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Economics of offshore aquaculture of Pacific threadfin (*Polydactylus sexfilis*) in Hawaii

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Abstract

A feasibility study for an offshore Pacific threadfin (*Polydactylus sexfilis*) cage production system was conducted for Hawaii. The hypothetical six-cage system was based on the bio-technological requirements of and productivity demonstrated by the Hawaii Offshore Aquaculture Research Project (HOARP). At a farm-gate price of US$4.00/lb, several areas of efficiency improvements are required in order to reach profitability based upon current model inputs for the six-cage system in Hawaii. The total cost of production is estimated at US$3.97/lb for the production system projected to yield 914,271 lb of Pacific threadfin annually. The largest costs contributing to annual operating expenses of US$3,626,556 were feed (30%), labor (17%), stocking (12%) and shipping (11%). Based on sensitivity analyses, increased stocking densities, survival rates and average growth rates have the largest potential for reducing production costs. HOARP is among the first reported successful deployments of a fully submerged cage system in the United States. This study details the technological requirements, associated costs and reports recommendations for farm management in light of the financial strains of full-scale commercial deployment.

Keywords: Economics; Offshore cage culture; Pacific threadfin; Hawaii

1. Introduction

The open ocean environment is a favorable venue for Hawaii aquaculture. Offshore cage culture can provide new economic opportunities, particularly for regions such as

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Hawaii with land constraints, steep ocean floor gradients and stable temperatures. Cage culture systems also provide natural habitats that take advantage of natural ocean currents for water exchange as well as regional climates and deep ocean topologies.

The rising regional and global demands for fish and fishery products may fall short of wild fishery capture harvests. Such demands may be met by offshore aquaculture while alleviating pressure on harvesting of wild stock. The local market in Hawaii also exhibits favorable signs for increased aquaculture productivity. Hawaii consumers demonstrate an increasing demand for seafood with consumption rates that are twice the national average (Hawaii Department of Agriculture, 2000a). Marketing initiatives may also help to establish an export market for Hawaii offshore aquaculture products.

This study evaluates the viability of a commercial offshore aquaculture production system for Pacific threadfin. Pacific threadfin (*Polydactylus sexfilis*), commonly known as *moi* in Polynesia, is a potentially lucrative product for Hawaii aquaculture. The Pacific threadfin's delicate flavor is attractive for food and is cause for popularity among sport fisherman. Its increasing popularity resulted in overfishing which depressed the once thriving local market (Ostrowski and Molnar, 1998). The Pacific threadfin continues to receive nationwide exposure in recent media (Ishikawa, 2002). Despite the Pacific threadfin's encouraging public image, market forces may not favor commercial cage production of the specie.

In 1999, the Hawaii Agricultural Statistics Service reported an exchange of 119,568 lb of Pacific threadfin and an associated farm-gate sales revenue of US$459,150 (Hawaii Department of Agriculture, 2000b). The 1999 figures correspond to a 288% increase in production and 215% increase in sales revenue from 1998. The average farm-gate price has decreased from US$5.16/lb to US$3.84/lb. Market forces may therefore exert downward pressure on sale prices in response to larger supply. The risk of declining sale prices and currently undeveloped export market for Pacific threadfin compels commercial offshore practitioners to pursue economic efficiencies in order to remain competitive.

Few studies have investigated the economics of offshore cage culture. A recent study on cage culture in Puerto Rico concluded that offshore aquaculture may be profitable based on present worth (Brown et al., 2002). A single cage, however, was noted to be capable of surpassing Puerto Rico's entire current catch for the species studied. The livelihood of local fishing industries may be compromised by depressed market value of species caused by mass-production offshore. Consequently, the export market must be nurtured, and parameters that favor regional production (e.g., low labor as is the case for Puerto Rico) should be investigated. Lisac and Muir (unpublished) built upon previous studies that report theoretical comparisons based on preliminary techniques by providing field data for open, sheltered and land systems. Lisac and Muir concluded that offshore systems may be more profitable than land-based systems, and it is only recently that offshore systems are becoming competitive with land-based and near-shore systems. In addition to providing experimental data for measuring the feasibility of offshore cage systems for finfish, this study addresses the concerns of environmental expenses not considered in the theoretical comparison of land-based and offshore cage culture techniques.

Two 1995 studies available from the Centre International de Hautes Etudes Agronomiques Méditerranéennes (CIHEAM) are relevant to offshore cage culture, but provide limited accounts for production economics. Bourgeois and Aquilina (1995) reported production levels of 1,322,751 lb/year of sea bass and sea bream in St. Paul Bay and Meliheha Bay in Malta. Although they did not provide a feasibility analysis, they reported that feed was the largest expenditure, comprising 20% of production costs. Stephanis (1995) also investigated the production costs for sea bass and sea bream cages systems in Greece. Economies of scale were reported for production systems ranging from 130,070 to 440,917 lb/year. Stephanis also indicated that operating costs were lower for larger more vertically integrated production systems (economies of scope), those companies able to produce their own fry. However, the extent to which seedstock price affects profitability was not investigated.

Detailed economic analyses of offshore production are rather limited in published literature. The economic analysis in this study first seeks to develop a detailed cost structure in order to identify the most significant costs. Secondly, a series of sensitivity analyses performed on the baseline cost structure (such as sensitivity to seedstock price) highlight those strategies that may be most effective for improving commercial viability.

2. Methodology—cost structure

In Phase I of the Hawaii Offshore Aquaculture Research Project (HOARP), the Oceanic Institute (OI) and the University of Hawaii Sea Grant College Program, in partnership with state governmental agencies, commercial farmers and seafood processors developed a prototype cage system for Pacific threadfin. Phase I combined newly developed sea cage designs from Ocean Spar Technologies of Washington with the Oceanic Institute's Pacific threadfin mass culture and fish management methodologies. Phase II sought to improve the technology by increasing final harvest density, improving feed utilization, reducing harvest size variability and engaging in regular monitoring activities.

A detailed cost structure required numerous inputs from persons knowledgeable of the production technology and external environment. Based on the production technologies and biological parameters observed during Phase II of the Hawaii Offshore Aquaculture Research Project and synthesizing the parameters with ecological, financial and market parameters, an economic model was established that is capable of measuring many of the critical parameters relevant to offshore cage production in Hawaii.

