation, excess feed could be reduced or feed composition may be changed if fish growth rates and production yields are met. Phase II is testing effects of fish raised at a harvest density of 20kg/m^3.

3.2.2.2 Procedure

SCUBA was used to collect ten replicate sand samples in cylindrical 5x5 cm core. Five were taken under the cage and another five were taken up current from the cage. These served respectively as experimental and control sampling sites. Samples were formalin preserved, elutriated over sieves, and specimens 0.5 mm or greater in size were sorted, identified and enumerated. Sediment sampling was repeated at monthly intervals to estimate temporal changes (February 17, April 21, June 21, July 25, August 16, October 19 and November 18, 2000).

Invertebrates found in samples were separated into four major taxa: polychaetes, nematodes, crustaceans and *Ophryotrocha* (a genus of *polychaetes* that was abundant in some of the Phase I samples, referred to as *dorvilleids* in earlier reports). Experimental and control groups were compared using two-sided T-tests to determine if any statistically significant differences existed between the two sites.

Three groups of samples (February, July and November 2000) were identified to a lower taxonomic level (family) in order to compare richness (number of families) and abundance (number of individuals) between the two sites.

3.2.2.3 Results

Of the seven sets of samples collected and analyzed for benthic community composition only two showed statistically significant differences among the four major groups. The July samples showed more polychaetes under the net and significantly more crustaceans at the control site (Table 8). In August the crustacean trend did not continue, though there was still a slightly significant difference between the polychaetes under the net and at the control site (p=.046). September and October samples showed no significant difference between any of the four major groups though there was a noted increase in dorvilleids under the net. November samples indicated significant differences in nematodes (p= .044) and *Ophryotrocha* (p= .007), which continued to increase (Table 9).

The number of families in both experimental, and control samples, increased slightly over the duration of the experiment. The main difference found was in the abundance of *Ophryotrocha* and Capitellids. Capitellids were more abundant in the July and November net samples, while *Ophryotrocha* were abundant in the November net samples (Fig. 7).

Table 8. Data for July and August 2000 (top and bottom respectively). July polychaetes are significantly higher under the net and crustaceans are higher at the control site. August data shows a continuation of higher polychaete numbers under the net but crustaceans at the control site were no longer significantly more abundant.

July 2000

Net	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	76.8	55.6	0.6	4.6
SE	10	6.9	0.6	1.03

Control	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	99.2	25.8	0.0	62.0
SE	36	9.1	0.0	18.5

Aug. 2000

Net	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	114.5	41.7	.6	2.75
SE	36	9.1	.6	1.4

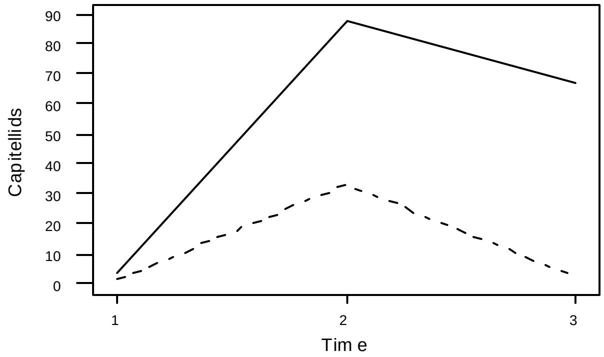
Control	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	58.6	11.2	0.0	10.4
SE	11	1.8	0.0	4.7

Table 9. November 2000 data shows a significant difference in nematodes and an increase in the number of *Ophryotrocha* under the net.

November 2000

Net	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	115.8	20.2	20.2	61.6
SE	29.0	4.0	4.0	11.0

Control	**Nematodes**	**Polychaetes/other**	***Ophryotrocha***	**Crustaceans**
Mean	28.4	27.0	.20	40.4
SE	6.1	8.6	.20	22.0



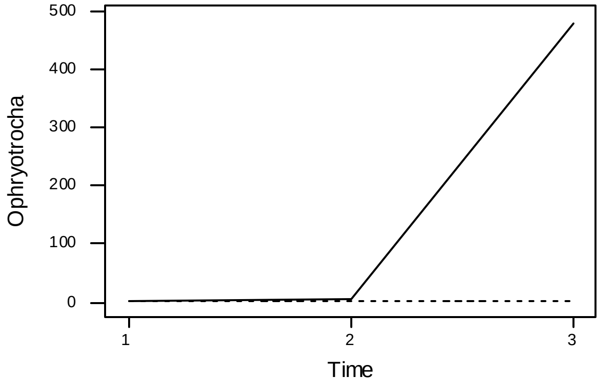


Figure 7. Capitellids (top) and *Ophryotrocha* (bottom) became much more abundant under the net cage (solid line) than at the control site (dotted line). Samples were taken February 2000 (1), July 2000 (2), and November (3).

3.2.2.4 Discussion

The data shows that although there were statistically significant differences found in the polychaetes and crustaceans during July and August these trends did not continue into future samples. The majority of the samples showed no significant difference between the community composition at the two sites. Standard deviations between replicates were often high at both sites indicating a patchy infaunal community.

During Phase I, a change in the abundance of an infaunal polychaete (*Ophryotrocha*) was observed. Persistence of this trend in the benthos during periods of feeding was tested in Phase II. The *Ophryotrocha* that appeared so rapidly in Phase I (within three months) did not appear in large numbers during Phase II until six months, (October 19 sample) after stocking. *Dorvilleids* have a short life cycle with rapid population build up, which allows them to take advantage of a newly available food source. They may respond to environmental parameters other than food availability, e.g., warmer water temperatures or unsuccessful competition with other dominant members of the community. These polychaetes took six months to show up in Phase II samples, which may be an indication that less food is reaching the substrate and therefore less food is available to the benthos. This could be due to several factors. A change in the feeding schedule was implemented in Phase II including separate (smaller) morning and afternoon feedings instead of a single large feeding each day. A new feed-catch tray was installed at the top of the cage preventing much of the excess feed from falling through the net and reaching the benthos. Increased numbers of wild aggregating fish (mostly broom-tail filefish, *Aluterus scriptus)* were observed eating the feed that had accumulated on the bottom.

The increase in *Ophryotrocha* and capitellids below the cage is not unusual. They have also been seen in high numbers near sewage outfalls on Oahu and in other enriched environments (Swartz *et al*. 1999, Tsutsumi *et al*. 1990). Their presence does not prove negative impact, though it does indicate an extra food source for detritivores. According to the Pearson and Rosenberg pollution gradient model an extremely low number of taxa found under the cage compared to the number in the sand at the control site would be an indication that the net community was experiencing negative impact from the increased organics (Pearson and Rosenberg 1978) of excess fish feed and fish wastes. However, all six of the samples identified to the family level show a similar number of families at both sites. The higher abundance of capitellids and *Ophryotrocha* under the cage does not seem to have negatively affected the community structure by out competing and eliminating other community members, rather it seems to be effectively taking advantage of a new food source. The other components of the benthos that respond to organic enrichment are the nematodes, some nereidids and tubicolous polychaetes and some crustaceans.

3.3 Preliminary evaluation of trophic level interactions of resident species and evaluate the influence of the cage system as a fish aggregation device.

3.3.1 Effects on Surrounding Cage Environment

3.3.1.1 Rationale

It is well known that cages, like many other structures in water, act as fish aggregation devices (Rountree 1989; Pickering and Whitmarsh 1996). Concentration of local species can have both positive and negative effects. One socially important issue in Hawaii is a perceived threat to native fishing rights due to cage operations. These concerns may be alleviated if fishermen are allowed to harvest species attracted to the cage. While not necessarily desirable from an operations point of view, impacts are much less of a concern when a submersible system is used, since most operating equipment (e.g., the cage structure, mooring lines) and fish themselves are not directly exposed. Compromises between operations and local communities need to be sought if offshore culture in Hawaii is to exist amicably with sport and commercial fishing operations. There is also great concern in Hawaii about the attraction of sharks to the cage and perceived impacts on recreational and tourist activities. In addition, wild species that accumulate around the cage may represent vectors for transmission of disease or parasites to fish in the cage (Carss 1990), or may contract diseases from fish in the cage. Documentation of the types and numbers of species either taking up residence or transient around the cage would provide much needed evidence to assess the environmental and social impacts of offshore aquaculture in Hawaii.

3.3.1.2 Procedure

Surveys for fish abundance were conducted daily by SCUBA. Observations were conducted either once or twice daily for a total of approximately 30-40 minutes. Divers counted fish and invertebrates within 50 yards of the cage and in all directions. Fish and other invertebrates were classified into resident (observed on a daily basis) and transient (observed periodically) species. Fish such as the dominant resident species (broomtail filefish, scad mackerel) and some of the transient species (false albacore, yellowfin tuna) were caught using hook and line then weighed to estimate total biomass. An underwater camera was used to verify species, abundance, and to estimate length. Estimates of transient species biomass was from best estimates of length that were converted to wet biomass using conversion factors generated by the Hawaii Division of Aquatic Resources.

3.3.1.3 Results

Figure 8 presents the general order of accumulation of resident and transient species about the cage, and estimated biomass accumulation. Peak biomass (800 kg), consisting of several resident and transient fish species, was obtained about 176 days after fish were stocked. The most abundant resident species was the broomtail filefish (*Aluterus scriptus).* Isolated events of passing tunas (*Euthynnus alletteratus, Thunnus albacoares)* were recorded on several occasions. Sandbar sharks (*Carcharhinus plumbeus)* came into the area during the peak biomass and harvest period. Several species of mussels (unidentified) and oysters, *Margaritifera spp.,* settled onto the outside and inside of the net material, and inside bottom surface of the cage throughout the trial. Sea urchins *(Echinothrix calamaris)* and nudibranchs (*Stylocheilus longicauda)* also collected on the net material. Concentrations of algae and oysters appeared to increase as length of the trial and biomass increased, although total biomass of these species was not quantified. A detailed list of resident and transient species is included in Appendix E.

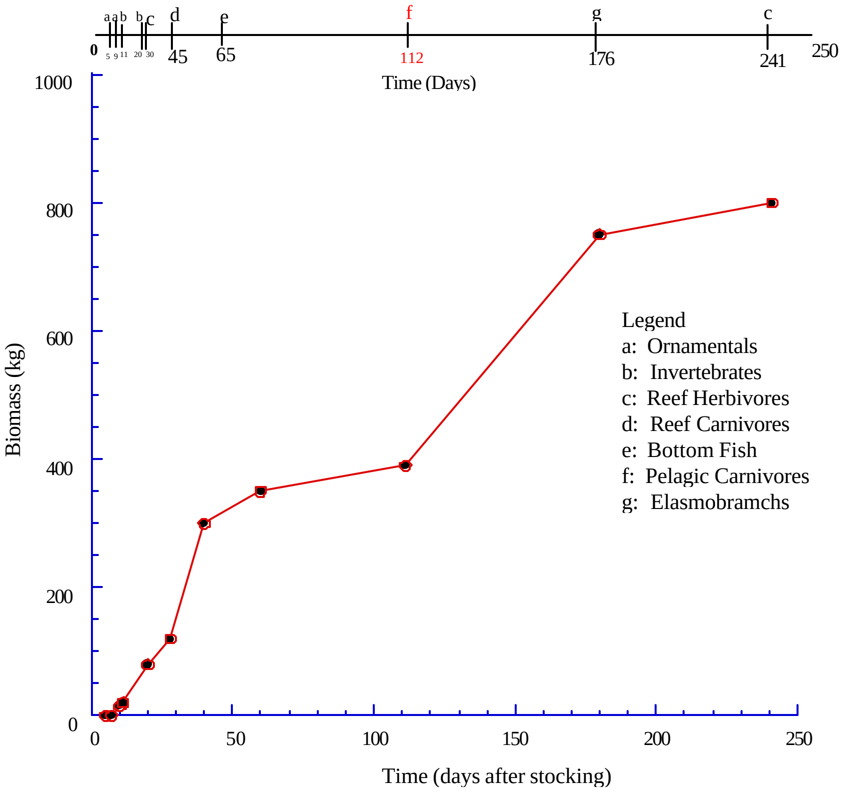


Figure 8. Order of recruitment and accumulated biomass increase of resident and transient fish species around SeaStation^{TM} 3000 during HOARP Phase II.

3.3.1.4 Discussion

Peak biomass density of resident and transient species during HOARP Phase II (800 kg) was approximately 17% higher than that recorded during Phase I (681 kg). This was despite the fact that peak biomass of threadfin in the cage was more than double that during Phase I. This indicated that accumulation of species about the cage was a phenomena limited by habitat similar to any other fish aggregation device (Pickering and Whitmarsh 1996) and not density of the fish in the cage. The higher peak density was due primarily to establishment of large schools of scad mackerel *(Decapterus macarellus)*, which in turn contributed to greater incidents of transient carnivorous pelagic fish. These included the false albacore tuna (*Euthynnus alletteratus)*, yellowfin tuna (*Thunnus albacoares)*, and on two occasions, ono (*Acanthocybium solandri*) and greater amberjack (*Seriola dumerili*). The latter two were primarily resident species.

The most noticeable correlation with increased biomass of fish in the cage was the increased number of sandbar sharks (*Carcharhinus plumbeus*) (from 4 to 10) that occurred prior to and during the harvest period. During HOARP Phase I, sharks were observed only during harvest. During HOARP Phase II sharks appeared beginning 176 days after stocking the threadfin and maintained residency through the end of harvest. Three to four sharks were observed on a regular basis prior to harvest. The number increased to ten sharks during harvest. Despite this increase, there was at no time any indication that the sharks posed a threat to the safety of the divers or the harvest operations. Further, the threadfin inside the cage appeared unaware, or at least, unaffected by the activity and accumulation of species outside the cage.

