Accounting for Economic Risk and Uncertainty in Offshore Aquaculture: A Case Study of Korean Rock Bream Production

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Abstract Interest is growing in offshore aquaculture as a means of overcoming environmental concerns that plague nearshore and coastal aquaculture production. The challenge of dealing in the offshore environment adds expenses that are not present in other aquaculture production systems. We collected financial and production performance data from a commercial scale offshore aquaculture production system for rock bream off the coast of Korea. Financial performance of the system was evaluated using Aquasim, a stochastic financial simulator. To compare performance, we focused on the ten year internal rate of return and net present value based on different assumptions regarding fish survival rates and market prices. The baseline model which used the observed survival and market prices had a high probability of financial success and an internal rate of return of 18%. Financial performance became a lot riskier when we assumed that survival rates followed a triangular distribution with a 25% minimum survival that increased 5% per year, even when the mean survival rate was as high as 97%. Rock bream aquaculture could be successful under that survival scenario if prices are high for the first five years and then start declining due to the industry expanding. In that case, the internal rate of return is around 14%, but with greater variability than the baseline. If prices fall from the initial baseline level in the early years of production, then the operation has little chance of surviving.

Introduction

The continued development of aquaculture as a means of increasing the world's fish supply is a balance between cost efficiency in production and environmental costs that are external to the operation. At one extreme are recirculating systems that are greatly isolated from the environment, but have high investment and operating costs that, at present, are mostly economically viable for high-valued species. These systems have a relatively low impact on the environment since there is little, if any, water exchange, and the effluent can be easily managed. More open systems such as shrimp ponds or coastal net-pen systems have lower costs, but are experiencing growing concerns about environmental impacts (Naylor 2006; Whitmarsh *et al.* 2006; Goldburg *et al.* 2001). Offshore ocean aquaculture systems, within the high energy marine environment and deeper waters, may ameliorate some of the environmental problems of the current systems which tend to be more nearshore and in shallower water (Kalantzi and Karakassis 2006). However, these environmental gains may be offset by higher investment costs, higher operating expenses and greater risk.

As with any new production process, there is little data available about the economic performance until a sufficient size industry develops from which to gather data. Potential investors and government agencies that seek to support the development of aquaculture must rely, at best, on data from experimental or pilot-scale systems, or expert opinion on which to base their decisions. Economic analysis of the performance of two offshore aquaculture systems in the United

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States, one off of Puerto Rico (Brown et al. 2002) and one placed off of Hawaii (Kam et al. 2003), have been conducted based on just such speculative data. In this paper, we base an economic analysis of rock bream, Oplegnathus fasciatus, culture in the offshore waters of Jeju Island, Korea, on the actual performance of a privately owned and operated aquaculture enterprise. Since the data is limited to one year of operation, we use stochastic simulation to project the necessary conditions for long term success for similar offshore operations.

Methodology

Financial Analysis

A basic accounting approach is standard for examining farm enterprises in general and has been applied widely in aquaculture. Greater attention has been paid to accounting for uncertainty and risk, particularly when dealing with relatively new aquaculture operations. Examples of incorporating risk in aquaculture include studies on salmon (Kumbhakar 2000), catfish (Kazmierczak and Soto 2001; Nelson et al. 2001), crawfish (McCullogh et al. 2001) and shrimp (Valderrama and Engle 2001). Sottorio collected data from 16 companies in Spain involved in aquaculture production of eight finfish species. Lipton and Gempesaw (1997) used a software program they specifically developed for evaluating risk in aquaculture enterpises, Aquasim, to compare production technologies for hybrid striped bass.