The economic model incorporates 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,[1] scaled from the existing HOARP single-cage production system. The six-cage production system is estimated to embody a 5000-m^2 surface area and encumber a bottom area (including

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[1] The choice of a six-cage system is based on an earlier preliminary costing, which indicated that it is a desirable configuration to capture scale economies as well as a reasonable modular type-unit for effective operations and expansion. A six-cage configuration is also within the range evaluated by Lisac and Muir (unpublished).

anchoring) of approximately 450,000 m^2. The cage used in the model is the SeaStation 3000™, a 2600-m^3 biconical sea cage. Submerged 40 ft from the surface, the cage is out of the higher energy zone to minimize potential harm to the cage or fish. Anchored in 100-ft deep waters, the cage does not obstruct boat or ship traffic. The cage is made of a steel core, with cement ballasts at the bottom, and a framework of steel pipes connected by a strong synthetic mesh that divers can enter. The net material, Spectra, has the strength of steel and was developed by NASA. The lightweight material is manufactured by Net Systems of Bainbridge, Washington. Uneaten food and fecal matter flow out of the cage and strong ocean currents dissipate waste matter. Natural flow for such exchange is a significant advantage of an open ocean system in comparison to near-shore net pens. Fish congregating near the cage are also able to consume any extra feed that falls through the net.

2.1. General and financial

General and financial parameters that reflect costs relevant to a site located in Hawaii are listed in Appendix A. Parameters include general and financial assumptions for market sale price, seedstock price, feed price, fuel costs, lease information and financial information.

2.2. Production

The production parameters used were based on Oceanic Institute practices and performance data reported by the HOARP Phase II. The production parameters assumed are exhibited in Table 1. 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 the 6-month period.

2.3. Labor

A total of 15 employees are required to support the six-cage production system: 7 salaried personnel and an equivalent of 7 full-time divers and 1 part-time diver. Two captains are included as salaried employees for a total of 10 employees with diving certification. The number of divers required is based upon ship carrying capacities and labor estimates for stocking, harvesting and maintenance operations. Appendix B summarizes employee assumptions and the salaries of personnel.

Table 1
Production parameters

Month of cage operation	0	1	2	3	4	5	6
Days post-hatch	50	80	110	140	170	200	230
Average 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

Growing concerns for the degradation effects of feeds and animal wastes is faced by animal agriculture production systems worldwide (Ostrowski et al., 2001). The costs associated with monitoring analyses and sampling, however, are less than 3% of the total operating costs. The monitoring intensity for the offshore production is based on provisional monitoring requirements of the single HOARP cage and was modified for the six-cage system.

The number of divers is based on daily activities, periodic maintenance, harvesting and stocking required for the annual production of 914,271 lb of Pacific threadfin. Daily activities (8 h/day) include feedings, cage maintenance, environmental survey and travel time. The Pacific threadfin are fed commercial fish pellets that provide a rich diet for optimal growth. They are fed twice daily through a pipe into the cage, operated from a boat at the surface. Two divers scrub the cage daily to ensure that water continues to flow through the mesh. The average periodic maintenance amounts to 180 h/month.

Stocking occurs once per month with 135,000-d50 fry (2.1 g) for a total annual seedstock of 1,620,000 fry. A single cage harvest of 76,189 lb of fish spans a period of approximately 8 days. This harvesting duration is based upon a total bin capacity of 10,500 lb (15 700-lb capacity bins) and four divers harvesting daily (4 h of diving time).

2.4. Initial outlay

The initial capital outlay amounts to US$1,816,465. The major start-up costs include: six submersible cages, US$420,000 (23% of the initial outlay); Environmental Assessment/Environmental Impact Statement (EA/EIS) fees, US$250,000 (11%); 100-ton support vessel for feed, US$240,000 (13%); and 47-ft 400 HP boat for stocking and harvesting, US$150,000 (8.3%). When costs are annualized (US$138,982 annually) with respect to the useful life of each asset, the largest depreciation expenses include US$42,000 (30%) for the six submersible cages, netting US$18,000 (13%), EA/EIS US$12,500 (9.0%) and support vessel US$12,000 (8.6%). A table summarizing the capital outlay and annualized depreciation is located in Appendix A.

2.5. Energy, supply and other

Recurring costs for energy (US$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 US$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, assuming that the six-cage system exhibits some scale economies. The remaining supply costs, maintenance and other costs amount to US$542,791 per year. Detailed energy, monitoring, supply and other costs are indicated in Appendices C and D. 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 US$5000 per year reflect federal, state and county permits that may include but not be limited to: U.S. 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.

3. Results and analysis

A series of sensitivity analyses that study variations in critical parameters such as sale price, growth, feed cost, financial leverage and stocking density may suggest to commercial enterprises avenues in which to respond to the complex and difficult-to-forecast local and export market for Pacific threadfin. There is considerable need to address areas for improvement in light of possible decline in market prices resulting from larger supply volumes. With respect to the conservative base model used in this study, the six-cage commercial venture is not profitable. Therefore, a commercial enterprise must seek production efficiencies in order to be successful. Sensitivity analyses were performed for feed price, feed cost, FCR, growth rate, seedstock price, sale price, stocking density, survival rates and financial leverage.

The analyses indicate that improvements in survival rates, average growth rates and feed efficiency may be effective in lowering unit production cost. When considering the relevant (i.e., achievable) ranges for production parameters, however, cage production enterprises may seek increased profitability through higher stocking densities or improvements in survival rates. Sensitivity to seedstock price and growth rates within appropriate ranges effect only moderate improvements to profitability in comparison to changes in stocking densities and feed efficiencies. In addition to the consideration of relevant changes in parameters, implementing changes in production practices should also consider the ease of adjusting the parameters, additional risks associated with the changes and the effect of production outcomes with respect to the market demand for Pacific threadfin.

For a six-cage production system with a yield of 914,271 lb of Pacific threadfin, the cost of production is US\$3.97/lb. The largest costs contributing to annual operating expenses of US\$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. The annual profit and loss (Table 2) exhibits a breakdown of the cage production system cost, which is assumed to be stable in year 2. Measures of productivity in terms of density, feed conversion ratio (FCR) and survival were estimated (Table 3). 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, mortalities and FCR. The income statement and cash flow summaries for the first 5 years of business are located in Appendices F and G.