Most of the resident species were observed consuming feed passing through the cage. However, resident species consisted primarily of pelagic herbivores, which were more often observed grazing on microalgae from the top surface of the submerged cage. This grazing activity had the beneficial effect of limiting the growth of algae on the cage and thus limiting the need to clean the cage. In fact, the net was free of any accumulated algae coverage throughout the trial, and cleaning was unnecessary.

3.3.2 Effects on Coral Rubble Site

3.3.2.1 Rationale

In addition to relative species at the immediate area about the cage, there was opportunity to determine the effect of cage activities on a coral rubble site. This site was located approximately one-half mile shoreward (north) of the sea cage, referred to in this project as the DAR site. The Department of Aquatic Resources had required monitoring of this site in the revised monitoring program.

3.3.2.2 Procedure

Three surveys for fish abundance were performed on July 20, 2000 (within two weeks of stocking the cage), November 17, 2000 (just after peak biomass in the cage was attained), and January 9, 2001 (after harvest of the cage was completed). Surveys were conducted at the DAR site (Plate Figure 2). This site is the closest hard-bottom reef habitat to the sea cage, and is the approximate location of one of the stations sampled for water quality. The bottom in the area around the sea cage and for several hundred meters shoreward is deep sand (Plates 1.1, 2.1, & 3.1), gradually sloping upward from a depth of 32 m at the sea cage to the reef edge at a depth of 18 m. At the reef edge there is a transition from deep sand to the reef slope, composed primarily of limestone rubble (Plates 1.2, 2.2, & 3.2) and then to the reef flat at a depth of 12-14 m, composed primarily of limestone plate covered with scattered coral heads (Plates 1.3, 2.3, & 3.3). During each survey, quantitative counts of fish species composition and abundance were done at three stations at the limestone rubble edge (E1, E2, E3), two on the limestone reef slope (S1 & S2) and one on the limestone reef flat (F1). A single quantitative survey of fish at the sea cage was performed on January 9, 2001.

At each station, stationary plot sampling (SPS) was done following the technique described by Bohnsack and Bannerot (1986). At randomly chosen stations within each area type, a diver on SCUBA noted the species, abundance and total length in inches of all fish observed within a 7.0m radius cylinder. Species were listed during the first five minutes, then abundance and size were recorded during the second five minutes. Highly mobile species were counted when first sighted since they tend to move out of the area quickly. The 7.0m radius was initially measured with a fiberglass tape and estimated thereafter. Length data were converted to wet weight biomass using the conversion factors generated by the Hawaii Division of Aquatic Resources.

3.3.2.3 Results

Results of the individual stationary plot sampling for fish abundance at the DAR site and at the sea cage are presented in Appendix F as tables 1-3. A summary table of the three surveys is also presented in Appendix F as Table 4. The ocean bottom at the DAR site is relatively flat limestone plate with a thin sand-algal mat and a few potholes. There is little vertical relief and coral coverage is low, primarily scattered *Pocillopora meandrina* and *Porites lobata* (Plate 1.6, 2.5). The seaward edge of the limestone plate slopes gently downward to the rubble edge and then becomes deep sand.

Between all the surveys, biomass, the number of species, and the numbers of individuals varied greatly with no recurring trend found at any one station. Five families of fish were commonly found at all stations, generally with one to two species per family. These families were the hawkfish (cirrhitids), damselfish (pomacentrids), wrasses (labrids), surgeonfish (acanthurids), and triggerfish (balistids).

The highest number of cirrhitids and pomacentrids were observed on the reef slope and reef flat where corals heads were more abundant (Plates 1.3, 1.4, 1.5, 2.3, 2.4, 2.5, 3.3, 3.4). These fish are small (3–10 cm) and contribute a small amount to the overall biomass of the areas. The labrids were the most diverse family present, with often four to six different species seen within a single sample. The highest numbers of individuals were observed at the reef edge stations, were they were found closely associated with the rubble. Acanthurids were transient throughout the areas, seen more in the first survey than in subsequent surveys, and more often in the flat area of the reef. They were the largest fish seen on the surveys with adults of 10 to 16 inches. Their presence or absence caused large variations in the biomass at each station for each survey. Balistids were commonly observed two to three individuals per station, with one species, *Sufflamen bursa* sighted in nearly every SPS for all surveys. The balistids are another large fish and added greatly to the biomass of the station during the SPS.

In this survey, the rubble edge area had the highest number of fish species and individuals. Most of these were small labrids (wrasses) which associated closely with the rubble. Fish on the slope and reef flat were generally associated near coral heads. A few large acanthurids (surgeon fish) and balistids (trigger fish) roamed throughout the area. The reef flat had the fewest species and individuals. The reef slope had an intermediate number of species and individuals. A school of opelu moved through Station E2 during one of the SPS. These fish are highly transitory and are not included in the resident biomass number for Station E2. The approximately 200 fish in the school added 32 g m^{-2} to the fish biomass for E2, which would have increased it from 12.3 to 44.6 g m^{-2}.

Visual surveys of the sea cage performed during Phase I and Phase II (Table 9) showed populations primarily of the large filefish, *Aluterus scriptus*, which were observed actively picking encrusting growth from the sea cage netting. Also common were palani, *Acanthurus dussumieri*, with visits by open-water carnivores such as the amberjack *Seriola dumerlii* and skipjack *Katsuwonus pelamis*. Sandbar sharks, *Carcharhinus pulmbeus*, were frequently observed cruising over the bottom.

Table 9. Abundance of fish observed outside the sea cage on January 9, 2001.

Family	Species	No. of Individuals
Carcharhinidae	*Carcharhinus plumbeus*	1
Carangidae	*Seriola dumerli*	21
Acanthuridae	*Acanthurus dussumieri*	10
Monocanthidae	*Alutera scriptus*	300
Tetraodontidae	*Arothron hispidus*	1
Diodontidae	*Diodon histrix*	1
	No. of families	6
	No. of species	6
	No. of individuals	334
	Biomass (g m^{-2})	4.5

3.3.2.4 Discussion

There was no evidence of impact of the cage activities on the DAR site resident fish community. Species observed at the reef site were different than those observed at the cage, indicating little overlap in resident species. The most common families observed at the DAR site (i.e. the cirrhitids, pomacentrids, labrids, acanthurids, and balistids) were not present at the cage. The one species of acanthurid seen at the cage, *Acanthurus dussumieri*, was not observed at the DAR site. One species of labrid, *Thalassoma duperrey*, was seen at both sites. It is likely, however, that these wrasses did not emigrate from the adjacent reef area to the cage. Instead, their small size (<3 cm) suggests these fish had recently been recruited.

3.4 Assessment of the production cost structure and profitability of offshore cage culture of Pacific threadfin in Hawaii to develop a realistic assessment of economic and marketing impact.

3.4.1 Rationale

Offshore cage culture in Hawaii is non-existent at this time. In order to assess its potential as a commercial enterprise, it is necessary to estimate its profitability as well as its social, economic, and environmental impact in Hawaii. Market analysis and economic assessment is an important component. Profitability will depend not only on the culture techniques, but also on estimated market demand, product price, and enterprise budget. Enterprise budget or cost of production, together with market price, will determine if the expected profit can provide an adequate return to labor, capital, management, and risk. In addition, an enterprise budget will allow sensitivity analyses to be conducted on key areas where the operation can and should be improved as well as assessing the potential risk of the proposed operation. Risk analysis is of particular importance as most of the production (biological and physical) parameters are known.

In order to evaluate the viability of a commercial offshore aquaculture production system for Pacific threadfin, a detailed cost structure is critical. The detailed cost structure requires numerous inputs from persons knowledgeable of the production technology and external environment. By capturing the production technologies and biological parameters observed during HOARP Phase II and synthesizing the parameters with ecological, financial, and market parameters, an economic model can be established that is capable of measuring many of the critical parameters relevant to offshore cage production in Hawaii. A series of sensitivity analyses that study variations in critical parameters such as sale price, growth, feed cost, financial leverage, and harvesting density may suggest to commercial enterprises avenues in which to respond to the complex and difficult-to-forecast local and export markets for Pacific threadfin.

In 1999, the Hawaii Agricultural Statistics Service reported an exchange of 119,568 lbs of Pacific threadfin and an associated farm-gate sales revenue of $459,150. The 1999 production volume and sales revenue are equal to a 288% increase in production and 215% increase in sales revenue from 1998. Accordingly, the average farm-gate price has decreased from $5.16/lb to $3.84/lb. Market forces may therefore decrease sale prices in response to larger supply or non-responsive demand. Consequently, commercial enterprises may be obliged to pursue economic efficiencies in order to remain profitable.

The risk of declining sale prices and currently undeveloped export market for Pacific threadfin compels commercial offshore practitioners to pursue economic efficiencies. A series of sensitivity analyses performed on the baseline cost structure will highlight those strategies that may be the most effective for improving commercial viability.

3.4.2 Procedure

The economic model used for this analysis incorporated parameters from five major areas: General and Financial, Payroll, Energy and Supplies, Capital Expenditures, and Production. The system requirements were based on a hypothetical six-cage production system, scaled from the existing single-cage production system.

General and financial parameters that reflect costs relevant to a site located in Hawaii are listed in Appendix G. Parameters include general and financial assumptions for market sale price, seed stock price, feed price, fuel costs, lease information, and financial information. The six-cage production system is estimated to embody a 5,000 sq. meter surface area and encumber a bottom area (including anchoring) of approximately 450,000 sq. meters.

A total of fifteen employees are required to support the 6-cage production system: seven salaried personnel and an equivalent of seven full-time divers and one part-time diver. Two captains are included as salaried employees, for a total of ten employees with diving certification. The number of divers required was determined according to carrying capacities and labor estimates for stocking, harvesting, and maintenance operations. Appendix H summarizes employee assumptions and the salaries of personnel.

The number of divers is based on daily activities, periodic maintenance, harvesting and stocking required for the annual production of 914,271lbs of Pacific threadfin. Daily activities (8 hrs/day) include feedings, cage maintenance, environmental survey, and travel time. The average periodic maintenance is equal to 180 hours per month.

Stocking occurs once per month with 135,000-D50 fry (2.1g) for a total annual seed stock of 1,620,000 fry. A single cage harvest of 76,189 lbs of fish spans a period of approximately 8 days. This harvesting duration is based upon a total bin capacity of 10,500 lbs (15–700 lb capacity bins) and four divers harvesting daily (4 hrs of diving time).

Recurring costs for energy ($121,109) include fuel for boats, two fish pumps, an ice machine, pressure spray, and two trucks. Monitoring costs for in-house and lab tests total $77,980 per year. Monthly and quarterly monitoring requirements were based on an increase of approximately four times the existing monthly and quarterly monitoring required for the existing single cage system. The remaining supply costs, maintenance, and other costs are equal to $542,791 per year. Detailed energy, monitoring, supply, and other costs are indicated in Appendix I and Appendix J. Due to the exploratory nature of this study on a hypothetical cage production system, permits, licensing, and monitoring requirements are provisional estimates.

Permits and renewal costs of $5,000 per year reflect Federal, State, and County permits that may include but not be limited to: US Army Corps of Engineers 404 Permit, CZM Consistency Review, Endangered Species Reviews, Sections 106 Review, Historic Sites, DOH Section 401 Water Quality Certification, Conservation District Use Application/DLNR reviews, National Pollution Discharge Elimination System Permit, Zone of Mixing Permit, and Special Management Area Reviews.

The initial capital outlay is equal to $1,816,465. The major costs contributing to start up costs include: six submersible cages, $420,000 (23% of the initial outlay); EA/EIS fees, $250,000 (11%), one-hundred ton support vessel for feed, $240,000 (13%), and 47-ft 400HP boat for stocking and harvesting, $150,000 (8.3%).

When costs are annualized ($138,982 annually) with respect to the useful life of each asset, the largest depreciation expenses include $42,000 (30%) for the six submersible cages, netting $18,000 (13%), EIS/EA $12,500 (9.0%) and support vessel $12,000 (8.6%).

A table summarizing the capital outlay and annualized depreciation is located in Appendix K.

The production parameters used were based on Oceanic Institute practices and performance data reported by the Hawaii Offshore Aquaculture Research Project (HOARP) Phase II. The production parameters assumed are exhibited in Table 10.

Table 10. Production Parameters

Month	0	1	2	3	4	5	6
Days PH	50	60	110	140	170	200	230
Avg. Size (g)	2.1	15.00	85.00	170.00	247.00	339.00	415.00
FCR		2.12	1.70	1.48	3.39	2.97	2.54
Survival		65%	99%	99%	99%	99%	99%

Based on these parameters, productivity is estimated at 61.81% overall survival, cumulative FCR of 2.39, and an average daily growth rate of 2.29 g/day for a six month period.

3.4.3 Results

For a six-cage production system yielding 914,271 lbs of Pacific threadfin, the cost of production is $3.97/lb. The largest costs contributing to annual operating expenses of $3,592,536 were feed (30%), labor (17%), seedstock (13%) and shipping (11%). The conservative base model suggests that a commercial enterprise may not be profitable. A 20-year cash flow based on a 10% discount rate indicates a negative net present value (NPV).

The cage production system is based on initial stocking of 135,000 D50 fingerlings. Table 11 exhibits a breakdown of the cage production system cost structure. Measures of productivity in terms of density, feed conversion ratio (FCR), and survival are estimated in Table 12. The initial stocking density of 109 g/m^3 and final harvesting density of 13.32 kg/m^3 reflect the effective productivity based on monthly growth rates, mortality, and FCR. The Profit and Loss and Cash Flow summaries for the first five years of business, and Profitability Analysis are located in Appendices L-N.