Aquasim was used in this analysis of offshore aquaculture of rock bream. Aquasim is derived from Chicksim, a stochastic financial simulation program originally designed for analyzing chicken production (Gempesaw et al 1988). Aquasim is capable of simulating four discrete stages of fish production for a single species. The model is also capable of simulating multiple production cycles simultaneously, allowing for continuous stocking on up to a monthly basis. Fish are grown in the simulation based on user specified ending and starting weights and stage length in months. User specified stage-specific mortalities and feed conversion rates are applied to determine production levels and feed costs. Aquasim requires the user to specify ranges or standard deviations for a variety of variables related to the production process and for input and output prices. (Table 1)

In addition to incorporating risk and uncertainty via Monte Carlo simulations, Aquasim provides for a more realistic investment scenario than developed in typical enterprise budgets. The user can specify initial loans and terms, as well as terms for new loans that may be initiated within the time horizon should the cash flow situation require or when capital equipment needs to be replaced as indicated by the depreciation schedule. New loans are allowed during the simulation as long as the operation meets standard equity ratio tests. If the operation runs out of money and borrowing is not allowed due to insufficient equity, the simulation is declared insolvent. The number of insolvencies is tracked during the simulations to generate a probability of survival for the operation. Standard measures of performance such as internal rate of return and ending net worth are tracked for all the solvent iterations, and the mean values, ranges and coefficients of variation are provided for the scenario being tested.

Another feature of Aquasim is that it is a dynamic model with up to a ten year time horizon. Thus, the user can specify different parameter values for all ten years. For example, survival rates may increase or feed efficiency increase due to an assumption about the firm moving up the learning curve of production (Sotorrio 2002). The variance or ranges of the specified parameters can

Table 1. Financial information used in Aquasim.

Market Price	US$12.94/kg
Tax	10%
Discount rate	8%
Loan	US$150,000
Interest rate of loan	2.8%
Life of loan	2years

also increase or decrease over the time horizon. For example, experience may not lead to a higher mean survival rate, but it could lead to less variability in the survival rate.

A baseline scenario using Aquasim is developed using the actual data obtained from a commercial scale operation discussed below. Once the baseline performance is established in terms of net present value (NPV) and internal rate of return (IRR), several other scenarios are run for comparison. In particular we look in detail at a more realistic price scenario over the ten year time horizon, as well as a more realistic fish survival scenario. We then run the price scenario and survival scenario in a combined scenario that we feel most closely approximates the expected performance of the offshore rock bream system. We also conduct sensitivity analysis for key production parameters such as feed and seed costs.

Aquaculture Operation Description

The offshore rock bream cage production system was initially introduced in the Pyo-Sun area of Jeju Island in Korea on April 2005 as part of a commercial farming pilot project (Figure 1). The Pyo-Sun area is close to port facilities and fingerling production facilities. A consortium for the commercial project was formed by the Jeju Fisheries Research Institute (JFRI), a regional institute of the National Fisheries Research & Development Institute (NFRDI) of Korea and a private aquaculture enterprise, Noah Offshore Farm Company Limited.

The city of Jeju issued a permit to conduct the offshore farming in an area covering 10 ha of surface water, 4.5 km off Pyo-Sun for three years (May 2005 to May 2008). The offshore cage system is the Seastation 3000^{TM}, a 3000 m^3 biconical sea cage. This is the same cage system as is being used in Hawaii, Puerto Rico, and New Hampshire. The cage system was imported from the United States and currently, three cages are being employed.

Rock bream was selected as the species to be farmed due to its high market price compared to other major species such as the flatfish, Paralichthys olivaceus, and the rockfish ,Sebastes schlegelii.[1] Rock bream fingerlings are readily available, and it has performed well in other aquaculture systems. A total 677,467 fingerlings, weighing 5-10g per fingerling were stocked at the end of June 2005.

Production costs for the first 12 month production cycle were obtained from the Noah Offshore Farm. JFRI provided data on the performance of the fish within the system in terms of growth and survival. Financial parameters for the production of rock bream offshore farming are summarized in Table 2. Parameters include market sale price, tax rate, discount rate, and loan terms. The price of rock bream during the period was estimated to be relatively high (US$12.94/kg) compared to other farmed species. A discount rate of 8% is used to calculate the Net Present Value (NPV). The Noah Offshore Farm Co. Ltd. borrowed US$150,000 from the National Federation of Fisheries Cooperatives (NFFC) at a 2.8% interest rate during a 2-year period.[2]

The overall survival rate was 97%, and we initially assumed it ranged from 90-100%). The feed conversion rate (FCR) was 1.3 with an assumed standard deviation of 0.2. Thee fish had an average weight of 175g with an assumed standard deviation of 0.14g after the 12-month production period. The survival rate is relatively high compared to other species farmed in Korea in land-based raceways or in coastal cage systems. For example, the average survival rate of flatfish in the land-based farms is 80%. The difference might be because there were no serious natural disasters such as a typhoon or red tide during the last 12-month farming period and no problems with diseases that may occur in cage farming. This high rate of survival might be a significant advantage of an open ocean cage system in comparison to coastal cage systems or land-based cage systems.