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

Table 2
Annual profit and loss (year 2)

Annual income		US$/lb	% operating costs
Production			
Production months	100%		
Production amount (lb)	914,271		
Stocking (pieces)	1,620,000		
Revenue	3,657,085		
Operating costs (US$)			
Energy	121,109	0.13	3
Feed	1,092,453	1.19	30
Stocking	469,800	0.51	13
Labor	634,938	0.69	17
Salaries	291,000	0.32	8
Ocean lease rent	73,142	0.08	2
Supplies and other	65,598	0.07	2
Shipping	415,993	0.46	11
Monitoring	77,980	0.09	2
Maintenance	61,200	0.07	2
Excise tax	18,285	0.02	1
Contingency	164,455	0.18	5
Depreciation	138,982	0.15	4
Total operating costs	3,626,556	3.97	100
Taxable income	30,529	0.03	1
Federal tax	4579	0.01	0
State tax	1339	0.00	0
Income after taxes	24,551	0.03	1
Effective tax rate	22.27%		

threadfin in the local market. The estimated demand (market price) for Pacific threadfin indicates that increased 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 in improving production efficiencies.

Practitioners of offshore aquaculture provided insight into the potential changes in production parameters and suggested meaningful parameter ranges that offshore aqua-

Table 3
Productivity summary

Average harvest density	13.32	(kg/m^3)	
Stocking density	109.04	(g/m^3)	
	Daily average	Monthly average	Cumulative
Growth rate (g/period)	2.29	68.82	412.90
FCR		2.37	2.39
Survival (%)		92	62

farmers may realize. Sensitivity analyses on sale price, feed cost, growth rates, seed price, density, survival and financial leverage were explored based on feasible ranges advised by practitioners (Table 4).

Each of the following analyses focuses on production cost sensitivity to changes along one of nine parameters including: average growth rate, stocking density, FCR, feed price, sale price, seedstock price, survival, leverage and loan interest rate (Table 4). With respect to the range of relevant changes in production practices, collectively the analyses address which parameter changes may yield greater production efficiencies than others. All production costs in the sensitivity analyses exclude federal and state income tax unless otherwise noted. The IRR reported in the sensitivity analyses reflect the expected 20-year internal rate of return after tax.

3.1. Sensitivity to sale price

The effect of changes in the assumed sale price for Pacific threadfin on cost per pound and IRR was calculated (Fig. 1). The base model yields a US$3.97/lb production cost. Consequently, sale prices of Pacific threadfin at less than US$4.00/lb will render the commercial enterprise unprofitable. At a sale price of US$5.00 (approximately the 1998 farm-gate price), the enterprise could expect a 20-year IRR of 23%. The current estimated market value for Pacific threadfin is US$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.

3.2. Sensitivity to feed price

A sensitivity analysis to changes in feed costs indicates the anticipated linear relationship between feed price and the cost of production (Fig. 2). The analysis assumes comparable production results for substitute feed products. For a 1¢/lb increase (decrease) in feed cost, the production cost per pound of Pacific threadfin increases (decreases) 2.5¢/lb. Therefore, a percent change in the baseline feed price results in a 0.32% change in production cost with respect to the baseline production cost of US$3.97. The sensitivity of

Table 4
Parameter ranges

Parameter	Minimum	Baseline	Maximum
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3
FCR	1.00	2.39	2.50
Feed price	US$0.25/lb	US$0.50/lb	US$0.75/lb
Sale price	US$2.00/lb	US$4.00/lb	US$5.00/lb
Seedstock price	US$0.20 ea	US$0.29 ea	US$0.35 ea
Survival	50%	61.81%	100%
Leverage (% borrowed)	0%	0%	100%
Loan rate (30 years)	6%	–	12%

Fig. 1. Sale price sensitivity.

production cost to feed price was calculated for the range of 50%–150% of the baseline feed price of US$0.50/lb.

For a 914,271-lb production system, a feed price decrease of 5¢/lb corresponds to US$114,707 annual cost savings in production cost. Resultant changes in IRR, assuming a constant sale price of US$4.00, indicate that the 20-year rate of return may increase by as much as 6.96% for a 5¢/lb decrease in feed price. A feed price sensitivity analysis conducted (Fig. 2) illustrates the effect of changes in feed price on production cost and IRR within the range described earlier.

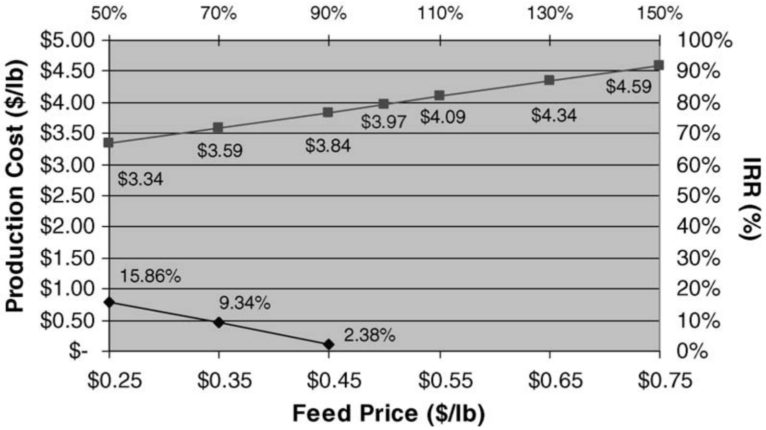

Fig. 2. Feed price sensitivity.

3.3. Sensitivity to FCR

A similar analysis was performed for changes in cumulative FCR (Fig. 3). The FCR range applied to the sensitivity analysis was recommended at 1.0–2.5. With respect to the baseline FCR of 2.39, this corresponds to a range of − 58.2% to + 4.6% change from the baseline. Analyses revealed that a percent change in FCR within this range corresponds to a + 0.32% change in the production cost from the US$3.97/lb baseline value. Therefore, a 16% improvement in the cumulative FCR to 2.0 suggests a 5.0% decrease in production cost to US$3.75/lb. While this sensitivity to FCR suggests that improved efficiencies may significantly reduce unit production costs, the range for improvement does not yield substantial benefits. Commercial cage production systems able to achieve a cumulative FCR of 1.0 (− 58.2% change from the baseline) can expect an IRR of 18.52%. A 20% IRR would require a cumulative FCR of 0.89, which may be unlikely for production systems to achieve.

3.4. Sensitivity to total feed cost

The sensitivity of production cost to total feed expenditure can be estimated and will be analogous to the results exhibited by the feed price sensitivity analysis (Fig. 2). 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. The cumulative FCR (2.39), for example, may be reduced by 37% to 1.50 and effect a reduced production cost equal to US$3.49/lb from 3.97/lb. This change in efficiency is also equivalent to reducing the feed price by 38%, i.e., from US$0.50/lb to US$0.31/lb.