Table 11. Annual Profit & Loss

Annual Income		**$ / lb**	**Before Tax**	*After Tax*
Production				
Production Months	100%			
Production Amt (lbs)	914,271			
Stocking (pcs)	1,620,000			
Revenue	3,657,085		102%	100%
Operating Costs ($)				
Energy	$ 121,109	$ 0.13	3%	3%
Feed	1,092,453	1.19	30%	30%
Stocking	469,800	0.51	13%	13%
Labor	634,938	0.69	18%	17%
Salaries	291,000	0.32	8%	8%
Ocean Lease Rent	73,142	0.08	2%	2%
Supplies and Other	65,598	0.07	2%	2%
Shipping	415,993	0.46	11%	11%
Monitoring	77,980	0.09	2%	2%
Maintenance	61,200	0.07	2%	2%
Excise Tax	18,285	0.02	1%	1%
Contingency	164,455	0.18	5%	5%
Interest	-	-	0%	0%
Depreciation	138,982	0.15	4%	4%
Total Operating Costs	**$ 3,626,556**	**$ 3.97**	100%	99%
Taxable Income	30,529	0.03	1%	1%
Federal Tax	4,579	0.01	0%	0%
State Tax	1,339	0.00	0%	0%
Income After Taxes	24,551	0.03	1%	1%
Effective Tax Rate	22.27%			
Cost per lb			$ 3.97	$ 3.97

Table 12. Productivity Summary

Avg. Harvest Density		13.32 (kg/m^3)	
Stocking Density		109.04 (g/m^3)	
	Daily Avg	Mo. Avg	Cumulative
Growth Rate (g/period)	2.29	68.82	412.90
FCR		2.37	2.39
Survival		92%	62%

3.4.3.1 Sensitivity Analysis

As suggested earlier, the local and export market for Pacific threadfin is currently being defined. The current market climate, however, reveals declining market prices for Pacific threadfin in the local market. The estimated demand (market price) for Pacific threadfin indicates that production efficiencies may be needed in order for a commercial cage enterprise to remain profitable. The following sensitivity analyses indicate the effect of changes in sale price on profitability, and parameters that may be considered when seeking production efficiencies. With respect to the range of relevant changes in production practices, collectively the analyses indicate that changes in selected parameters may yield greater production efficiencies than others. Sensitivity analyses on sale price, feed cost, growth rates, seed price, density, and financial leverage were explored.

Sale Price

The effect of changes in the assumed sale price for Pacific threadfin on cost per pound and IRR are exhibited in Figure 9.

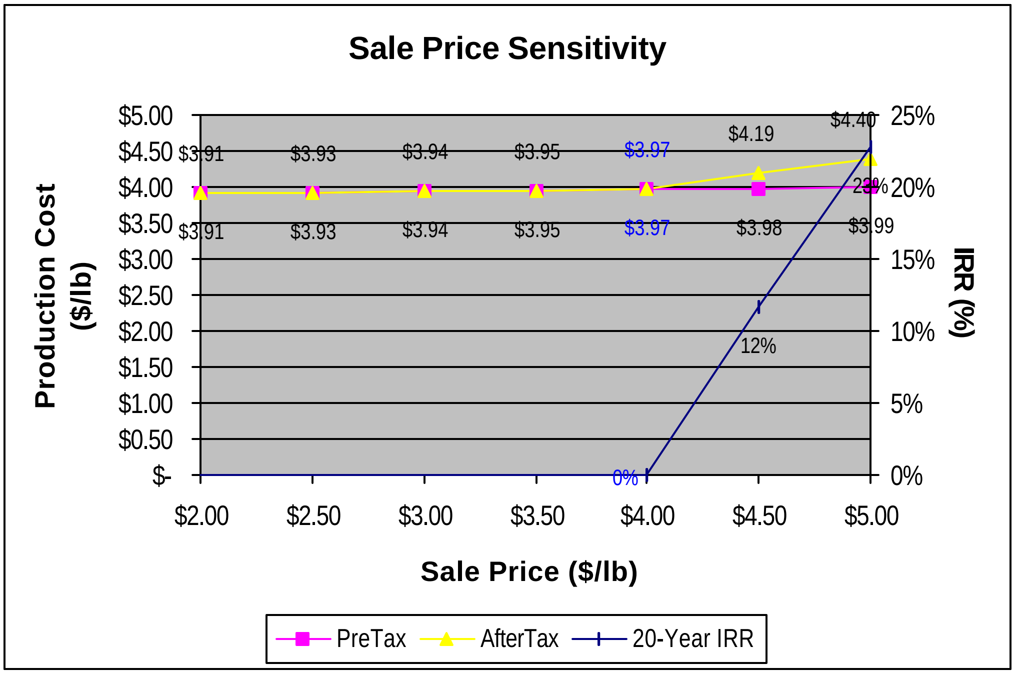


Figure 9. Sale Price Sensitivity

The base model yields a $3.97/lb production cost. Consequently, sale prices of Pacific threadfin at less than $4.00/lb will render the commercial enterprise unprofitable. At a sale price of $5.00 (approximately the 1998 farm-gate price), the enterprise could expect a maximum 20-year IRR of 23%. The current estimated market value for Pacific threadfin is $3.84/lb (farm-gate price), suggesting that a production system based on this conservative model may not be profitable. Consequently, several venues for improving efficiencies were studied in order to improve an enterprise's prospects for profitability.

Feed Price

A sensitivity analysis to changes in feed costs indicates the anticipated linear relationship between feed price and the cost of production (Fig. 10). The analysis assumes comparable production results for substitute feed products. That is, for a $0.05/lb increase (decrease) in feed cost, the production cost per pound of Pacific threadfin increases (decreases) $0.25/lb. Consequently, for a 914,271 lb production system, a feed price increase (decrease) of $0.05 corresponds to $109,245 annual increase (decrease) in production cost. Resultant changes IRR, assuming constant sale price ($4.00), indicate that the 20-year rate of return can decrease (increase) by as much as 6.5% for a $0.10/lb increase (decrease) in feed price. Figure 10 illustrates the effect of changes in feed price on production cost. While changes in production cost may advocate changes in sale price, the 20-year IRR is based on a $4.00 sale price and has been included to suggest the impact of savings from feed costs on profitability.

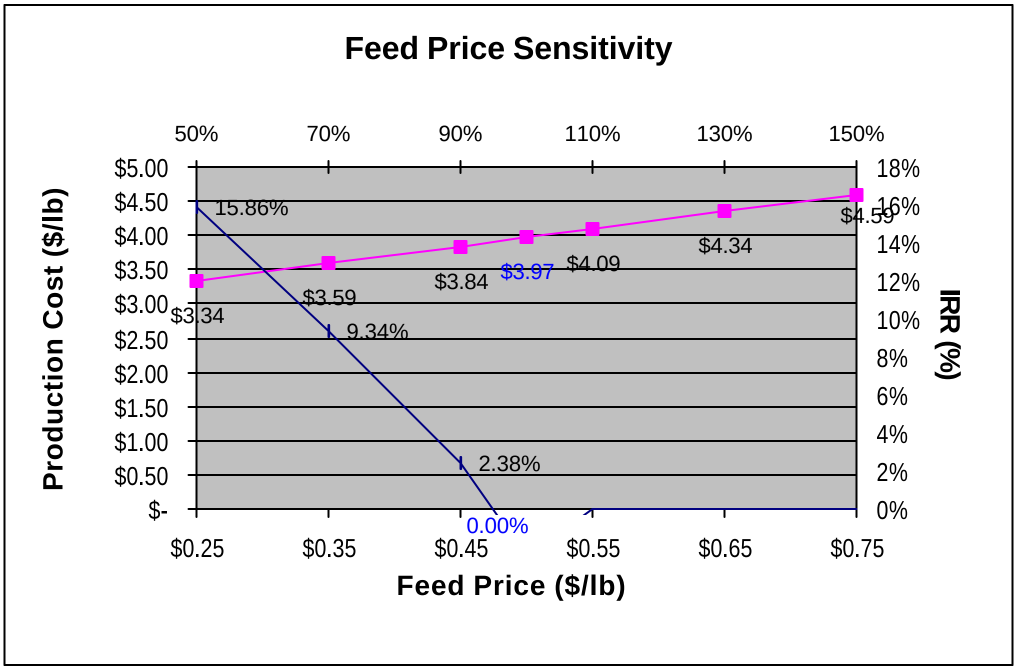


Figure 10. Feed Price Sensitivity

Based on a similar analysis, the sensitivity of production cost to total feed expenditure can be estimated (Figure 11). The total annual feed cost may be calculated based on the total annual production volume, average FCR, and feed price. For a given production yield, these costs may be interpreted as either a change in production efficiency (FCR), feed price, or equivalent combination of changes in FCR and feed price.

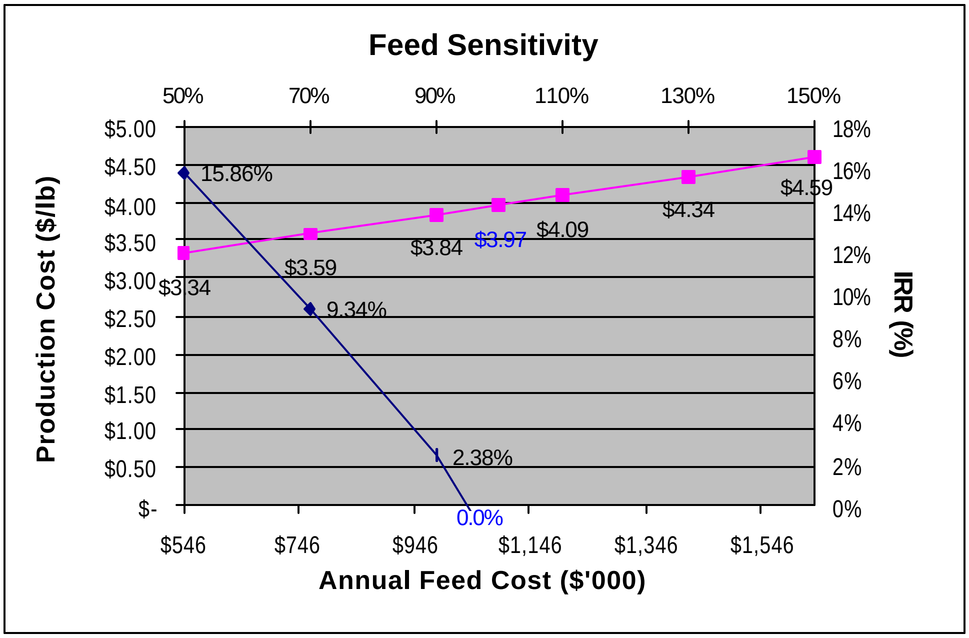


Figure 11. Total Cost Sensitivity

The cumulative FCR (2.37), for example, may be reduced by 37% to 1.50 and effect a reduced production cost equal to $3.51/lb from $3.97/lb. This change in efficiency is also equivalent to reducing the feed price by 37%, i.e. from $0.50/lb to $0.32/lb.

Figures 12 and 13 exhibit the combined effect of changes in either FCR or feed price along FCR or feed price levels, respectively. Figure 12**,** for example, indicates the production cost (before federal and state income tax) sensitivity to changes in feed price for different levels of FCR (e.g. efficiency constraints): 1.0, 1.5, 2.0, 2.37 (baseline), and 2.5. The price sensitivity range is from $0.25/lb - $0.75/lb of feed.

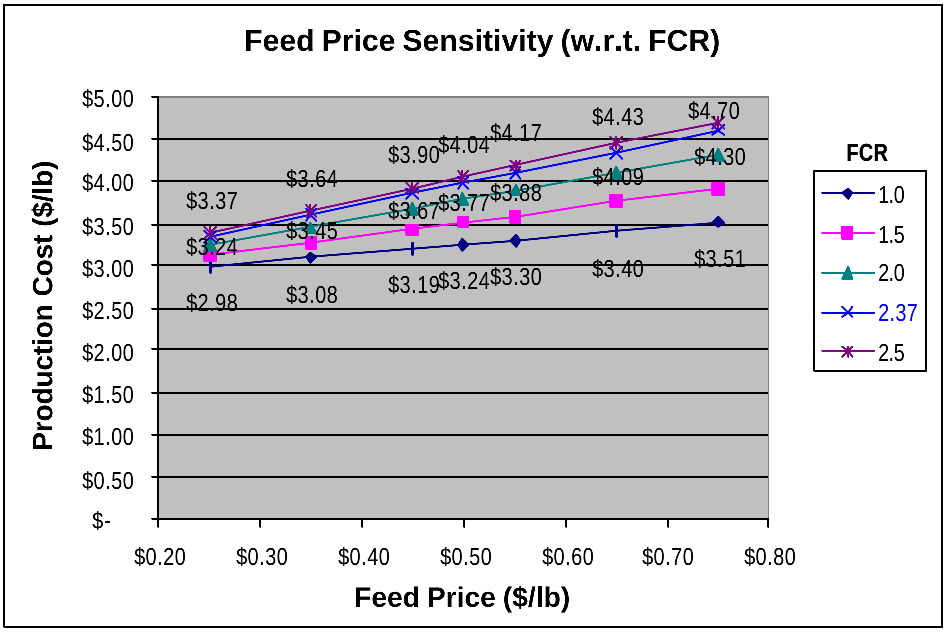


Figure 12. Feed Price Sensitivity (w.r.t. FCR)

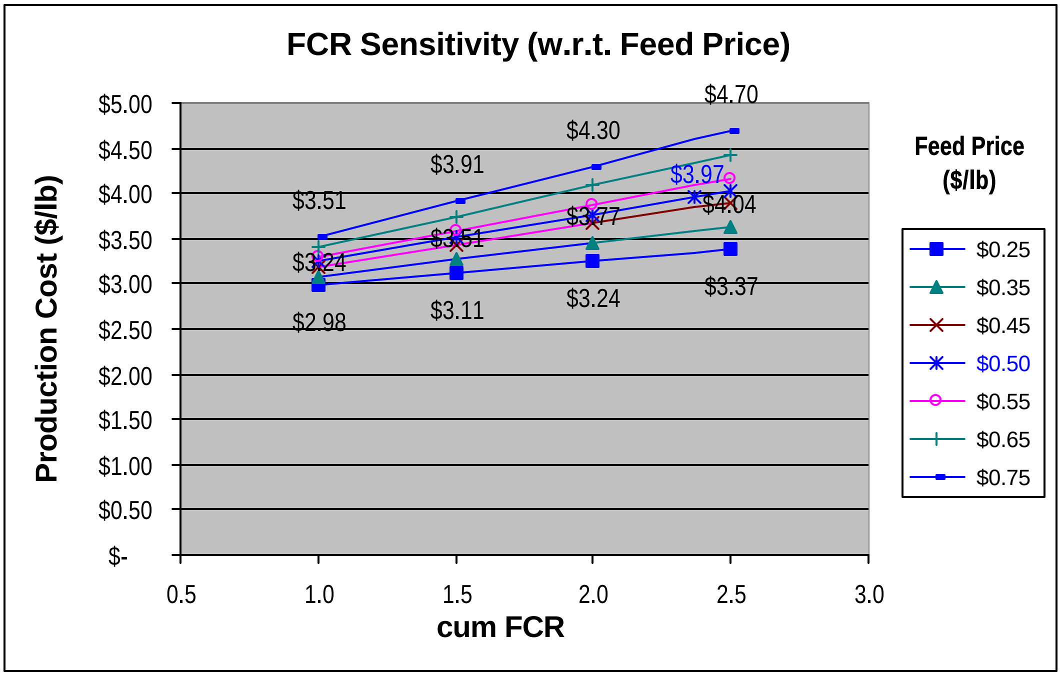


Figure 13. FCR Sensitivity (w.r.t. Feed Price)

Figure 13 exhibits the production cost sensitivity reported in Figure 12 in terms of changes to cumulative FCRs ranging from 1.0 to 2.5 for different levels of feed price (e.g. supply constraint): $0.25/lb, $0.35/lb, $0.45/lb, $0.50/lb (baseline), $0.55/lb, $0.60/lb, $0.65/lb, $0.75/lb.