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[1] The production of flatfish and rockfish accounted for 75.4% of Korea's total farmed finfish production in 2005. The annual average price per kilogram of a flatfish and a rockfish in 2005 was US$8.76 and US$9.26, respectively.

[2] This is a government subsidized rate, and other firms would expect to pay higher interest rates. However, the results that follow were not greatly sensitive to the interest rate used.

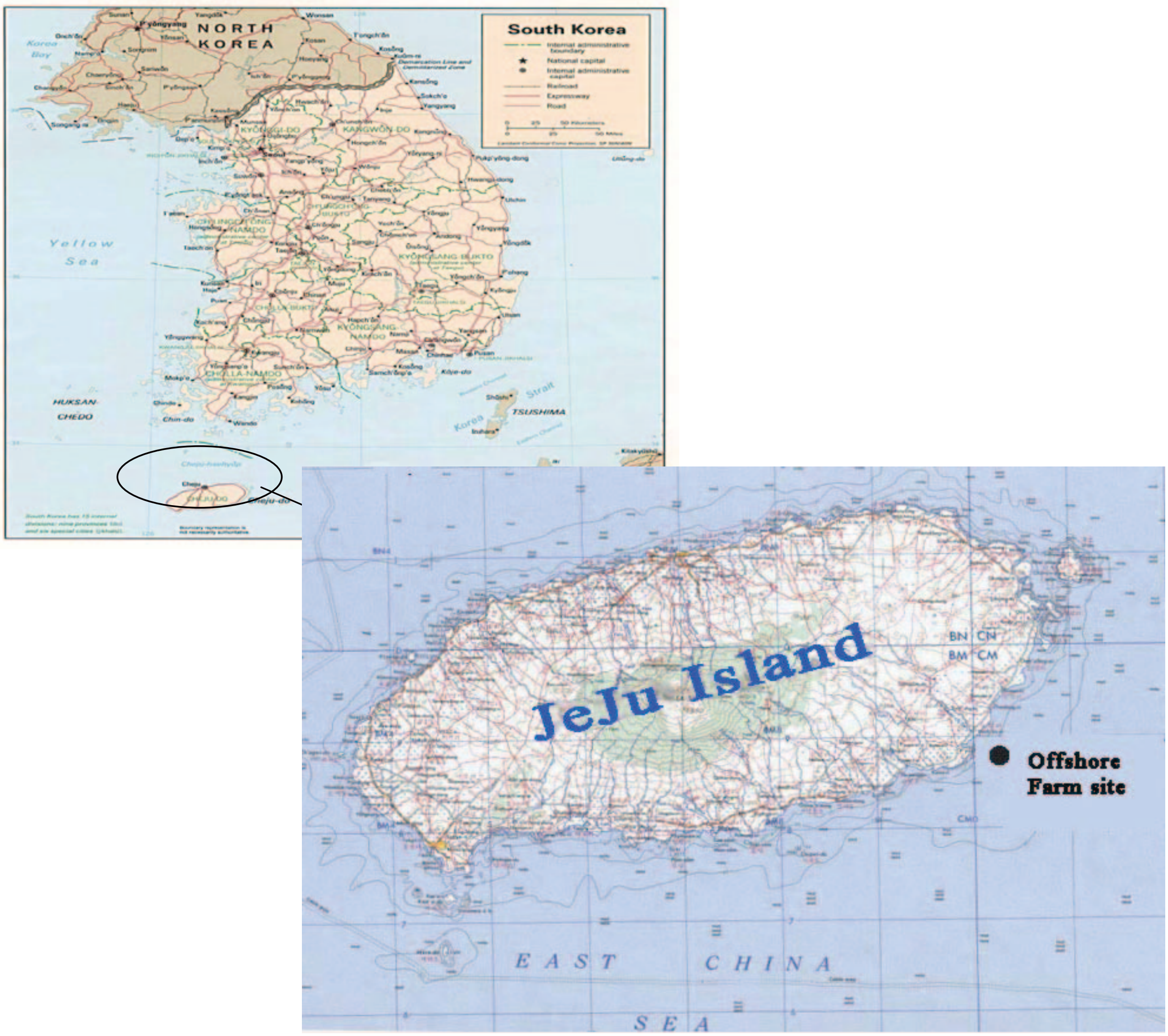

Fig. 1. Map of Jeju Island in South Korea and sight of offshore aquaculture facilities.