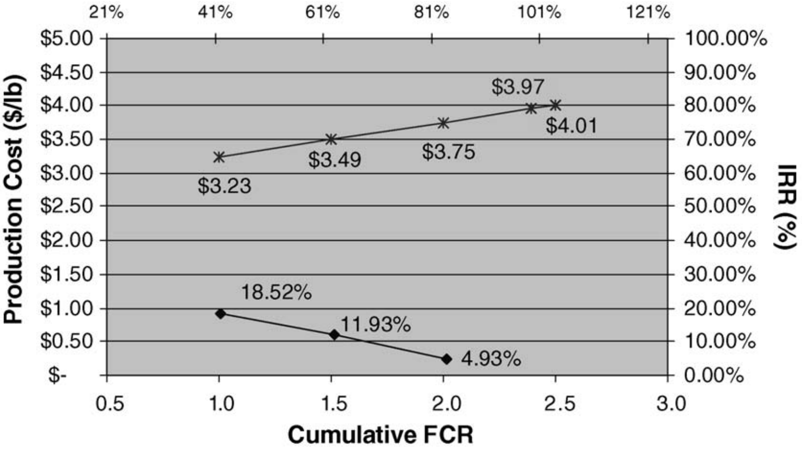

Fig. 3. FCR cost sensitivity.

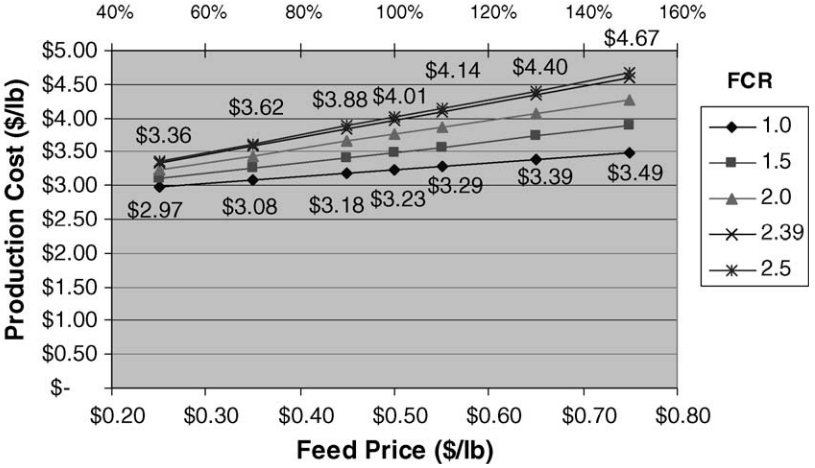

Fig. 4. Feed price–FCR interaction (w.r.t. FCR level).

3.5. Sensitivity to FCR and feed price interaction

Feed price–FCR sensitivity analyses (Figs. 4 and 5) exhibit the combined effect of changes in both FCR and feed price along FCR or feed price levels, respectively. Feed Price–FCR sensitivity analysis with respect to FCR level (Fig. 4), for example, indicate the cost sensitivity to changes in feed price for different levels of FCR (e.g., efficiency constraints): 1.0, 1.5, 2.0, 2.39 (baseline) and 2.5. The price sensitivity range is from US$0.25/lb to US$0.75/lb of feed. Feed price–FCR with respect to price level (Fig. 5)

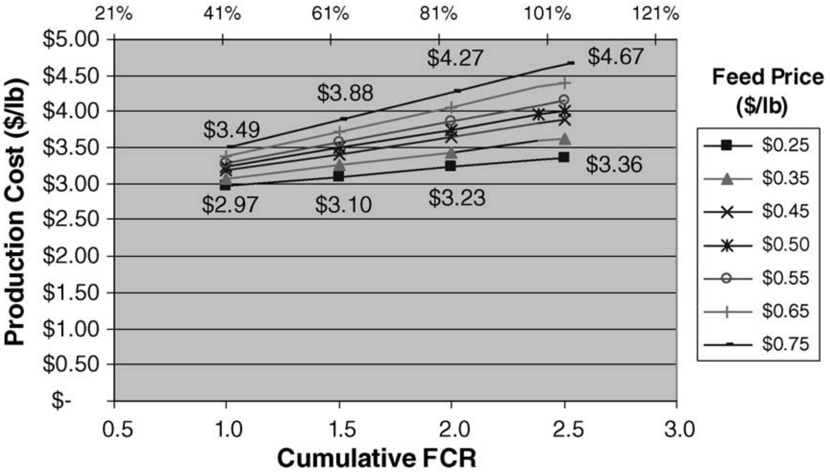

Fig. 5. Feed price–FCR interaction (w.r.t. price level).

exhibits the production cost sensitivity reported in the FCR level analysis (Fig. 4) in terms of changes to cumulative FCRs ranging from 1.0 to 2.5 for different levels of feed price (e.g., supply constraint): US$0.25/lb, US$0.35/lb, US$0.45/lb, US$0.50/lb (baseline), US$0.55/lb, US$0.60/lb, US$0.65/lb and US$0.75/lb.

These analyses reflect the interaction effect of changes in FCR and feed price on production cost with respect to FCR levels. For changes in feed price of ± US$0.10/lb, the effective change in production cost is ± US$0.25/lb. Sensitivity analyses for production cost along FCR and feed price levels provide practical information for production systems constrained by either FCR or feed price. As illustrated by the cost-to-feed price slopes (Fig. 5), at higher feed prices, FCR efficiencies are critical. Analogously, cost-to-FCR slopes (Fig. 4) illustrate how feed prices are critical particularly when systems are constrained by high FCRs (inefficiency). As with the previous feed cost sensitivity analyses, 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.

3.6. Sensitivity to growth rates

The effect of growth rates on production cost was also studied. Higher growth rates may be achieved through selective breeding. Changes in average daily growth rates were approximated by applying percentage changes to monthly growth data obtained from HOARP Phase II production results. The overall effect of higher average daily growth rates on production cost was also calculated (Fig. 6). An analysis was conducted within the average daily growth rate of 1.50–3.50. With respect to the 2.29 g/day baseline, the sensitivity range explored is 65%–153% of the baseline.