Feed cost sensitivity analyses reflect the impact of changes in efficiencies with respect to FCR on production cost. For changes in feed price of ±$0.10/lb, the effective change in production cost range is ±$0.25/lb. Sensitivity analyses for production cost along FCR and feed price levels provide information for production systems constrained by either FCR or feed price. As illustrated by the production-to-feed price slopes in Figure 13, at higher feed prices, FCR efficiencies are critical. Analogously, Figure 13 illustrates how feed prices are critical particularly when systems are constrained by high FCRs (inefficiency). Managers should also consider ranges relevant to their commercial systems and other influences on efficiency that may occur beyond those described here that have been assumed to remain constant.

Growth Rates

The effect of growth rates on production cost was also studied. Higher growth rates may be achieved through improved feeding (diet formulation and feeding regimen), management, and selective breeding. Applying percentage changes to monthly growth data obtained from HOARP Phase II production results approximated changes in average daily growth rates. The effect of higher average daily growth rates on production cost is exhibited in Figure 14. A 26% increase in the average daily growth rate from 2.29 to 3.00 lowers production cost from $3.97/lb to $3.52/lb. However, as illustrated in Figure 14, further improvements to growth rates yield subsequently smaller improvements to production costs while still improving profitability (IRR) for a fixed sale price. While changes in production cost may advocate changes in sale price, the 20-year IRR is based on a $4.00 sale price and has been included to suggest the impact of achieved growth rates on profitability. Costs associated with selective breeding are not included in this model and must be considered when exploring production efficiencies and the overall impact of attempts to achieve improved growth rates on production and profitability.

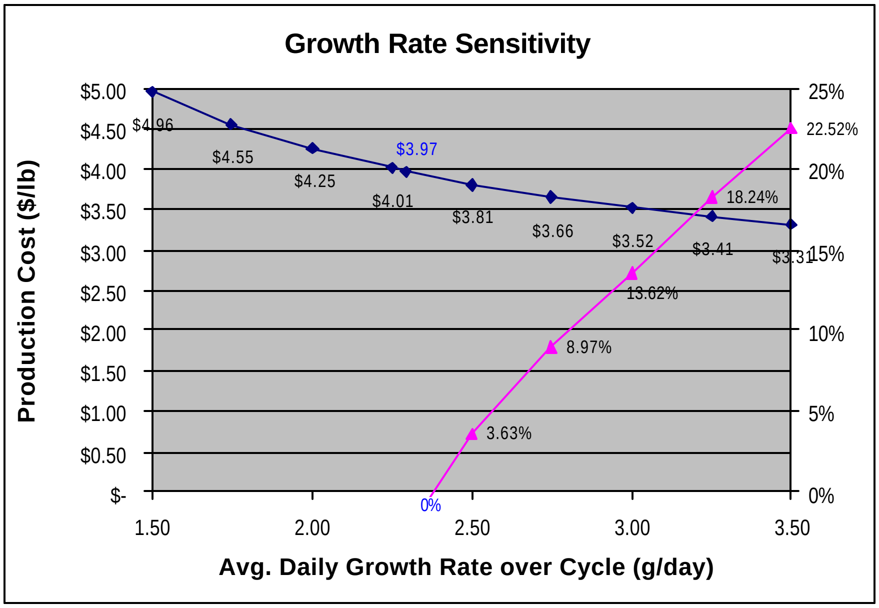


Figure 14. Growth Rate Sensitivity

Seedstock Price

The cost for D50 fry was estimated based on the addition of a hypothetical late nursery (Nursery II) facility to the hatchery model previously developed for Pacific threadfin (Martinez Cordero *et al*. 2001). In comparison to the $0.207 before-tax cost for D25, 1.0g fry, the cost per D50, 2.1g fry was estimated at $0.2495. A $0.25 sale price was applied to the D25 hatchery model and demonstrated a 44% maximum 20-year IRR. Accordingly, for a hatchery system encompassing a late nursery facility, a farm-gate fingerling price of $0.29 will yield a comparable maximum 20-year IRR of 44%. This sale price of $0.29 was used to estimate the fingerling price for the cage enterprise base model. The model assumes that transfer/shipping costs are incurred by the cage enterprise. Figure 15 illustrates the effect of changes in seed stock price on production cost.

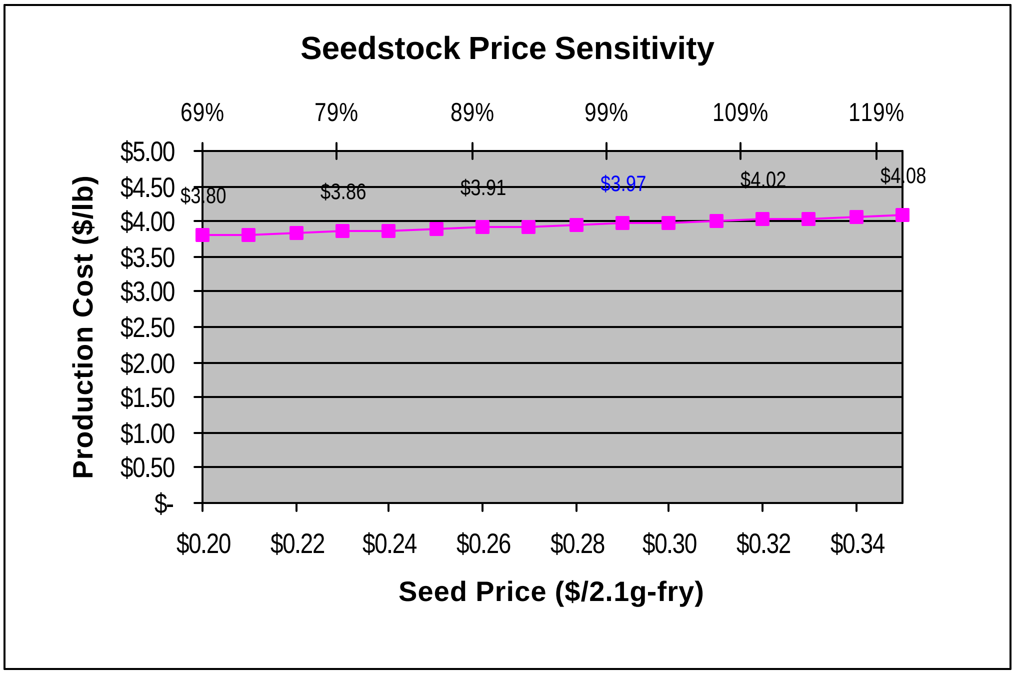


Figure 15. Seedstock Price Sensitivity

As indicated earlier, stocking costs represent 13% of total production cost. For relevant changes in fry price, production cost does not fluctuate appreciably. For a 1¢/fry increase in fingerling price, the production cost per pound increases by $0.02 (Fig. 15). Based on the relevant ranges indicated here and in the previous feed cost analyses, changes in fry price have a small effect in comparison to changes in feed costs.

Changes in Density

Changes in densities reflect size economies. This can be accomplished by either increasing stocking numbers or by improving survival of stocked fish. The simple analysis assumes changes in net income due to feed costs and increased production. Consequently, fixed costs assume no significant changes associated with labor, energy, and capital for the six-cage model.

Figure 16 illustrates the effect of changes in stocking density on production costs. Corresponding harvest densities are also indicated and are based upon mortality, growth, and feed rate (FCR = 2.37) assumptions used in the six-cage 914,271 lb production scale (base model). The figure reflects the decrease in unit cost as fixed costs are spread out over increased production levels (resulting from higher densities).

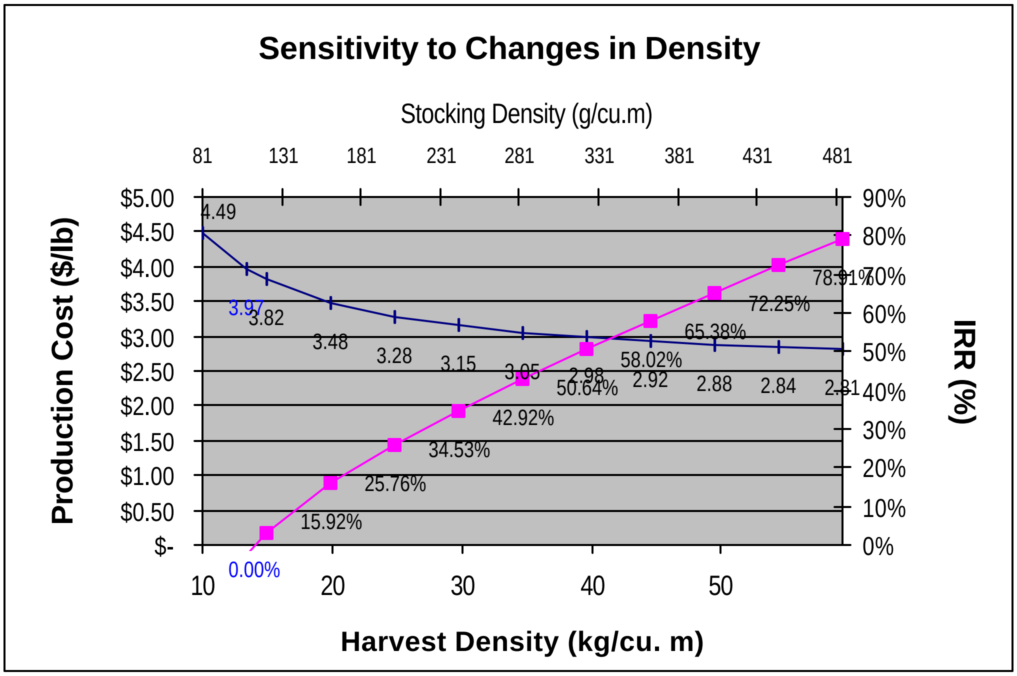


Figure 16. Sensitivity to Changes in Density (10 kg/m^3 to 60 kg/m^3)

Production costs (before tax) may be brought down to $2.81/lb if harvested at a density of 54.27 kg/m^3. This, however, assumes that all parameters aside from costs associated with feed and seed stock remain constant. Changes in stocking and harvesting densities however, should take into consideration the effect on overall production, market demand, and associated changes in market value (sale price) for Pacific threadfin.

Financial Leverage

The base model assumes 100% equity, i.e. 0% borrowed. Production cost sensitivity to changes in interest rates was performed for 25%, 50%, 75%, and 100% debt. The production costs exhibited in Figure 18 reflect pre-tax production costs (i.e. excluding federal and state income taxes). The maximum amount borrowed (=100%) for a period of 30 years is equal to $1,696,465 to cover the initial capital outlay for the cage enterprise. Figure 17 illustrates the effect of leveraging on production costs. Production costs increase when loan interest payments add to the costs of operations because of increased borrowing and/or higher interest rates.