Table 2. Production parameters for offshore rock bream culture.

PARAMETER	MEAN VALUE	DISTRIBUTION
Time to market	12 months	Not Applicable
Initial stocking	677,467 fingerlings	Not Applicable
Survival Rate	97%	Triangular (min=90%; max=100%)
Feed Conversion Ratio	1.3	Normal (s.d.=0.2)[3]
Average Market Size	175 g	Normal (s.d.=0.14)

[3] s.d. = standard deviation

However, since these potential natural disasters and disease outbreaks may eventually occur in future offshore farming production, we will focus some attention to a sensitivity analysis on the rate of survival. The FCR is also significantly lower than in other types of cage systems (for example, the FCR averaged at 3.5 in the land-based cage system for flatfish), giving the offshore cage system a decided advantage in this important cost category.

A total of nine full-time employees (including three owners) were hired to run the three cage offshore production system. Among them, one salaried person is in charge of an office work and the other five people are used as divers. Diver operations include repair and maintenance, feeding, harvesting and stocking. Salary per worker was US$2,200 per month and the total annual labor cost total was US$237,600, which includes US$79,200 that represents the opportunity costs of the three owners' time devoted to the project. Part time labor was used for stocking, harvesting and miscellaneous tasks. A total of 16 part-time employees were hired: one carpenter, five for stocking and harvesting, and ten divers. The total part-time labor costs were US$10,860. For future years, we assumed that labor costs varied with a standard deviation that was 10% of the observed costs from the actual operation.

The initial investment for the operation was US$869,273. The three submersible cages and associated gear (e.g., anchors, buoys, regular fish nets, harvest/stocking bin, spar, and rims etc.) cost a total of US$809,103, 93% of the initial capital outlay. Additional items included US$16,170 for nursery nets (2%), a feed storage warehouse for US$ 4,000 (0.4%), scuba gears at US$20,000 (2.3%); and a truck, US$20,000 (2.3%). All asset costs are annualized using straight-line depreciation. Annual operating expenses include the cost of fingerling, feed, energy, labor (including owners/managers), lease rent, interest, insurance, repair/maintenance, depreciation, and supplies, and are summarized in Table 6. The largest costs contributing to annual operating expenses of US$1,043,056 during full operation are fingerling (26%), feed (22.9%), full-time labor including farm owners opportunity cost (22.8%), and depreciation (10.5%). These costs represent 82% of total annual operating costs. This indicates fingerling and feed have the largest potential for reducing annual operating costs.

Recurring energy costs (US$14,400) consist of fuel for boats and trucks. Lease rent cost of US$41,250 per year includes the full-time lease of a boat and additional lease costs for boats and trucks rented temporarily during the time of stocking fingerlings and harvesting. Interest is incurred from US$150,000 that is borrowed from NFFC with a 2.8% interest rate during the life of 2 years. Due to the short production history of offshore farming, it is difficult to estimate an exact repair/maintenance costs. Thus, the cost of maintenance is a provisional estimate that is charged at US$10,000 per cage (Kam, *et al.*, 2003).

Results and Analysis

Baseline Scenario

The baseline model suggests that the production of rock bream offshore farming is profitable over a 10-year time horizon (Table 3). A 10-year cash flow based on an 8% discount rate indicates a positive NPV of US$3,151,402 (ranging from US$2,159,171-US$4,111,452). In addition, the IRR value was high at 18% (ranging from 12%-28%). At this level of performance there is virtually no risk of economic failure; all the iterations remained solvent throughout the time horizon and all had a positive return. The price of rock bream in this scenario is assumed to have a mean on US$12.94/kg and a standard deviation of $2.46 for all ten years.