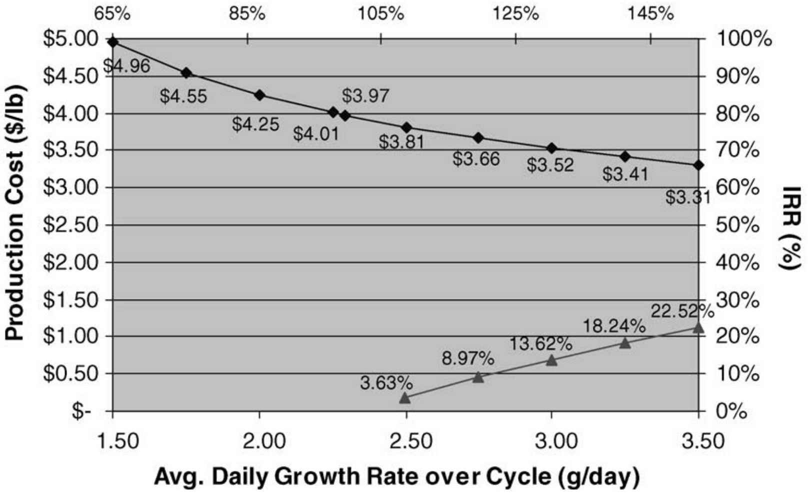

Fig. 6. Growth rate sensitivity.

An 11% increase in the average daily growth rate from 2.00 to 2.5 g/day lowers production cost by 6% (US$0.24/lb). Cost sensitivity to changes in growth rates, however, is nonlinear because costs increase more slowly at higher growth rates. At higher growth rates, fixed and stepwise variable costs decrease per-pound production costs because operating costs are spread out over larger production yields. Consequently, for an 11% increase in the average daily growth rate from 3.00 to 3.25 g/day, a cost savings of only 1.7% (US$0.11/lb) is expected. As illustrated in the growth rate sensitivity analysis (Fig. 6), further improvements to growth rates yield subsequently smaller improvements to production costs while still improving profitability (IRR), assuming a constant sale price of US$4.00/lb. Costs associated with selective breeding are not included in this model and should be considered when exploring production efficiencies and the overall impact of attempts to achieve improved growth rates on production and profitability.

3.7. Sensitivity to seedstock price

The cost for d50 fry was estimated based on the addition of a hypothetical late nursery (Nursery II) facility to the Pacific threadfin hatchery model (Kam et al., 2002) developed previously. In comparison to the 20.70¢ before-tax cost for d40 1.0-g fry, the cost per d50 2.1-g fry was estimated at 24.95¢. A 25¢ sale price was applied to the d40 hatchery model and demonstrated a 44% 20-year IRR. Accordingly, for a hatchery system encompassing a late nursery facility, a farm-gate fingerling price of 29¢ will yield a comparable 20-year IRR of 44%. This sale price of 29¢ was used to estimate the fingerling price for the cage enterprise base model. The model assumes that transfer and shipping costs are incurred by the cage enterprise. A seedstock price sensitivity analysis (Fig. 7) illustrates the effect of changes in seedstock price on production cost.

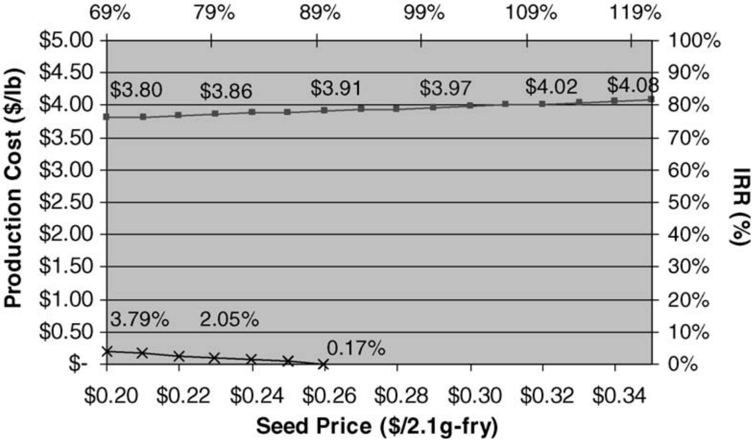

Fig. 7. Seedstock price sensitivity.

For a 1% change in fingerling price, the production cost per pound changes by 0.14% (0.35¢/lb).

As indicated earlier, stocking costs represent 13% of total production cost. For changes in fry price ranging from 20¢/fry to 35¢/fry, production cost does not fluctuate appreciably. Based on the range explored here and in the previous feed cost analyses, changes in fry price have a small effect in comparison to changes in feed costs. For a 1¢/fry increase in fingerling price, the production cost per pound increases by only 2¢ (Fig. 7).

3.8. Sensitivity to changes in stocking density

An analysis of cost sensitivity to changes in stocking density assumed that the variation in net income is caused by feed costs, costs associated with harvesting and revenue from increased production. Consequently, no significant changes were presumed for costs associated with energy (unrelated to harvesting), capital for the six-cage model and other fixed costs.

Sensitivity analysis for changes in stocking density (Fig. 8) 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 assumptions used in the six-cage 914,271-lb production scale (base model). The figure reflects size economies resulting from increased densities, where the unit costs decrease as fixed costs are spread out over increased production levels (resulting from higher densities).

Production costs (before tax) may be brought down to US$2.81/lb if harvested at a density of 59.20 kg/m^3. This, however, assumes that all parameters aside from costs associated with feed and seedstock remain constant. Changes in stocking and harvesting

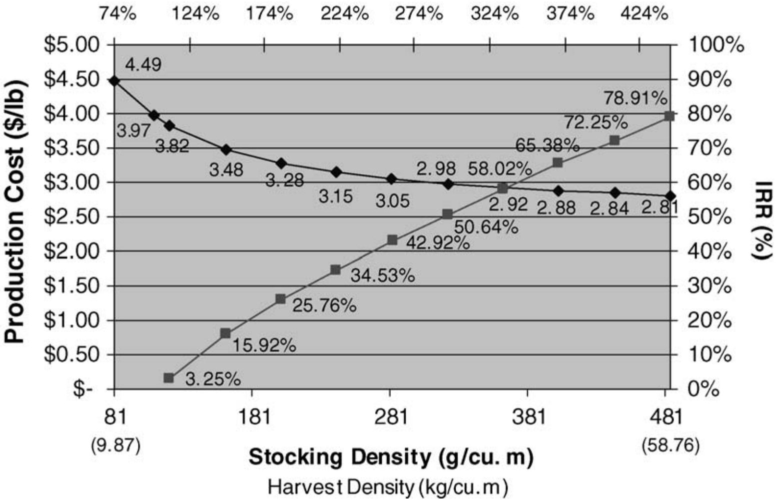

Fig. 8. Sensitivity to changes in density.

densities, however, should take into consideration the effect on overall production, market demand and associated changes in market value (sale price) for Pacific threadfin.