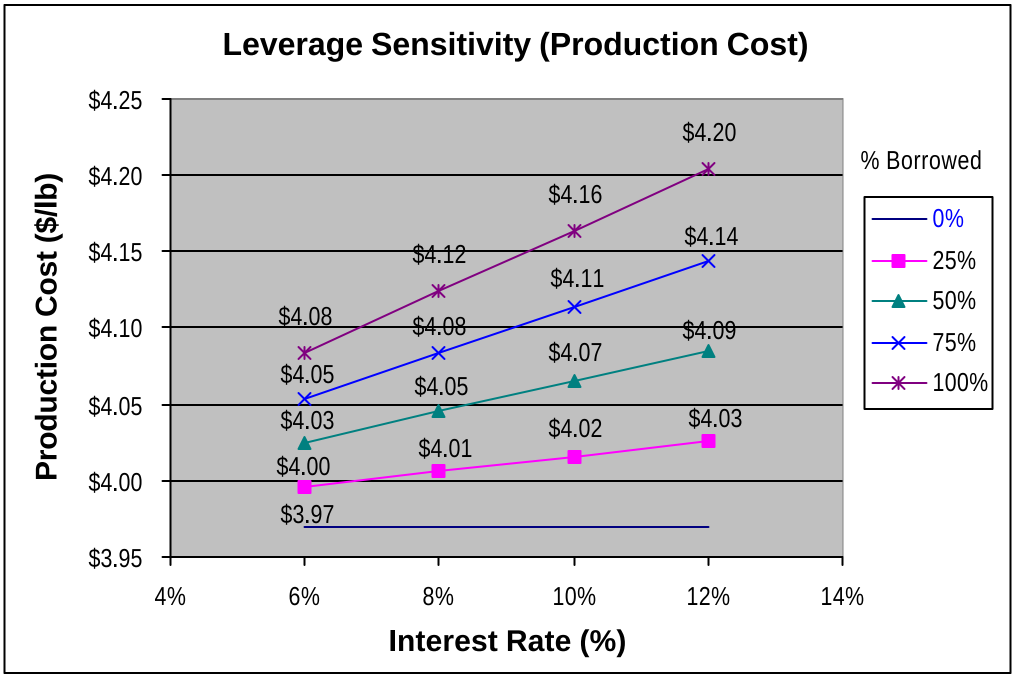


Figure 17. Leverage Sensitivity (Production Cost)

The base model may not accurately reflect the benefits of leveraging because of the high production costs with respect to the current market price for Pacific threadfin. Assuming a profitable base model in which the sale price is $5.00/lb, an enterprise with 100% equity may achieve a 20-year IRR of 28%. The 20-year IRR reflects the maximum return available to investors and retained earnings. Commercial enterprises may be interested in securing bank loans at reasonable rates, to increase the IRR available to investors and for retained earnings. The ability to reduce net income by the loan interest amount reduces income tax liability, increasing profitability and IRR available for investors and retained earnings (Fig. 18).

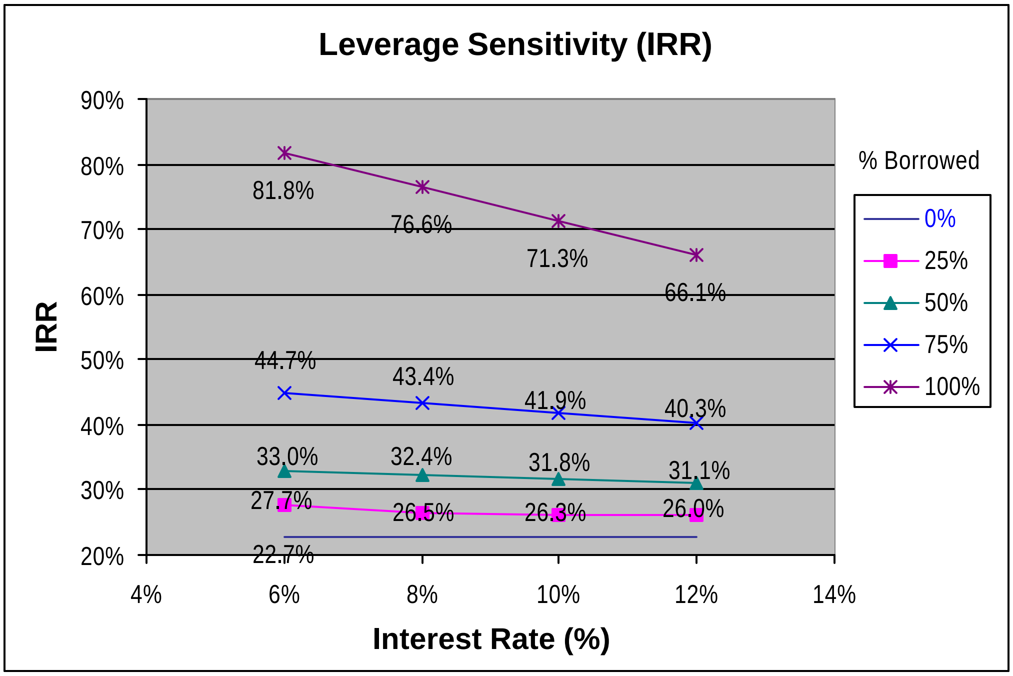


Figure 18. Leverage Sensitivity (Profitability based on $5.00/lb. sale price).

3.4.4 Discussion

The offshore cage production model defined the cost structure for cage-produced Pacific threadfin. For a six-cage production system yielding 914,271 lbs of Pacific threadfin, the cost of production is estimated at $3.97. The largest costs incurred are primarily feed, which is only slightly less then the combined costs associated with payroll, seedstock, and shipping. While the conservative cage production model suggests that the system may not be profitable under the assumed conditions, several avenues were explored that may improve production efficiencies and thus profitability.

Analyses on production efficiencies including feed costs, FCR, growth rates, harvest density, and financial leverage were explored. Based on changes in parameters that may be achieved by a specific enterprise, cage production systems can evaluate the parameters that will effect sizable benefits to cost savings and profitability. Sensitivity analyses performed on the base model indicate that changes in harvest density may have a greater effect on profitability than reduction in feed costs and fluctuations in fry price. Given that overall survival in the two offshore trials conducted to date is only 59.5% (61% for Phase I and 58% for Phase II), increased early survival through improvements in management (stocking and use of the nursery cage system) appear to be the best means to increase harvest density. Anticipated changes in seedstock prices have a small effect on production cost in comparison to feed costs. This is expected in consideration of the sizeable contribution of feed costs (30%) to the total production cost in comparison to stocking costs (13%). Selective breeding practices may yield efficiencies through higher growth rates, but may not provide a significant net benefit if the cost of such procedures is high. An analysis of the leveraging strategy was also explored as a secondary consideration for management, where a highly leveraged enterprise may achieve a higher rate of return available to investors and for retained earnings.

4.0 CONCLUSIONS AND FUTURE DIRECTIONS

4.1 Conclusions

HOARP Phases I and II was the first integrated, demonstration project to examine the biological, environmental, and economic feasibility of offshore aquaculture in the tropics of an indigenous species under completely submerged conditions. While Phase II achieved its goal of improving growth of Pacific threadfin (0.42 – 0.48 kg fish were harvested) and doubling harvest density (12.4 kg/m^3 maximum density, with over 34,843 kg harvested), there was little change in FCR (2.1), and overall harvest survival (58%) compared to Phase I. The latter was due primarily to unaccounted losses of fish (38%), presumably during the nursery stage, when even smaller fish were stocked. Further, routine liver histology conducted generated concerns for fish and human health that nearly prevented sale of harvested fish. The cage attracted a similar biomass of species (800 kg) as in Phase I, indicating that species aggregation about the cage was a habitat (cage dimension) and not a density (biomass in the cage) driven effect. Benthic community structure underneath the cage was no different than control sites. Expanded environmental monitoring revealed significant changes in total ammonia concentrations two cage diameters downstream, several hours after the first feeding of the day.

While the suitability of threadfin to offshore production was demonstrated, the bio-economic model generated under Phase II indicated improvements in several biological aspects of production are needed to ensue profitability of a commercial offshore threadfin farm. Biological performance directly influences waste production and is essential to maintain a competitive edge for U.S. producers, while ensuring production of wholesome, healthy seafood products. While early transfer of fish offshore optimizes onshore hatchery and support cost, unexplained losses in the nursery cage need to be defined and resolved to reach profitable harvest densities of near 40kg/m^3. Feeding costs also need to be reduced from an estimated \$2.77/kg (\$1.32/kg current feed price x 2.1 FCR).

Research to date has paved the way for commercialization. However, start-up companies will be limited to 100,000 pounds of production until zone of mixing requirements are established for compliance with NPDES regulatory standards. An approach to develop these requirements and an associated monitoring plan has been initiated and coordinated with state and federal agencies. But costs of environmental monitoring and compliance need to be reduced to ensure these do not impact heavily on the bottom line. The fate of the discharge of metabolic products from the cage system is still unknown and raises major questions with regulatory agencies. Moreover, the long-term effects of cage culture on the benthic biota and on the ecosystem outside the cage must be defined. Improvements in overall biological performance of Pacific threadfin and modeling of effluents from offshore operations will be necessary to establish environmentally and economically reasonable monitoring requirements for large scale operations.

The Pacific threadfin proved to be an excellent model for offshore testing and candidate for commercialization. Importantly, however, other species being explored in the region exhibit characteristics that may be economically and biologically more favorable in the long run, and provide the diversity needed for a budding offshore industry in the Pacific. This is particularly true in Hawaii since the local fishery has been severely impacted by the partial closure of the longline industry and by new restrictions to traditional fishing grounds. This suggests strongly that additional effort should be placed on the culture of other species that can replace the fish being lost to the closures and restrictions. Without development of alternative species to challenge economic assumptions and increase the product mix, offshore production in the Pacific region has little margin for error in profitability, market penetration and opportunity for growth.

4.2 Future Directions

In view of the results of this project, several areas of future endeavor can be proposed to provide the enabling technologies essential to the bottom line to reduce risk and improve profitability of offshore aquaculture production in Hawaii, the Pacific region, and ultimately, the entire U.S. These include: (1) long-term monitoring of multiple cages to investigate some of the unresolved issues relative to environmental aspects of open ocean aquaculture; (2) research aimed at improving nursery survival and understanding the feed and nutritional requirements of the fish to be grown in the cages; (3) research into the live cycles of other indigenous species so a greater number of species can be raised if economics warrant; and (4) beginning a program aimed at animal health and product quality.

The specific outputs from such efforts that will enable offshore production in Hawaii and elsewhere include:

1) Improved nursery survival will allow commercial companies to reach profitable harvest densities and with deployment of nursery cages, reduce costs of onshore hatchery support systems. Such nursery cage technologies would be applicable to areas outside Hawaii as well.

2) Optimized diet formulation and physical characteristics of the feed will increase production efficiency and minimize waste output from the cage, thereby improving profitability and environmental compatibility of the operation through reduced feeding costs and the risk of adverse environmental effects.

3) Optimized feeding regimen will also increase production efficiency and minimize wastage through improved fish health and product quality. This ensures the production of wholesome healthy seafood products and a marketing edge for long-term sustainability as concerns for animal agriculture production worldwide are increasing.

4) Determination of shelf-life and potential for long-term product storage would enable development of marketing and distribution tools essential for start-up of a large, seafood production operation and its long-term goals of sustainable profitability. Little scientific information exists on warm-water marine species.

5) Research into development of alternative offshore species indigenous to Hawaii and the U.S. mainland will increase the seafood product portfolio, and challenge economic models. Development of species with sashimi (raw) grade qualities has particular value-added appeal to counter the comparatively high production costs for U.S. aquaculture farmers and maintain international competitiveness.

6) Determination of the ecological impact and economic value of the developing fish community around the cage will provide needed information for environmental impacts

statements of a multi-cage offshore facility and any added value that can be extracted from an offshore aquaculture operation.

7) Information on the effects of operation of a multi-cage offshore facility on waste discharge and the benthic community structure will provide data needed for an offshore venture to establish environmental monitoring and permit requirements. It would also serve as a model for effects in the tropics for comparison with other regions in the country.

8) Characterization of the dispersal patterns of water chemistry constituents around a multi-cage facility will provide state and federal regulators the appropriate models to establish permit requirements, and aid development of appropriate, yet cost-effective tools for collection of data and monitoring by commercial companies.

There is opportunity for offshore aquaculture research and development in the Pacific. HOARP I and II have paved the way for development of a coordinated and cooperative approach to research the key biological, environmental, and economic issues for commercialization of the technology in the region. This technology has focused on the use of submersible cage designs to address concerns of competing uses of valuable ocean resources. The Pacific threadfin holds absolute promise for commercialization, and new species being developed can help expand the seafood portfolio. Several research questions are critical to improving profitability and long-term sustainability of a potential offshore industry. Public perception of offshore aquaculture in the region is high and results indicate that this form of aquaculture, conducted with an appreciation for minimizing the real and perceived impacts on the environment, can be a viable business opportunity in Hawaii and the Pacific region.

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Appendix B. Results for Total Suspended Solids (mg/L) HOARP Phase II, May 17, 2000 - December 20, 2000

Sample ID	5/17/00	5/24/00	6/5/00	6/9/00	6/16/00	6/22/00	6/29/00	7/6/00	7/14/00	7/21/00	7/26/00	8/3/00
UA-1	1.331	2.542	0.274	4.448	2.830	2.026	2.540	3.462	5.758	1.384	0.714	0.891
UA-2	1.501	1.342	3.810	2.366	13.108	2.138	3.918	*	5.425	1.234	1.260	0.200
UB-1	*	1.162	3.042	3.428	3.022	0.746	1.984	2.104	2.992	1.202	1.000	0.932
UB-2	*	2.248	3.662	1.944	2.340	1.666	2.744	*	1.920	1.748	1.085	1.108
DA-1	1.173	1.016	2.226	3.896	2.348	2.145	2.774	2.090	4.252	0.964	1.170	0.788
DA-2	0.799	1.472	0.246	3.066	3.062	1.798	4.368	*	1.603	1.184	1.190	1.020
DB-1		1.644	1.502	2.338	3.614	2.430	1.846	1.788	7.257	1.640	0.535	0.161
DB-2		0.784	2.906	3.084	3.858	2.830	0.958	*	4.139	1.521	1.404	0.097
D+15A-1		0.822	2.150	1.626	1.434	3.690	3.648	3.555	1.935	1.704	0.828	1.294
D+15A-2		0.948	1.812	1.704	6.046	2.928	0.996	*	2.450	1.155	2.101	1.638
D+15B-1		1.888	2.058	2.996	1.926	1.928	1.572	0.585	0.370	3.560	1.486	1.264
D+15B-2		1.802	0.896	12.630	1.272	2.860	5.748	*	3.692	1.519	1.026	0.977
D+30A-1								*				
D+30A-2								*				
D+30B-1								*				
D+30B-2								*				
DAR-A-1								11.614				
DAR-A-2								*				
DAR-B-1								3.06				
DAR-B-2								*				
DN+15A-1								4.435				
DN+15A-2								*				
DN+15B-1								1.906				
DN+15B-2								*				
DS+15A-1								4.327				
DS+15A-2								*				
DS+15B-1								3.009				
DS+15B-2								*				
DM+30A								3.783				
DM+30B								2.504				
DT+30A								1.186				
DT+30B								1.193				

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage, (D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage, DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage . All samples taken at 18m depth. (DM+30) 30m downstream depth (30M), (DT+30) 30m downstream at top of cage depth 13.2m, * no data required for sample site.