Market Price Scenarios

Two alternative scenarios of rock bream prices over the ten years were analyzed (Table 4). These scenarios were developed based on prior experience with other Korean farmed species. Scenario one mimics the price path of flatfish and rockfish, which decreased by about 5% per year once farming began. The second scenario reflects what happened to average annual prices for sea bream and other breams with the onset of aquaculture. For breams, prices initially increased

Table 3. Results of the baseline model

Performance Indicator	Min	Mean	Max	Coefficient of Variation
Net Present Value (NPV)	2,159,171	3,151,402	4,111,452	14.51
Internal Rate of Returns (IRR)	0.12	0.18	0.28	19.34
Ending Net Worth	3,238,416	3,938,428	4,685,190	9
Ending Total Debt	0	0	0	0
Leverage Ratio (debt/equity)	0.00	0.00	0.00	0.00
Equity/Asset Ratio	1.00	1.00	1.00	1.00
Average Annual				
Cash Receipts	1,369,010	1,495,614	1,630,364	3
Cash Production Costs	945,043	984,030	1,019,412	1
Net Cash Income	389,469	511,583	632,868	11
Net Income	308,344	430,459	551,744	13

Table 4. Results of different price scenarios on the performance of offshore rock bream culture.

Performance Indicator	Scenario 1		Scenario 2	
	Mean	CV[4]	Mean	CV
Net Present Value (NPV)	1,131,419	35	3,805,201	12
Internal Rate of Return (IRR)	0.01	300	0.24	15
Ending Net Worth	2,099,660	12	4,231,567	7
Annual				
Cash Receipts	1,194,617	3	1,673,018	3
Cash Production Costs	977,103	1	1,021,986	1
Net Cash Income	217,514	19	698,474	8
Net Income	136,389	31	617,349	10

[4] CV = coefficient of variation

by almost 6% annually for the first four years as demand expanded, but prices decreased by 5% as production increased in years six through ten. When Aquasim was run using the first scenario the mean NPV decreased by 62% to US$1,131,419. The IRR decreased from a mean of 18% and a range of 12%-28% to a mean of 1% and a range of 0%-8%. The mean net annual income dropped accordingly from US$430,459 to US$136,389. The effect of changes in market price of Scenario 2 is summarized in Table 4. The mean NPV increased from US$3,151,402 of the baseline model to US$3,805,201 when the price increased by 6% annually for the first 4 years and then decreased by 5% for the later 6 years. The IRR also increased from 18% (12%-28%) in the baseline model to 24% (15%-33%). The mean net annual income rose accordingly from US$430,459 to US$617,349.

Survival Rate Scenarios

The results above are based on the actual performance of the Korean rock bream aquaculture operation, but we feel that the survival rates experienced may represent an overly optimistic scenario. While the results may represent actual survival rates under ideal conditions, it is likely that problems would arise over the ten year time horizon that would result in periodic mortalities at a much greater level than observed. To capture the possibility of occasional larger scale mortalities, we change the minimum survival rate for the triangular distribution of survival from 90% to 25%, but keep the most likely value at 97%. We also run a scenario in which the minimum survival rate in the first year is 25%, but the minimum survival rate increases 5% a year over the ten year time horizon. This scenario is used to simulate the effect of increasing skill and knowledge by the operators which make it less likely for there to be a major mortality as experience is gained. For comparison, we also run a scenario where the most likely survival rate is lowered from 97% to 85%, with a minimum of 70% and a maximum of 97%.

Of the survival rate scenarios run, only the one representing a decrease in the minimum survival rate to 25% over the entire time period significantly lowered the probability of economic success of the enterprise, from 100% in the baseline scenario to 76%. The internal rate of return for the operation drops to only 3% and has a high coefficient of variation of 75% (Table 5). The probability of economic success increases to 97% if the minimum survival is allowed to increase by 5% per year, but the internal rate of return is a modest 8% with a coefficient of variation of 75%.