3.9. Survival rates

The production cost sensitivity to survival rates was also explored within a range of 50%–100%. From the baseline overall survival rate of 61.81%, a percent increase in survival rate decreases unit production costs by 2.74% (Fig. 9). While this sensitivity to survival rates suggests that a reduction in mortality may significantly reduce unit production costs, the range for improvement does not yield the expected benefits resulting from increased stocking densities. If survival rates of 100% could be achieved, the expected IRR is 26.15% in comparison to the maximum stocking density proposed, which may generate an IRR of up to 79%.

3.10. 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 the survival sensitivity analysis (Fig. 9) 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 US$1,696,465 and covers the initial capital outlay for the cage enterprise. The leverage sensitivity analysis (Fig. 10) 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.

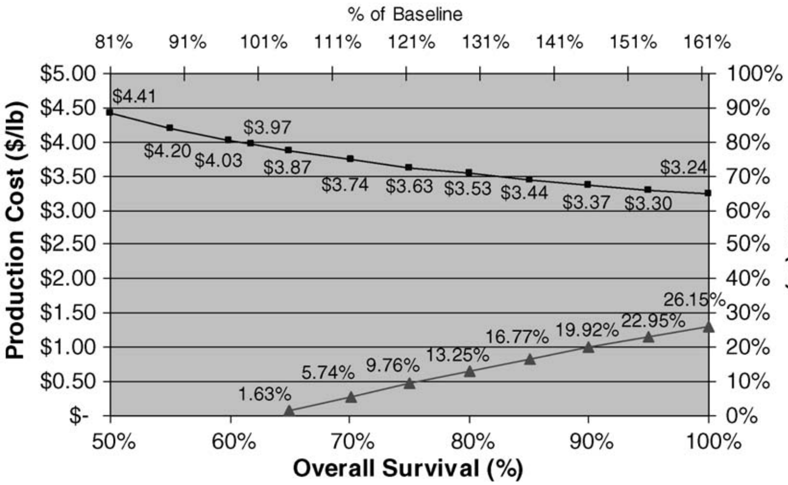

Fig. 9. Survival sensitivity.

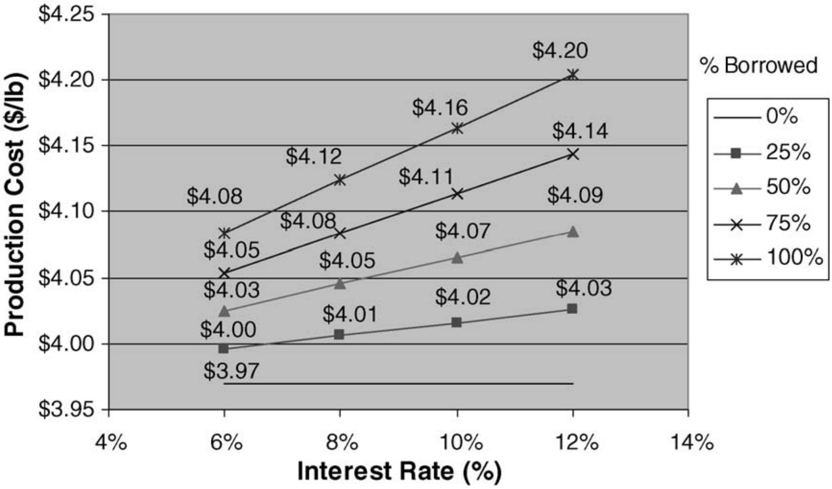

Fig. 10. Leverage sensitivity (production cost).

The base model may depict 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 US$5.00/lb, an enterprise with 100% equity may achieve a 20-year IRR of 23%. 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. 11).

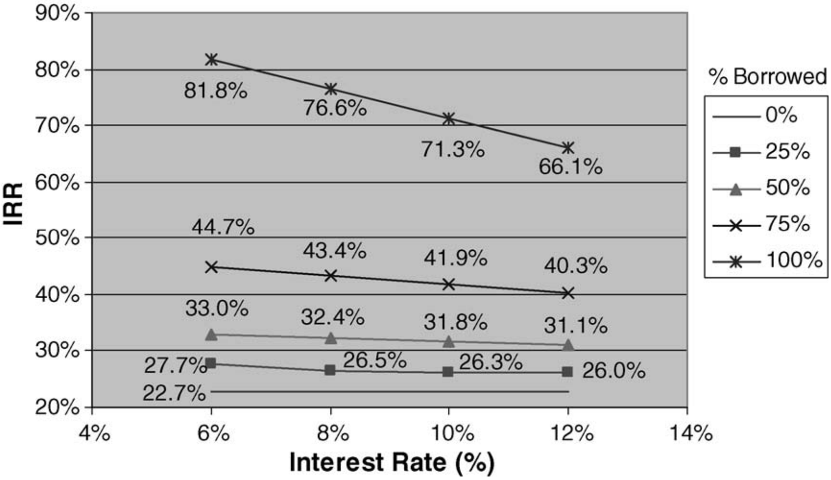

Fig. 11. Leverage sensitivity (profitability based on US$5.00/lb sale price).

4. Concluding remarks

The offshore cage production model exhibits the cost structure based on the HOARP demonstration system for Pacific threadfin. For a six-cage production system yielding 914,271 lb of Pacific threadfin, the cost of production per pound is estimated at US$3.97. The largest costs incurred are primarily feed, which is only slightly less than the combined costs associated with payroll, seedstock and shipping. The conservative cage production model described in this study may not be profitable under the assumed conditions. However, the inputs used in this study were based on an extrapolation of one trial of the single-cage system. Future research from on-farm experience or follow-up trials will need to be conducted in order to verify the results of this study.

Offshore aquaculture which is considered to have greater risk than land-based systems is expected to have a higher IRR than land-based systems. Preliminary analyses comparing land-based and offshore culture of Pacific threadfin in Hawaii suggest that slightly greater returns may be achieved by the offshore system (Leung et al., 2002). Other studies comparing land-based and offshore, however, indicate returns achieved by offshore systems that are much higher in comparison to land-based production (Lisac and Muir, unpublished). The six-cage system must increase production efficiency in order to provide a positive rate of return that justifies the added risk incurred by offshore aquaculture. In this study, several avenues were explored that may improve production efficiencies and thus profitability.