Appendix B cont. Results for Total Suspended Solids (mg/L) HOARP Phase II, May 17, 2000 - December 20, 2000

Sample ID	8/10/00	8/17/00	8/23/00	8/31/00	9/7/00	9/14/00	9/21/00	9/28/00	10/5/00	10/12/00	10/19/00	10/26/00
UA-1	1.233	1.616	2.451	2.87	7.602	0.176	1.212	3.0	1.5	1.5	4.7	1.7
UA-2	1.277	0.899	4.973	0.574	2.804	1.222	0.266	2.0	2.6	3.4	3.5	2.6
UB-1	1.012	0.793	2.533	2.903	3.602	1.409	1.444	2.0	0.8	2.2	2.7	0.4
UB-2	2.446	2.032	2.952	1.086	2.277	0.372	1.433	0.6	1.7	1.8	0.8	3.0
DA-1	1.729	1.923	1.070	0.364	0.37	1.115	1.278	2.7	0.6	0.8	1.5	23.0
DA-2	2.163	0.998	1.353	2.103	4.336	1.069	1.047	2.2	2.4	0.5	3.6	3.0
DB-1	1.952	2.166	2.387	2.356	1.374	1.76	1.946	1.2	0.5	1.1	1.9	0.0
DB-2	1.704	1.512	3.175	1.996	0.79	1.295	1.011	1.4	3.0	3.6	2.7	1.9
D+15A-1	3.010	1.529	1.822	2.088	2.646	1.262	0.392	1.3	2.4	1.8	1.4	0.3
D+15A-2	0.228	3.181	1.530	2.825	3.385	0.249	0.885	0.5	0.4	2.6	0.5	5.1
D+15B-1	0.078	2.649	0.876	0.881	1.924	0.587	0.902	1.6	1.4	0.1	1.3	1.5
D+15B-2	1.441	0.937	2.143	1.391	1.963	2.691	2.071	1.2	2.6	0.7	1.9	1.5
D+30A-1	0.711	3.837	0.249	1.787	2.681	0.767	0.986	1.1	1.3	1.0	2.6	0.3
D+30A-2	1.262	0.628	4.779	1.427	1.563	2.006	0.292	2.0	2.8	4.3	3.4	2.9
D+30B-1	2.654	1.850	1.310	2.28	2.381	*	1.226	1.5	2.3	1.6	0.9	0.4
D+30B-2	10.065	5.196	0.764	1.93	2.54	*	1.834	0.1	0.1	0.7	0.4	3.3
DAR-A-1		2.529				*						1.1
DAR-A-2		0.741				*						1.6
DAR-B-1		1.522				1.727						0.5
DAR-B-2		0.318				0.572						2.9
DN+15A-1		0.794				0.665						0.3
DN+15A-2		0.297				2.191						1.5
DN+15B-1		1.440				1.488						2.0
DN+15B-2		1.344				1.077						1.9
DS+15A-1		3.536				2.375						0.3
DS+15A-2		0.415				0.782						1.1
DS+15B-1		1.473				0.402						1.2
DS+15B-2		2.494				1.152						1.8

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage,
(D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage,
(DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage . All samples taken at 18m depth.
(DM+30) 30m downstream depth (30M), (DT+30) 30m downstream at top of cage depth 13.2m.
* no data required for sample site.

Appendix B cont. Results for Total Suspended Solids (mg/L) HOARP Phase II, May 17, 2000 - December 20, 2000

Sample ID	11/3/00	11/9/00	11/16/00	11/22/00	12/1/00	12/8/00	12/20/00
UA-1	0.3	2.9	3.0	3.3	4.2	0.3	3.1
UA-2	2.3	6.7	2.7	*	4.9	1.5	3.1
UB-1	5.6	4.1	2.2	4.6	3.8	0.4	4.2
UB-2	3.9	1.5	2.6	*	2.9	1.4	4.7
DA-1	2.3	1	4.1	2.7	6.9	3.4	1.1
DA-2	3.4	2.5	4.5	*	2.2	4.1	2.0
DB-1	0.9	1.3	1.7	5.5	1.4	3.3	7.2
DB-2	2.7	2	1.7	*	2.1	3.4	1.9
D+15A-1	1.6	0.9	0.8	5.7	1.5	0.7	3.1
D+15A-2	0.6	3.1	3.9	*	1.1	1.6	1.3
D+15B-1	1.4	1.4	1.7	4.2	1.9	1.1	0.5
D+15B-2	0.8	2	0.7	*	1.8	1.7	2.7
D+30A-1	0.4	1.9	0.9	0.5	2.6	1.8	2.7
D+30A-2	0.9	1.7	0.7	*	2.7	1.8	1.8
D+30B-1	1.5	1.7	1.6	0.7	1.2	1.8	2.2
D+30B-2	0.9	1.4	1.7	*	1.2	1.4	2.2
DAR-A-1				2.8			0.9
DAR-A-2				*			1.8
DAR-B-1				0.5			0.8
DAR-B-2				*			1.2
DN+15A-1				1.6			1.5
DN+15A-2				*			2.4
DN+15B-1				1.7			1.6
DN+15B-2				*			0.7
DS+15A-1				2.0			1.8
DS+15A-2				*			2.5
DS+15B-1				1.9			2.3
DS+15B-2				*			1.2
DT+30A				1.2			
DT+30B				0.4			
DM+30A				0.4			
DM+30B				3.0			

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage, (D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage, (DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage . All samples taken at 18m depth. (DM+30) 30m downstream depth (30M), (DT+30) 30m downstream at top of cage depth 13.2m

* no data required for sample site

Appendix C. Results for Ammonia (ug-N/l), HOARP II, May 9, 2000 - December 20, 2000

Sample ID	5/9/00	5/17/00	5/23/00	6/5/00	6/9/00	6/16/00	6/22/00	6/29/00	7/6/00	7/14/00	7/21/00	7/26/00
U-A	1.12	66.50	14.00	0.70	15.40	0.70	0.70	1.12	1.12	1.12	0.42	5.74
U-B	0.14	1.26	56.14	0.70	17.08	0.98	1.54	1.12	1.26	8.96	2.38	6.16
U-C	0.84	*	*	*	*	*	*	0.28	*	*	*	*
U-D	0.84	*	*	*	*	*	*	*	*	*	*	*
D-A	13.72	8.96	11.06	0.84	46.62	3.08	9.94	1.82	2.66	12.18	3.36	13.72
D-B	9.10	12.88	59.92	0.70	46.62	3.92	12.60	1.54	2.52	6.72	5.32	0.56
D+15-A			24.36	0.98	10.78	2.94	8.54	1.40	64.68	3.78	11.06	73.36
D+15-B				0.00	8.96	1.68	5.60	1.40	5.74		11.90	2.38
DAR-A									0.98			
DAR-B									1.54			
DN+15-A									2.10			
DN+15-B									1.68			
DS+15-A									11.20			
DS+15-B									1.82			
DM+30-A									21.00			
DM+30-B									1.54			
DT+30-A									1.40			
DT+30-B									1.68			

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage,
(D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage,
(DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage. All samples taken at 18m depths.
(DM+30) 30m downstream depth (30M), (DT+30) 30m downstream at top of cage depth 13.2m.
* no data required for sample site.

Appendix C cont. Results for Ammonia (ug-N/l), HOARP II, May 9, 2000 - December 20, 2000

Sample ID	8/3/00	8/10/00	8/17/00	8/23/00	8/31/00	9/7/00	9/14/00	9/21/00	9/28/00	10/5/00	10/12/00	10/19/00
U-A	66.08	2.10	0.56	3.08	0.84	1.68	8.96	2.24	0.70	1.40	0.84	0.84
U-B	66.08	2.38	0.84	1.82	0.28	1.26	8.82	0.98	0.84	1.54	1.12	1.26
D-A	54.46	1.26	51.10	2.10	3.08	1.68	46.90	18.76	2.10	2.10	1.96	1.82
D-B	30.66	1.12	50.68	1.96	3.50	2.38	45.08	20.02	2.24	2.94	2.10	1.82
D+15-A	123.90	0.42	23.24	3.64	0.98	9.24	20.72	13.72	2.10	17.36	10.64	1.54
D+15-B	31.08	1.26	24.36	2.66	0.84	3.64	16.94	14.42	1.82	0.98	7.70	0.84
D+30-A		0.00	6.58	0.84	1.68	9.24	2.10	21.70	1.54	5.18	1.12	1.82
D+30-B		0.28	7.56	1.82	1.68	7.84	1.68	20.44	1.68	7.56	2.66	2.10
DAR-A			0.28				1.40					
DAR-B			1.54				2.10					
DN+15-A			1.40				19.60					
DN+15-B			1.54				19.18					
DS+15-A			5.32				18.62					
DS+15-B			9.38				25.90					
DM+30-A			6.58				19.60					
DM+30-B			7.56				19.18					
DT+30-A												
DT+30-B												

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage,
(D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage,
(DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5m from cage. All samples taken at 18m depths.
(DM+30) 30m downstream depth (30M), (DT+30) 30m downstream at top of cage depth 13.2m.
* no data required for sample site.

Appendix C cont. Results for Ammonia (ug-N/l), HOARP II, May 9, 2000 - December 20, 2000

Sample ID	10/26/00	11/3/00	11/9/00	11/16/00	11/27/00	12/1/00	12/8/00	12/20/00
U-A	1.96	6.30	6.58	3.92	4.06	3.36	1.54	0.98
U-B	2.10	7.56	6.72	3.64	4.06	3.64	3.64	0.84
D-A	11.62	7.70	4.76	5.04	4.20	3.08	1.68	2.10
D-B	11.76	8.26	4.34	6.16	4.06	2.66	1.82	2.24
D+15-A	2.80	16.66	3.22	2.80	2.94	1.26	2.52	1.82
D+15-B	2.80	15.12	4.20	3.64	2.80	1.54	2.66	1.26
D+30-A	3.50	16.80	5.32	4.48	1.82	1.54	1.40	0.42
D+30-B	2.66	17.92	6.58	3.22	1.26	1.54	1.12	0.42
DAR-A	0.70				1.12			0.70
DAR-B	0.98				1.40			0.56
DN+15-A	2.52				0.70			0.84
DN+15-B	2.66				0.84			1.26
DS+15-A	0.28				0.84			0.70
DS+15-B	0.70				1.54			0.56
DM+30-A					2.24			
DM+30-B					1.40			
DT+30-A					0.84			
DT+30-B					0.70			

(U) upstream values at rim of cage, (D) downstream values at rim of cage, (D+15) 15m downstream from rim of the cage,
(D+30) 30m downstream from the rim of the cage, (DN+15) 15m downstream to the north lateral edge of the rim of cage,
(DS+15) 15m downstream south lateral edge of the rim of cage, (DAR) reef approximately 0.5 m from cage. All samples taken at 18m depths.
(DM+30) 30 m downstream depth (30M), (DT+30) 30 m downstream at top of cage depth 13.2m
* no data required for sample site

Appendix D. Quarterly Water Quality: Nutrient Results for March 9, 2000, July 6, 2000 & November 27, 2000.

3/9/00

Location		TP µg/l	Turbidity NTU	Chl-A µg/l	TSS µg/l	NO$_3$-N µg/l	NO$_2$-N µg/l	NO$_3$+NO$_2$ µg/l	TN µg/l	PO$_4$ µg/l
Downstream 25m W (S)		60.0	0.1	0.1	1.0	nd	nd	nd	51.7	nd
	(M)	60.0	0.1	0.1	1.7	nd	nd	nd	51.7	nd
	(B)	66.4	0.0	0.1	1.0	nd	nd	nd	51.7	nd
Downstream 70m W (S)		52.5	0.0	0.1	0.9	nd	nd	nd	58.2	nd
	(M)	45.0	0.2	0.1	1.2	nd	nd	nd	64.6	nd
	(B)	59.0	0.1	0.1	0.5	nd	nd	nd	51.7	nd
Downstream 88m W (S)		52.5	0.3	0.1	0.5	nd	nd	nd	51.7	nd
	(M)	52.5	0.1	0.1	0.3	nd	nd	nd	64.6	nd
	(B)	51.7	0.0	0.1	1.4	nd	nd	nd	45.2	nd
Upstream 70m E (S)		52.5	0.1	0.1	0.7	nd	nd	nd	58.2	nd
	(M)	52.5	0.1	0.1	1.5	nd	nd	nd	90.5	nd
	(B)	81.2	0.1	0.1	1.5	nd	nd	nd	84.0	nd
Control 70m N (S)		60.0	0.1	0.1	1.0	nd	nd	nd	77.5	nd
	(M)	75.0	0.1	0.1	1.3	nd	nd	nd	71.1	nd
	(B)	51.7	0.1	0.1	1.6	nd	nd	nd	51.7	nd
Control 70m S (S)		60.0	0.1	0.1	nst	nd	nd	nd	51.7	nd
	(M)	45.0	0.2	0.1	1.7	nd	nd	nd	51.7	nd
	(B)	73.8	0.1	0.1	1.3	nd	nd	nd	51.7	nd
Upstream 88m E (S)		60.0	0.1	0.1	1.6	nd	nd	nd	58.2	nd
	(M)	67.5	0.3	0.1	1.1	nd	nd	nd	122.8	nd
	(B)	73.8	0.1	0.1	1.4	nd	nd	nd	71.1	nd
Cage (inside)		52.5	0.0	0.1	1.4	nd	nd	nd	58.2	nd
		37.5	0.1	0.1	1.2	nd	nd	nd	45.2	nd
		73.8	0.1	0.1	0.6	nd	nd	nd	122.8	nd
Control 200 m S (S)		52.5	0.1	0.1	1.7	nd	nd	nd	58.2	nd
	(M)	60.0	0.1	0.1	1.0	nd	nd	nd	58.2	nd
	(B)	81.2	0.1	0.1	1.0	nd	nd	nd	64.6	nd
Downstream 500m W (S)		37.5	0.1	0.1	1.2	nd	nd	nd	45.2	nd
	(M)	73.8	0.2	0.1	1.8	nd	nd	nd	71.1	nd
	(B)	73.8	0.1	0.1	1.2	nd	nd	nd	38.8	nd
Downstream 1000m W (S)		60.0	0.1	0.1	1.8	nd	nd	nd	45.2	nd
	(M)	59.0	0.1	0.1	1.1	nd	nd	nd	51.7	nd
	(B)	73.8	0.1	0.2	1.1	nd	nd	nd	77.5	nd
MDL		4.5					2.2	2.7	3.6	4.0

Appendix D cont. Quarterly Water Quality: Nutrient Results for March 9, 2000, July 6, 2000 & November 27, 2000.