Combined Price and Survival Scenario

To obtain a more realistic and conservative scenario for rock bream offshore aquaculture in Korea, we combine the two price scenarios with the scenario of a minimum survival rate of 25% that increases 5% per year. The most likely survival rate remains at 97% with a maximum of 100%. Results from the two model runs are given in Table 6. For the declining price scenario,

Table 5. Results of different survival scenarios on the performance rock bream culture.

Min, Mean, Max Survival (%)	25, 97, 100		25(+5%/yr), 97, 100		70, 85, 97	
Performance Indicator	Mean	CV	Mean	CV	Mean	CV
Net Present Value (NPV)	504,669	157	1,235,332	53	1,717,098	23
Internal Rate of Return (IRR)	0.03	157	0.08	75	0.09	45
Ending Net Worth	1,982,738	30	2,648,968	17	2,898,548	10
Annual						
Cash Receipts	1,150,761	9	1,268,728	6	1,311,277	4
Cash Production Costs	946,798	2	958,759	2	963,022	2
Net Cash Income	203,963	46	309,970	22	348,254	13
Net Income	121,860	81	228,847	30	267,130	17

Table 6. Results of combining price scenarios with survival scenario (25+(5%/yr), 97%, 100%)

	Price Scenario 1		Price Scenario 2	
Performance Indicator	Mean	CV	Mean	CV
Net Present Value (NPV)	-533,005	-126	1,828,001	38
Internal Rate of Return (IRR)	0.00	0	0.14	50
Ending Net Worth	982010	49	2,904,044	16
Annual				
Cash Receipts	1,008,643	7	1,314,568	6
Cash Production Costs	958,689	2	757,752	2
Net Cash Income	49,953	127	356,816	20
Net Income	-33,289	-209	275,692	25

the added risk due to a lower minimum survival rate results in only a 22% probability of financial success of the enterprise. The average net present value is negative. The modeled firm has sufficient capital and profitability in the first three or four years to avoid bankruptcy 92% of the time. The situation is much improved for the scenario where initially prices rise and then decline because the price rise offsets the lower survival in the early years. For this scenario, probability of financial success is again near 100% with a 14% IRR. The results are more variable than the price scenario or survival rate scenario alone.

Sensitivity to Feed and Fingerling Costs

Fingerling and feed costs are the first (26%) and second (23%) largest percentages of average annual operating cost expenditures in the baseline model. Because of their importance, we briefly examine sensitivity of the baseline model results to different assumptions about fingerling and feed costs using total production costs and internal rate of return as the primary indicator of farm performance. Kam et al. (2002) discuss the important role of having a ready and appropriately priced source of seed for a successfully aquaculture production industry. If seed is difficult to come by, this will be reflected in higher fingerling costs to the producer. Fingerling costs are varied in 10% increments from -20% of the baseline value to a 50% increase over the baseline. The feed cost range examined is a little narrower, ranging from -20% to a 20% increase over the baseline.

Figures 2 and 3 show the effect of changing fingerling and feed costs on overall production costs and IRR. IRR is slightly more sensitive to assumptions about fingerling costs which is not surprising given that it makes up a slightly higher percentage of the annual operating costs. IRR for a 20% decrease in fingerling costs increases to 21%, and for a decrease of 20% in feed costs, IRR increases to 20%. A price increase of 50% for fingerlings reduces the IRR to 11% and a 20% price increase for feed reduces the IRR to about 16%. For a 20% decrease in fingerling price, it is indicated that the production cost per kilogram of rock bream decreased by US$0.46/kg, from US$9.02/kg of the baseline model to US$8.56/kg. Accordingly, the resultant changes for the 10-year mean IRR yields about 3% more than the baseline model, from 18% to 21%. On the other hand, a fingerling cost increase of 50% corresponds to US$135,493 annual cost increases in production cost. That is, the production cost per kilogram of rock bream increased by 13%, from US$9.02/kg in the baseline model to US$10.21/kg. The resultant changes for the 10-year mean IRR yields about 7% less than the baseline model, from 18% to 11%.