Analyses on production efficiencies including feed costs, FCR, growth rates, stocking density, survival rates and financial leverage were conducted. Based on changes in parameters that may be achieved by a specific enterprise, managers of 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 survival rates, followed by average growth rates, FCR and feed price are parameters which have a greater potential impact on profitability (Table 5). However, when considering the parameter ranges that can possibly be achieved,

Table 5
Production cost sensitivity to parameter changes

Parameter	Average % change in production cost for a % increase in parameter	Baseline (= 100%)	Minimum (change from baseline) (%)	Maximum (change from baseline) (%)
Average growth rate	− 0.36	2.29 g/day	− 34.6	+ 52.6
Stocking density	− 0.10	109.04 g/m^3	− 25.9	+ 344.4
FCR	+ 0.32	2.39	− 58.2	+ 4.6
Feed price	+ 0.32	US$0.50/lb	− 50.0	+ 50.0
Sale price	+ 0.03	US$4.00/lb	− 50.0	+ 25.0
Seedstock price	+ 0.14	US$0.29 ea	− 31.0	+ 20.7
Survival	− 2.74	61.81%	− 19.1	+ 61.7

Table 6
Parameter values required for profitability

Parameter	Minimum	Baseline (=100%)	Maximum	Value required for profitability (>20% IRR)	% change from baseline
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day	3.35 g/day	+46.3%
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3	177.36 g/m^3	+62.7%
FCR	1.00	2.39	2.50	0.89[a]	– 62.8%[a]
Feed price	US$0.25/lb	US$0.50/lb	US$0.75/lb	US$0.18/lb[a]	– 64.0%[a]
Sale price	US$2.00/lb	US$4.00/lb	US$5.00/lb	US$4.88/lb	+21.8%
Seedstock price	US$0.20 ea	US$0.29 ea	US$0.35 ea	[a,b]	–[b]
Survival	50%	61.81%	100%	90.25%	+46.0%

[a] Parameter value required for 20% 20-year IRR outside of sensitivity range.

[b] Seedstock price required < US$0.00 ea, % change not feasible. (A fry sale price of US$0.00 ea yields a 14.44% IRR).

changes to survival rates, stocking densities and growth rates should be explored in order to reduce unit production costs (Table 6). An analysis of 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.

The required parameter changes needed in order to achieve profitability were also determined (Table 6). In order for the commercial production system to achieve a 20% 20-year IRR, the largest changes required from the baseline inputs are stocking density, FCR, feed price and seedstock price. With respect to the ranges explored in the sensitivities, changes to seedstock price, FCR and feed price alone will not enable the commercial enterprise to be profitable. Rather, increased stocking densities, survival rates and average growth rates appear to have the largest potential for reducing unit production costs.

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%). Proportionately large feed expenditures are expected for efficient production systems (e.g., Brown et al., 2002; Bourgeois and Aquilina, 1995; Stephanis, 1995; Lisac and Muir, unpublished). Research is needed to reduce the cost of feed through use of fishmeal substitutes and refining the nutritional needs of the finfish. Feed costs may be reduced based upon additional research to refine nutritional requirements of threadfin and increase the use of less expensive grain and oilseed products as fishmeal replacements. Moreover, with increased offshore production, bulk shipments of marine feed to the islands will reduce freight and overall milling costs.

The largest operating costs measured in this study were similar to those reported by Stephanis (1995): feed (31% of the total production costs), followed by stocking (22%) and labor (12%). The average market price for sea bass and sea bream was US$4.24/lb (6.6 1994 ECU/kg) with a production cost of approximately US$3.54/lb (5.5 1994 ECU/kg). Feed and labor were also among the largest production costs for the Malta cage system reported by Bourgeois and Aquilina (1995), 22% and 9%, respectively. For the sea bass/sea bream system, seedstock was supplied internally and did not contribute significantly to production costs. Consequently, it appears that the Malta cage system was able to benefit from economies of scope due to vertical integration as suggested by Stephanis.

Selective breeding practices may yield efficiencies through higher growth rates, but may not significantly reduce stocking costs to provide a net benefit if the cost of such procedures are high. Moreover, while improved survival rates indicate sizable benefits through improved production efficiencies, improvement of survival rates alone do not appear to provide the reduced production costs that may result from increased stocking densities and feed efficiencies. Tapping export markets and increased local demand, however, could bring sale prices above the minimum US$4.88/lb sale price (Table 6) required for profitability (20% IRR).

In conclusion, efficiencies must be sought in order for cage-culture of Pacific threadfin to be profitable in Hawaii. The results of the sensitivity analyses suggest increased stocking densities, survival rates and growth rates are potential means of reducing production costs. The local market for Pacific threadfin may not support the high volume of production from offshore cage culture. Depressed local market prices may be the consequence. In order for the six-cage production system to avoid intense competition with land-based producers and remain profitable, efficiency strategies such as higher stocking densities, improved survival rates and growth rates are needed, as well as exploring export markets.[2]

Acknowledgements

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[2] A local aquaculture firm has recently entered into a 20-year lease with the State of Hawaii to use 28 acres under water at the site of the HOARP. The lease was the first issued in the country for offshore culture. The firm is currently producing about 5000 lb of Pacific threadfin a week from two cages. The fish are sold to local markets and restaurants as well as on the U.S. mainland (Lum, 2002). This is a positive sign favoring the commercial viability of cage culture in Hawaii.

Appendix A. General and financial assumptions

Fingerling type and cost	Unit		Unit price
Fingerlings	US$/piece		US$0.29
Growout fish	US$/lb		US$4.00
Feed type and cost	**Unit**		**Unit price**
Moore Clark	US$/lb		US$0.50
Fuel type and cost	**Type**	**Unit**	**Rate**
Electricity	1	US$/kWh	US$0.17
Diesel fuel	2	US$/gal	US$0.96
Gasoline	3	US$/gal	US$1.90
Lease information	**Unit**		**Value**
Production area	m^2		450,000
Lease rent	% Gross		2
Annual lease rent	US$/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	years		

Appendix B. Payroll

Assumptions		Salary	Hourly		
Shift length	h/day	8.00	8.00		
Days/week	days	5.00	5.00		
Weeks/year	weeks	52.00	52.00		
Benefits	%	25%	25%		
Operations	months/year	12.00	–		
Salaried employees	**Quantity**	**Rate (US$/month)**	**% Full time**	**Total (US$)**	**% of total**
Captain (also divers)	2	US$3500	100	84,000	13.2
Divers	0	US$3120	100	–	0.0
Truck Driver	1	US$2200	100	26,400	4.2
Harvest Person	2	US$1800	100	43,200	6.8
Accountant	1	US$2600	100	31,200	4.9
Manager	1	US$4000	100	48,000	7.6
				232,800	36.7