6-Jul-00

Location	TP ug/L	Turbidity NTU	Chl-A ug/L	TSS ug/L	NO_3-N ug/L	NO_2-N ug/L	NO_3+NO_2 ug/L	TN ug/L	PO_4 µg/l
UA	n/d	0.3	0.2	3.5	n/d	n/d	n/d	346.6	n/d
UB	n/d	0.3	0.1	2.1	n/d	n/d	n/d	344.9	n/d
DA	n/d	0.1	0.1	2.1	n/d	n/d	n/d	333.1	n/d
DB	n/d	0.1	0.1	1.8	n/d	n/d	n/d	334.2	n/d
DSA+15	n/d	0.1	0.1	4.3	n/d	n/d	n/d	371.0	n/d
DSB+15	n/d	0.1	0.1	3.0	n/d	n/d	n/d	338.0	n/d
DAM+30	n/d	0.1	0.1	3.8	n/d	n/d	n/d	361.9	n/d
DBM+30	n/d	0.1	0.0	2.5	n/d	n/d	n/d	328.5	n/d
DAR-A	n/d	0.1	0.1	11.6	n/d	n/d	n/d	337.8	n/d
DAR-B	n/d	0.1	0.1	3.1	n/d	n/d	n/d	346.2	n/d
DNA+15	n/d	0.2	0.1	4.4	n/d	n/d	n/d	346.6	n/d
DNB+ 15	n/d	0.1	0.1	1.9	n/d	n/d	n/d	384.6	n/d
DAT+30	n/d	0.0	0.1	1.2	n/d	n/d	n/d	347.5	n/d
DBT + 30	n/d	0.1	0.1	1.2	n/d	n/d	n/d	351.1	n/d
DA+ 15	n/d	0.1	0.1	3.6	n/d	n/d	n/d	332.5	n/d
DB +15	n/d	0.1	0.1	0.6	n/d	n/d	n/d	436.5	n/d
MDL	11.8				1.8	0.4		1.4	11.8

27-Nov-00

Location	TP ug/L	Turbidity NTU	Chl-A ug/L	TSS ug/L	NO_3-N ug/L	NO_2-N ug/L	NO_3+NO_2 ug/L	TN ug/L	PO_4 µg/l
UA	102.0	0.5	0.7	3.3	5.0	1.1	6.1	324.0	8.7
UB	98.0	0.4	2.8	4.6	3.4	2.2	5.6	436.0	13.3
DA	64.5	0.2	0.2	2.7	3.5	1.7	5.2	261.0	7.8
DB	89.9	0.2	0.6	5.5	1.7	3.2	4.9	301.0	7.8
DSA+15	89.3	0.1	0.1	2.0	2.4	2.2	4.6	264.0	7.1
DSB+15	90.5	0.2	0.1	1.9	2.7	2.4	5.1	319.0	6.5
DAM+30	56.7	0.0	0.1	0.4	4.1	1.3	5.4	315.0	6.5
DBM+30	68.5	0.0	0.1	3.0	3.1	2.0	5.1	301.0	6.8
DAR-A	80.6	0.0	0.1	2.8	2.4	2.2	4.6	298.0	6.8
DAR-B	112.0	0.0	0.1	0.5	3.5	1.8	5.3	294.0	6.8
DNA+15	69.4	0.0	0.1	1.6	4.1	1.3	5.4	257.0	7.1
DNB+ 15	99.8	0.1	0.1	1.7	3.5	1.0	4.5	254.0	6.8
DAT+30	50.8	0.0	0.1	1.2	2.8	1.7	4.5	246.0	7.4
DBT + 30	107.0	0.0	0.1	0.4	3.5	1.4	4.9	241.0	7.8
DA+ 15	70.1	0.0	0.1	5.7	3.2	1.7	4.9	238.0	6.8
DB +15	80.9	0.0	0.1	4.2	3.8	1.4	5.2	249.0	7.1
DA+30	74.7	0.0	0.1	0.5	2.9	1.8	4.7	263.0	7.4
DB+30	49.6	0.2	0.2	0.7	3.4	2.1	5.5	277.0	7.1
MDL	6.9				0.7	0.3	1.0	1.4	0.1

Appendix E. Common names of resident and transient (*) species identified around Sea Station 3000 HOARP Phase II during report period of October 16 – November 15, 2000.

Ornamentals	**Invertebrates**	**Reef Herbivores**	**Pelagic Herbivores**	**Reef Carnivores**
Butterfly fish	**Mollusks**	**Filefishes**	**Filefishes**	Great Barracuda *Sphyraena barracuda* *
Milletseed *Chaetodon miliaris*	Oysters *Margaritifera spp.*	Shy *Cantherhines verecundus*	Scribbled/broomtail *Aluterus scriptus*	**Jacks**
Bluestripe *C. miliaris*	Mussels (unknown)	**Puffers**		Bluefin *Caranx melampygus* *
Bluehead *C. kleinii*	Barnacles *Lepas anserifera*	Porcupinefish *Diodon hystrix*		Yellowspotted *Carangoides orthogrammus* *
Pebbled *C. multicinctus*	**Crustaceans**	Stripebelly *Arothron hispidus*		Leatherback *Scombinoides* orthogrammus *
Anthias	Banded coral *Stenopus hispidus*	Spotted – *Arothron meleagris*		Amberjack *Seriola dumerilli*
Bicolor *Pseudanthias bicolor*	Blue crabs *Callinectes sapidus* *			Ono *Acanthocybium solandri**
Surgeon fish	Collector Crab *Simocarcinus simplex*			
Yellowfin *Acanthurus xanthopterus*	**Echinoderms**			
Blue spine *Acanthurus xanthopterus*	Cussion star *Culeita novaeguineae**			
Trumpetfish	Blue Spotted urchin *Astrppyga radiata* *			
Trumpetfish *Aulostomus chinensis*	Banded urchin *Echinothrix calamaris* *			
Cornetfish	**Nudibranchs**			
Cornetfish *Fistularia commersonii*	Seahares *Stylocheilus longicauda*			
Hawk fishes				
Longnose *Oxycirrhites typus*				
Hawaiian Bigeye – *Myripristis Berndti**				
Wrasses				
Hawaiian hogfish *Bodianus bilunulatus*				
Saddleback *Thalassoma duperrey*				
Blackside rasorfish *Xyrichtys umbrilatus*				
Frogfish				
Antemmarius commesonii				
Damsels				
Domino *Dascyllus albisella*				

Appendix E cont.

Bottom fish	**Pelagic carnivores**	**Mammals**	**Elasmobrancs**
Bonefishes	**Mackerels**	Spinner dolphins *Stenella longirostris**	**Rays**
Bonefishes *Albula sp.* * Squirrel fish *Priacanthus meeki*	Scad Mackerel *Decapterus macarellus*		Eagle Ray *Aetobatis narinari** Stingray *Dasyatis sp.* *
Snappers	**Needlefishes**		**Sharks**
Gray *Aprion virescens* * Bluestripe *Lutjanus kasmira* *	Crocodile needle *Tylosurus crocodiles* *		Sandbar *Carcharhinus plumbeus*
Eels	**Tunas**		
Garden *Gorgasia hawaiiensis* * Conger *Conger cinereus* *	False Albacore *Euthynnus alletteratus* * Yellowfin *Thunnus albacoares* *		

Appendix F.

Table 1. Abundance of fish observed at the DAR site, inshore (north) of the Sea Cage on 20 July 2000.

Station	F1	S1	S2	E1	E2	E3
Depth (m)	12.8	13.7	13.1	16.8	16.2	15.5
Visibility (m)	12.2	13.7	13.7	15.2	15.2	15.2
Species						
Carangidae						
Caranx melampygus				1		
Decapterus macarellus					200*	
Cirrhitidae						
Cirrhitops fasciatus			2			
Paracirrhites arcatus	9	7	6	1	4	4
Mullidae						
Mulloides flavolineatus		7				3
Parupeneus multifasciatus		1			2	4
Chaetodontidae						
Chaetodon fremblii						1
Chaetodon kleini						2
Pomacentridae						
Chromis vanderbilti		10	2	5	1	6
Dascyllus albisella				3	6	1
Plectroglyphididon imparipennis					1	
Plectroglyphididon johnstonianus	1	2	6			
Stegastes fasciolatus		5				
Labridae						
Coris gaimard						1
Halichoeres ornatissimus						1
Labroides phthirophagus					1	
Macropharyngodon geoffroy					5	
Novaculichthys taeniourus					2	
Oxycheilinus bimaculatus		2	1	7		2
Pseudocheilinus evanidus					4	2
Pseudocheilinus octotaenia		1				
Pseudojuloides cerasinus		3			16	21
Stethojulis balteata			1		2	2
Thalassoma duperrey	1	5	9	3		4
Scaridae						
Scarus sp. (juv.)					2	5
Acanthuridae						
Acanthurus nigrofuscus					1	
Acanthurus nigroris						1
Acanthurus olivaceus	1			2	3	1
Acanthurus triostegus			4			
Naso lituratus	2	1	1	1	3	2
Naso unicornis				1		
Balistidae						
Melichthys vidua		1				
Sufflamen bursa	4		3	3	3	3
Sufflamen fraenatus	1	2	1	3		4
Tetraodontidae						
Arothron hispidus				1		
Canthigaster coronata				1		
Canthigaster jactator	5	1	3	2	7	1
Diodontidae						
Diodon histrix						1
number of families	6	7	6	7	8	10
number of species	8	14	12	13	17	22
number of individuals	24	48	39	34	63	72
biomass (g m-2)	26.2	14.4	17.2	35.2	12.3	20.7

* transient school

Appendix F cont.

Table 2. Abundance of fish observed at the DAR site, inshore (north) of the Sea Cage on 17 November 2000.

	Station	F1	S1	S2	E1	E2	E3
	Depth (m)	12.5	13.7	13.1	16.2	15.8	15.5
	Visibility (m)	13.7	12.2	12.2	12.2	12.2	10.7
Family	Species						
Carangidae							
	Decapterus macarellus		4				
Cirrhitidae							
	Cirrhitops fasciatus			1			
	Paracirrhites arcatus	12	7	10	1	6	6
Mullidae							
	Parupeneus multifasciatus	1	1	1			3
Pomacentridae							
	Chromis vanderbilti	55	26	34			40
	Dascyllus albisella			3			2
	Plectroglyphididon johnstonianus	3	3	4			1
Labridae							
	Anampses chrysocephalus						9
	Anampses cuvier				3		
	Coris gaimard	1					
	Labroides phthirophagus	1					
	Macropharyngodon geoffroy						8
	Oxycheilinus bimaculatus	2		8	10	2	4
	Pseudocheilinus evanidus			1	5	6	11
	Pseudocheilinus octotaenia						4
	Pseudojuloides cerasinus		3	12	10	27	39
	Stethojulis balteata	1					10
	Thalassoma duperrey	8	2	7	3		5
Acanthuridae							
	Acanthurus olivaceus	3		3			
	Naso brevirostris	3					
	Naso hexacanthus	16	1				1
	Naso lituratus	4		2		1	
Blenniidae							
	Plagiotremus goslinei	1	1				
Balistidae							
	Melichthys vidua				1		
	Sufflamen bursa	4	2	3	4	4	3
	Sufflamen fraenatus	1		1	1	2	1
Monacanthidae							
	Pervagor spilosoma		2				
Tetraodontidae							
	Canthigaster coronata	1					1
	Canthigaster jactator	4	5		2	3	2
Diodontidae							
	Diodon histrix	1					
	number of families	9	10	6	4	5	7
	number of species	19	12	14	10	8	18
	number of individuals	122	57	90	40	51	150
	biomass (g m-2)	37.8	33.2	6.2	31.5	37.2	19.4

Appendix F cont.

Table 3. Abundance of fish observed at the DAR site, inshore (north) of the Sea Cage on 9 January 2001.