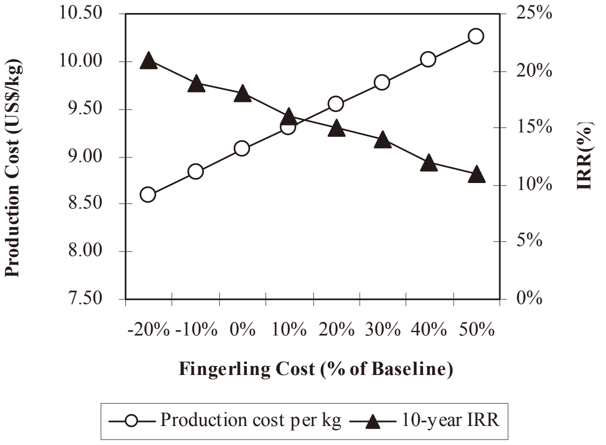

Fig. 2. Results of sensitivity analysis of different fingerling costs.

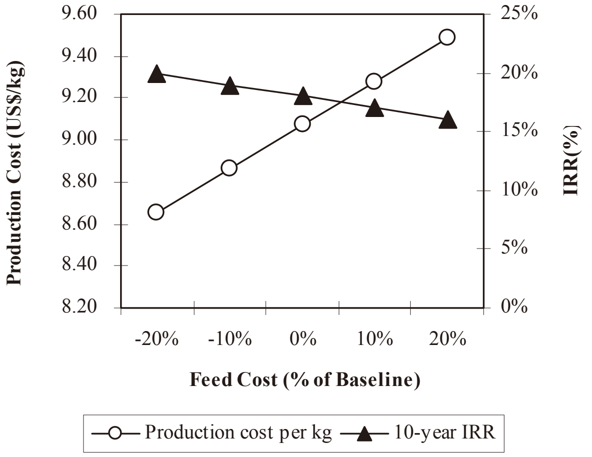

Fig. 3. Results of sensitivity analysis for changing feed costs.

Discussion

Data collected from the Korean offshore aquaculture farm for rock bream suggests that under ideal conditions this enterprise could be low risk and highly profitable. The combination of extremely high survival rates, fast growth to market size, and a high market price are the major factors contributing to the predicted success. However, if the na_ve assumption about constant market prices for the ten year planning horizon is replaced with a more realistic expectation of price declines as the industry expands, growers will face lower returns and higher risk. A better understanding of the market situation in Korea is necessary to evaluate which of the three price scenarios is more likely to occur: the baseline scenario of constant high price; the optimistic scenario of higher prices in the first few years, and then declining prices; or the pessimistic scenario of immediate price declines as the industry grows.

The price decline scenarios that investors choose to believe become more important when more realistic assumptions about fish survival rates in these systems are introduced. The one year experience with this operation off the coast of Jeju Island experiences almost no mortality or loss of fish. This demonstrates that with luck and ideal conditions, these systems perform very well. What is not captured in this single observation is the small chance of a major disaster that would cause a large loss of fish. Nets can be torn and fish escape, storms can cause problems and human error, particular with a new technology can lead to large mortalities. Although these systems are designed to minimize these risks, they still exist, and when something does go wrong, it can have a big impact. We chose to model this by extending the left tail of the triangular distribution of fish survival so that there was a small chance that only 25% of the fish would survive during a production cycle. Even when keeping the most likely survival rate as high as 97%, this introduction of increased risk had a profound effect on the results. Only if compensated for by higher fish prices in the first five years of production, does the performance of the operation remain economically viable. If instead, a scenario of fish prices falling from the baseline level holds, the operation has virtually no chance of being financially successful.

We briefly touched on other factors such as feed and fingerling costs which can affect the financial performance and probability of success of the operations. While they both have similar effects on internal rates of return and net present value, predictions about the time path of these costs will be affected by different factors. Fingerling costs and production will be much more of a local issue. A growing offshore rock bream industry should lead to expansion of fingerling production, economies of scale and cost-saving technological advancement. Some of those cost savings might be offset by increased demand for rock bream seed. Feed costs are much more susceptible to world-wide changes in fish meal and grain markets, and thus, are less dependent on local market conditions..

Our initial results are encouraging that offshore rock bream culture can provide a significant return on investment. However, as was demonstrated, there is no escaping the uncertainties in fish prices and other factors that can impact performance. The excitement that often accompanies any discussion about the potential for offshore aquaculture needs to be tempered by these economic realities. It has potential, but it is far from a sure thing.

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