Appendix B (*continued*)

Salaried employees	Quantity	Rate (US$/month)	% Full time	Total (US$)	% of total
Benefits				58,200	9.2
Total salaried payroll				291,000	45.8

Hourly employees	Quantity	Rate (US$/h)	h/week	Total (US$)	% of total
Divers	7.35	US$18.00	40.00	275,151	43
Benefits				68,788	11
Total hourly wages				343,938	54
Total payroll				634,938	100

Appendix C. Capital outlay and annualized depreciation

Capital costs	Useful life (years)[a]	Unit cost (US$)	Quantity	Cost (US$)	% of outlay	Annual cost (US$)	% of annual cost
Construction and permits							
Permits (EIS/EA)	20	250,000	1	250,000	13.76	12,500	8.99
Warehouse and office (2000 ft^2)	20	200,000	1	200,000	11.01	10,000	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	1500	15	22,500	1.24	1125	0.81
Harvest Equipment (Gel Pack System and Stainless Steel Table)	10	2000	1	2000	0.11	200	0.14
Nursery Net	10	5000	6	30,000	1.65	3000	2.16
Regular Fish Net (Seine Net)	5	15,000	6	90,000	4.95	18,000	12.95

(continued on next page)

Appendix C (*continued*)

Capital costs	Useful life (years)[a]	Unit cost (US$)	Quantity	Cost (US$)	% of outlay	Annual cost (US$)	% of annual cost
Other offshore equipment							
PVC Bin Flow-Through and Pump System	10	100	15	1500	0.08	150	0.11
YSI 85 Water Analysis + 100′ cord	5	1700	2	3400	0.19	680	0.49
YSI Photometer	5	1850	2	3700	0.20	740	0.53
Nets	2	3000	1	3000	0.17	1500	1.08
Scuba Gear	5	2000	6	12,000	0.66	2400	1.73
Support Vessel (100-ton barge)	20	240,000	1	240,000	13.21	12,000	8.63
Feed Camera System	10	1,615	1	1615	0.09	162	0.12
Feed Camera Attachments, additional	10	950	5	4750	0.26	475	0.34
Submersible Cages	10	70,000	6	420,000	23.12	42,000	30.22
Mooring System (including four anchors)	15	15,000	6	90,000	4.95	6000	4.32
Other equipment							
Office equipment	5	6000	1	6000	0.33	1200	0.86
Laboratory equipment	5	5000	1	5000	0.28	1000	0.72
Tools	10	5000	1	5000	0.28	500	0.36
Communication devices	10	1000	1	1000	0.06	100	0.07
Total equipment				1,816,465	100.00	38,982	100.00

[a] Estimates for years for depreciation were based on estimates by Hawaii practioners. The extent to which the useful life is overestimated suggests that profitability may be lower than reported in this study.

Appendix D. Energy

Energy type		Rate	Electricity conversion (K)
Electricity	1	US$0.17/ kW h	0.7475 kW/HP-h
Diesel fuel	2	U$0.96/ gal	0.0449 gal/HP-h
Gasoline	3	US$1.85/ gal	0.0608 gal/HP-h

Equipment	Quantity	Fuel type	Power (HP)	Ann h/ea	Energy (US$)	% of total	Average h/day/ea	Total h/day
Air Blower	1	2	40.0	4380	7554	6.2	12.00	12.00
Boat (47′)—Stocking/Harvest	1	2	400.0	162	2794	2.3	0.44	0.44

Appendix D (*continued*)

Equipment	Quantity	Fuel type	Power (HP)	Ann h/ea	Energy (US$)	% of total	Average h/day/ea	Total h/day
Boat (32′)—Maintenance	1	2	300.0	548	7081	5.8	1.50	1.50
Fish Pump (Feed System)	2	2	5.5	2190	1039	0.9	6.00	12.00
Ice Machine	1	1	80.0	8760	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 E. Other operating costs

Cost description	Units	Cost (US$/unit)	Total (US$)	% 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	2160	0.3
Warehouse rent (ft^2)	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 and 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	1200	1200	0.2
Subtotal			1200	0.2
Other (rounded to ’00)				
Maintenance	1	61,200	61,200	9.9
Supplies and miscellaneous	1	2000	2000	0.3
Legal and audit	1	1000	1000	0.2
Insurance	1	7000	7000	1.1
Advertising	1	5000	5000	0.8
Permit renewal	1	5000	5000	0.8
Miscellaneous	1	29,600	29,600	4.8
Subtotal			110,800	18
Total			620,771	100

Appendix F. 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 amount (lb)	457,136	914,271	914,271	914,271	914,271
Revenue	1,828,543	3,657,085	3,657,085	3,657,085	3,657,085
Operating costs (US$)					
Energy	74,666	121,109	121,109	121,109	121,109
Feed	802,490	1,092,453	1,092,453	1,092,453	1,092,453
Stocking	469,800	469,800	469,800	469,800	469,800
Labor	634,938	634,938	634,938	634,938	634,938
Salaries	291,000	291,000	291,000	291,000	291,000
Lease rent	36,571	73,142	73,142	73,142	73,142
Supplies and other	65,598	65,598	65,598	65,598	65,598
Shipping	207,997	415,993	415,993	415,993	415,993
Monitoring/analysis	77,980	77,980	77,980	77,980	77,980
Maintenance	61,200	61,200	61,200	61,200	61,200
Excise tax	9143	18,285	18,285	18,285	18,285
Contingency	136,569	166,075	166,075	166,075	166,075
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	0	4579	4579	4579	4579
State tax	0	1399	1399	1399	1399
Income after taxes	(1,178,391)	24,551	24,551	24,551	24,551
Cost per pound before tax	6.58	3.97	3.97	3.97	3.97
Cost per pound 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 G. Statement of cash flows (first 5 years)

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	0	0	0	0	0	0
Inflow total	0	1,828,543	3,657,085	3,657,085	3,657,085	3,657,085
Cash outflow						
Cash operating costs[a]		2,867,953	3,487,575	3,487,575	3,487,575	3,487,575
Loan payment		0	0	0	0	0
Income tax		0	5978	5978	5978	5978
Capital expenditure	1,816,465	0	0	3000	0	3000
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)

[a] Total operating costs (less depreciation and interest expenses).

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