	Station	F1	S1	S2	E1	E2	E3
	Depth (m)	12.5	13.7	13.1	16.2	15.8	15.5
	Visibility (m)	12.2	13.7	13.7	13.7	12.2	12.2
Family	Species						
Muraenidae							
	Gymnomuraena nebulosa					1	
	Gymnothorax meleagris	1				1	
	Gymnothorax undulatus				1		
Scorpaenidae							
	Scorpaenopsis diabolis		1				
Cirrhitidae							
	Cirrhitops fasciatus	2	1	1			
	Paracirrhites arcatus	9	12	17	1	3	2
Pomacentridae							
	Chromis vanderbilti		30	45			
	Dascyllus albisella	4	25		1		
	Plectroglyphididon johnstonianus	2	8	5			
Labridae							
	Coris venusta					1	
	Novaculichthys taeniourus					1	
	Oxycheilinus bimaculatus	4	1	4	5	2	19
	Pseudocheilinus evanidus			1	5	4	5
	Pseudocheilinus octotaenia			1			
	Pseudojuloides cerasinus		6	16	9	16	30
	Stethojulis balteata		1			1	
	Thalassoma duperrey	2	5	11	2		
Scaridae							
	Scarus sp. (juv.)			4			
Acanthuridae							
	Naso hexacanthus		1				
Gobidae							
	Coryphopterus sp.				1		
Balistidae							
	Melichthys vidua		2		1		
	Sufflamen bursa	2	1	2	1	1	3
	Sufflamen fraenatus	1					1
Monocanthidae							
	Pervagor aspricaudus		1				
Ostraciidae							
	Ostracion meleagris		1				
Tetraodontidae							
	Canthigaster coronata			1			
	Canthigaster jactator	3	2	2	1		2
	number of families	6	9	6	7	4	4
	number of species	10	16	13	11	10	7
	number of individuals	30	98	110	28	31	62
	biomass ($g\ m^{-2}$)	6.8	12.5	5.6	8.4	6.9	10.3

Appendix F cont.

Table 4. Summary table of fish counts for three surveys at the DAR station, inshore (north) of the sea cage.

Station	F1	F1	F1
number of families	6	9	6
number of species	8	19	10
number of individuals	24	122	30
biomass (g m-2)	26.2	37.8	6.8

Station	S1	S1	S1
number of families	7	10	9
number of species	14	12	16
number of individuals	48	57	98
biomass (g m-2)	14.4	33.2	12.5

Station	S2	S2	S2
number of families	6	6	6
number of species	12	14	13
number of individuals	39	90	110
biomass (g m-2)	17.2	6.2	5.6

Station	E1	E1	E1
number of families	7	4	7
number of species	13	10	11
number of individuals	34	40	28
biomass (g m-2)	35.2	31.5	8.4

Station	E2	E2	E2
number of families	8	5	4
number of species	17	8	10
number of individuals	63	51	31
biomass (g m-2)	12.3	37.2	6.9

Station	E3	E3	E3
number of families	10	7	4
number of species	22	18	7
number of individuals	72	150	62
biomass (g m-2)	20.7	19.4	10.3

Station			Sea Cage
number of families			6
number of species			6
number of individuals			334
biomass (g m-2)			20.4

Appendix G. General and Financial Assumptions

Fingerling Type & Cost

	Unit	Unit Price
Fingerlings	$/piece	$ 0.29
Growout Fish	$/lb	$ 4.00

Feed Type & Cost	**Unit**	**Unit Price**
Moore Clark	$/lb	$0.50

Fuel Type & Cost	**Type**	**Unit**	**Rate**
Electricity	1	$/kwh	$ 0.17
Diesel Fuel	2	$/gal	$ 0.96
Gasoline	3	$/gal	$ 1.90

Lease Information	**Unit**	**Value**
Production Area	sq. m	450,000
Lease Rent	% Gross	2%
Annual Lease Rent	$/year	73,142

Financial Information	**Unit**	**Value**
Excise Tax	%	0.5%
Contingency	%	5.0%
Discount Rate	%	10.0%
Maintenance	%	6.5%
% Borrowed	%	0.0%
Interest Rate	%	10.0%
Miscellaneous Expenses	%	5.0%
Life of Loan	yrs	

Appendix H. Payroll

Assumptions		**Salary**	**Hourly**
Shift Length	Hrs/Day	8.00	8.00
Days/Week	days	5.00	5.00
Weeks/Yr	weeks	52.00	52.00
Benefits	%	25%	25%
Operations	Months/Year	12.00	-

Salaried Employees	**Qty**	**Rate ($/Mon)**	**% Full Time**	**Total ($)**	**% of Total**
Captain (also divers)	2	$ 3,500	100%	84,000	13.2%
Divers	0	$ 3,120	100%	-	0.0%
Truck Driver	1	$ 2,200	100%	26,400	4.2%
Harvest Person	2	$ 1,800	100%	43,200	6.8%
Accountant	1	$ 2,600	100%	31,200	4.9%
Manager	1	$ 4,000	100%	48,000	7.6%
				232,800	36.7%
Benefits				$ 58,200	9.2%
Total Salaried Payroll				$ 291,000	45.8%

Hourly Employees	**Qty**	**Rate ($/Hr)**	**Hrs/Wk**	**Total ($)**	**% of Total**
Divers	7.35	$ 18.00	40.00	275,151	43%
Sub-Total				275,151	43%
Benefits				$ 68,788	11%
Total Wages				$ 343,938	54%
Total Payroll				$ 634,938	100%

Appendix I. Energy

Energy Type			**Rate**		**Electricity Conversion (K)**	
Electricity	1	$	0.17	/kwh	0.7475	kw/HP-hr
Diesel Fuel	2	$	0.96	/gal	0.0449	gal/HP-hr
Gasoline	3	$	1.85	/gal	0.0608	gal/HP-hr

Equipment	**Qty**	**Fuel Type**	**Power (HP)**	**Ann Hrs/Ea**	**Energy ($)**	**% of Total**	**Avg Hrs/ Day/Ea**	**Ttl Hrs/Day**
Air Blower	1	2	40.0	4,380	$7,554	6.2%	12.00	12.00
Boat (47') - Stocking/Harvest	1	2	400.0	162	$2,794	2.3%	0.44	0.44
Boat (32') - Maintenance	1	2	300.0	548	$7,081	5.8%	1.50	1.50
Fish Pump (Feed System)	2	2	5.5	2,190	$1,039	0.9%	6.00	12.00
Ice Machine	1	1	80.0	8,760	$89,054	73.5%	24.00	24.00
Pressure Spray (net cleaning)	1	2	11.0	288	$137	0.1%	0.79	0.79
Truck	2	2	200.0	780	$13,451	11.1%	2.14	4.27
Total					$ 121,109	100.0%		

Appendix J. Other Operating Costs

Cost Description	Units	Cost ($/Unit)	Total ($)	% of Total
Operating Supplies				
Shipping	914,271	0.455	415,993	67.0%
Oxygen Cylinder, Rent	24	0.75	18	0.0%
Oxygen Fill	24	90	2,160	0.3%
Warehouse Rent (sq.ft)	1	12,000	12,000	1.9%
Oxygen Manifold	2	70	140	0.0%
Zinc Metal	48	10	480	0.1%
SubTotal			430,791	69.4%
Monitoring				
Water Analysis Test Kit	6	40	240	0.0%
Bottles for Water Analysis	15	64	960	0.2%
Ammonium & TSS Tests	576	30	17,280	2.8%
Lab Water Analysis Test Suite	256	175	44,800	7.2%
Sediment Analyses	84	175	14,700	2.4%
SubTotal			77,980	12.6%
Utilities				
Electricity, Other	1	1,200	1,200	0.2%
SubTotal			1,200	0.2%
Other (rounded to '00)				
Maintenance	1	61,200	61,200	9.9%
Supplies, Misc	1	2,000	2,000	0.3%
Legal & Audit	1	1,000	1,000	0.2%
Insurance	1	7,000	7,000	1.1%
Advertising	1	5,000	5,000	0.8%
Permit Renewal	1	5,000	5,000	0.8%
Miscellaneous	1	29,600	29,600	4.8%
SubTotal			110,800	18%
Total			$ 620,771	100%

Appendix K. Capital Outlay and Annualized Depreciation

Capital Costs - Depreciation	**Useful Life (yrs)**	**Unit Cost ($)**	**Qty**	**Cost ($)**	**% of Outlay**	**Ann. Cost ($)**	**% of Ann. Cost**
Construction & Permits							
Permits (EIS/EA)	20	250,000	1	250,000	13.76%	12500	8.99%
Warehouse & Office (2000 sq. ft)	20	200,000	1	200,000	11.01%	10000	7.20%
Electrical Installation	20	15,000	1	15,000	0.83%	750	0.54%
Energy Systems							
Air Blower	20	10,000	1	10,000	0.55%	500	0.36%
Boat (47') - Stocking/Harvest	20	150,000	1	150,000	8.26%	7500	5.40%
Boat (32') - Maintenance	20	50,000	1	50,000	2.75%	2500	1.80%
Fish Pump (Feed System)	20	20,000	2	40,000	2.20%	2000	1.44%
Ice Machine	10	50,000	1	50,000	2.75%	5000	3.60%
Pressure Spray (net cleaning)	5	10,000	1	10,000	0.55%	2000	1.44%
Truck	20	50,000	2	100,000	5.51%	5000	3.60%
Other Offshore Equipment							
Harvest/Stocking/Hauling Bin	20	1,500	15	22,500	1.24%	1125	0.81%
Harvest Eq (Gel Pack System & Stainless Steel Table)	10	2,000	1	2,000	0.11%	200	0.14%
Nursery Net	10	5,000	6	30,000	1.65%	3000	2.16%
Regular Fish Net (Seine Net)	5	15,000	6	90,000	4.95%	18000	12.95%
PVC Bin Flow-Through & Pump System	10	100	15	1,500	0.08%	150	0.11%
YSI 85 Water Analysis + 100' cord	5	1,700	2	3,400	0.19%	680	0.49%
YSI Photometer	5	1,850	2	3,700	0.20%	740	0.53%
Nets	2	3,000	1	3,000	0.17%	1500	1.08%
Scuba Gear	5	2,000	6	12,000	0.66%	2400	1.73%
Support Vessel (100 ton barge)	20	240,000	1	240,000	13.21%	12000	8.63%
Feed Camera System	10	1,615	1	1,615	0.09%	161.5	0.12%
Feed Camera Attachments, additional	10	950	5	4,750	0.26%	475	0.34%
Submersible Cages	10	70,000	6	420,000	23.12%	42000	30.22%
Mooring System (incl. 4 anchors)	15	15,000	6	90,000	4.95%	6000	4.32%
Other Equipment							
Office Equipment	5	6,000	1	6,000	0.33%	1200	0.86%
Laboratory Equipment	5	5,000	1	5,000	0.28%	1000	0.72%
Tools	10	5,000	1	5,000	0.28%	500	0.36%
Communication Devices	10	1,000	1	1,000	0.06%	100	0.07%
Total Equipment				$ 1,816,465	100.00%	$ 38,982	100.00%

Appendix L. Income Statement (first 5 years)

INCOME STATEMENT	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Production					
Production Months	50%	100%	100%	100%	100%
Production Amt (lbs)	457,136	914,271	914,271	914,271	914,271
Sale of Assets					
Revenue	**1,828,543**	**3,657,085**	**3,657,085**	**3,657,085**	**3,657,085**
Operating Costs ($)					
Energy	802,490	1,092,453	1,092,453	1,092,453	1,092,453
Source-Water Pump	469,800	469,800	469,800	469,800	469,800
Feed	634,938	634,938	634,938	634,938	634,938
Stocking	291,000	291,000	291,000	291,000	291,000
Labor	36,571	73,142	73,142	73,142	73,142
Salaries	65,598	65,598	65,598	65,598	65,598
Lease Rent	207,997	415,993	415,993	415,993	415,993
Supplies and Other	77,980	77,980	77,980	77,980	77,980
Monitoring	61,200	61,200	61,200	61,200	61,200
Excise Tax	9,143	18,285	18,285	18,285	18,285
Contingency	136,569	166,075	166,075	166,075	166,075
Interest	-	-	-	-	-
Depreciation	138,982	138,982	138,982	138,982	138,982
Total Operating Costs	**3,006,934**	**3,626,556**	**3,626,556**	**3,626,556**	**3,626,556**
Taxable Income	**(1,178,391)**	**30,529**	**30,529**	**30,529**	**30,529**
Federal Tax		4,579	4,579	4,579	4,579
State Tax		1,399	1,399	1,399	1,399
Income After Taxes	**(1,178,391)**	**24,551**	**24,551**	**24,551**	**24,551**
Cost Per lb Before Tax	6.58	3.97	3.97	3.97	3.97
Cost per lb After Tax	6.58	3.97	3.97	3.97	3.97
Effective Tax Rate	0.0%	19.6%	19.6%	19.6%	19.6%

Appendix M. Statement of Cash Flows

CASH FLOW	**0**	**1**	**2**	**3**	**4**	**5**
Cash Inflow						
Sales Revenue		1,828,543	3,657,085	3,657,085	3,657,085	3,657,085
Borrowing	-					
Inflow Total	**-**	**1,828,543**	**3,657,085**	**3,657,085**	**3,657,085**	**3,657,085**
Cash Outflow						
Cash Operating Costs[1]		2,867,953	3,487,575	3,487,575	3,487,575	3,487,575
Loan Payment		-	-	-	-	-
Income Tax		-	5,978	5,978	5,978	5,978
Capital Expenditure	1,816,465	-	-	3,000	-	3,000
Outflow Total	**1,816,465**	**2,867,953**	**3,493,553**	**3,496,553**	**3,493,553**	**3,496,553**
Net Cash Flow	(1,816,465)	(1,039,410)	163,533	160,533	163,533	160,533
Discount Cash Flow	(1,816,465)	(944,918)	135,151	120,611	111,695	99,678
Cumulative Discount Cash Flow	(1,816,465)	(2,761,383)	(2,626,232)	(2,505,621)	(2,393,926)	(2,294,248)

Appendix N. Profitability Analysis

		20 Year Cash Flow Analysis	
	Cost ($/lb)*	**IRR (%)**	**NPV** ($)**
Before Tax	$ 3.97	-	**$ (1,855,937)**
After Tax	**$ 3.97**	**-**	**$ (1,867,281)**

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[1] Total Operating Costs (less depreciation and interest expenses).