JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Volume 36, No. 4
December 2005

Economic Evaluation of a Small-Scale Recirculating System for Ongrowing of Captive Wild Black Sea Bass *Centropristis striata* in North Carolina

KIMBERLY A. COPELAND AND WADE O. WATANABE
University of North Carolina Wilmington, Center for Marine Science, 7205 Wrightsville Avenue, Wilmington, North Carolina 28403 USA

CHRISTOPHER F. DUMAS
University of North Carolina Wilmington, Department of Economics and Finance, 601 South College Rd., Wilmington, North Carolina 28403 USA

Abstract

An economic analysis of a hypothetical small-scale marine recirculating aquaculture system (RAS) is conducted for ongrowing small, wild black sea bass *Centropristis striata* at the University of North Carolina Wilmington, Center for Marine Science (UNCW-CMS) aquaculture facility in Wrightsville Beach, North Carolina (NC). The analysis is based on production data from field trials and marketing data from the sale of tank-grown product. The growout facility consists of four 16.7-m³ (dia. x ht. = 5.58 x 1 m) fiberglass tanks supported by state-of-the-art RAS components, including particle traps and swirl separators, drum screen filter, trickling biological filter, UV sterilizer, heat pump, protein skimmer, and oxygen cone. Wild-caught, above minimum legal size black sea bass (24.2 cm TL, 350 g, 0.77 lb) were purchased from a commercial fisherman for $3.14/kg ($1.40/lb), stocked at a density of 21.1 kg/m³, and grown to a final weight of 1 kg (2.24 lb) in 200 d at 23 C resulting in 1.8 production cycles per year. Fish were fed a commercial pelleted diet ($0.94/kg; $0.42/lb) with a feed conversion ratio of 1.5. Final harvest density was 60 kg/m³ (0.50 lb/gal), and total harvestable weight was 3,982 kg (8,919 lbs) of fish per cycle, or 6,760 kg (15,022 lb) per year. The economic analysis assumes that the facility owner manages and operates the system on coastal property zoned commercial/industrial, where full strength seawater is available on demand from natural sources. Under the base case scenario, initial investment in construction and equipment is $84,506 (10-yr life), fish are grown to a harvestable weight of 1kg/fish (2.24 lb/fish), product price (farm gate basis) is $10.10/kg ($4.50/lb), and breakeven price is $7.02/kg ($3.13/lb). Depreciation, fingerlings, interest paid, electricity, and feed, account for 19.6%, 17.4%, 16.9%, 16.6%, and 12.3%, respectively, of total annual costs. Measures of financial performance for the base case, 10-yr scenario are: annual return to management, $18,819; net present value (5% discount rate), $145,313; internal rate of return on initial investment, 37%; and discounted payback period on initial investment, 3.2 yr. Sensitivity analysis showed that product price changes have the largest impact on annual returns, while changes in daily growth rate, initial weight, and survival have a strong impact on financial performance. Moderate effects are seen with changes in fingerling costs, feed costs, feed conversion ratio (FCR), final weight, and interest rates.

Market demand for black sea bass *Centropristis striata* has grown rapidly in recent years while commercial landings of the species have declined (NMFS 2003). With fishing pressure increasing on wild stocks and fishing regulations becoming more restrictive, there is growing interest in black sea bass mariculture (Berlinsky et al. 2000; Copeland et al. 2002, 2003). Recent studies have demonstrated that captive wild black sea bass can be raised in a recirculating tank system at high densities with good growth, feed conversion, and survival. However, there is little published information on the economics of black sea bass production in recirculating aquaculture systems (RAS) in the United States. The lack of economic data is an important constraint limiting the development of black sea bass mariculture. This study uses production data from recent field trials and computer simulation to analyze the economic performance of a small scale RAS for black sea bass. The sensitivity of model results to changes in key parameters is also investigated.

Materials and Methods

Pilot-Scale Growout Trials and Marketing Trials

Grow-out trials were conducted using wild-caught black sea bass from 1999 to 2003 in a recirculating system located in Wrightsville Beach, NC. In the first trial (Phase I), growth rates of wild-caught young black sea bass were compared on four different diets. A diet containing 50% protein and 12% lipid produced the highest growth rates. Fish were grown from 316 g to 1,051 g in 221 d (Copeland et al. 2002).

Phase II compared the growth rates of wild-caught black sea bass at four different stocking densities, ranging from 4.6 to 36 fish/m^3. Fish were grown from 249 g to 838 g in 201 d. Survival was uniformly high (84–99%), and there were no significant differences in growth rates across densities (Copeland et al. 2003).

Phase III of the growout trials evaluated higher stocking densities of 30 and 69 fish/m^3. Fish were grown from 307 g to 965 g in 258 d. Final biomass densities reached 30 and 58 kg/m^3 at stocking densities of 30 and 69 fish/tank, respectively. These results demonstrated that black sea bass can be successfully grown at commercial scale stocking densities (69 fish/m^3) (Copeland et al., unpublished data).

In conjunction with the pilot grow-out trials, preliminary marketing studies were conducted to determine consumer acceptance of tank-grown black sea bass. During these trials, small quantities of tank-grown black sea bass were sold fresh whole on ice to a regional wholesale fish market in New York City for \$5.04/kg (\$2.25/lb). Additional fish were sold to a Maryland-based restaurant supplier, and a local sushi restaurant in Wilmington, North Carolina, USA, where they received prices of \$11.20 and \$12.32/kg (\$5.00 and \$5.50/lb), respectively. In the latest trial, 690 lb of black sea bass were sold live to a Chinese fish market in Philadelphia, Pennsylvania, USA, where they received a price of \$13.20/kg (\$6.00/lb, farm-gate- \$4.46/lb).

Recirculating Aquaculture System

The simulated production facility is modeled on an existing RAS located at the UNCW-CMS Aquaculture Facility, Wrightsville Beach, NC, USA. The UNCW system is based on the North Carolina State University Fish Barn, located in Raleigh, NC, USA (Losordo et al. 2000). UNCW's state-of-the-art outdoor RAS is composed of two separate production units (Carroll et al. 2005). Tables 1–3 list key biological, economic, and engineering parameters. Each production unit consists of two 16.7-m^3 (dia. x ht. = 5.58 x 1 m) fiberglass tanks supported by particle traps and swirl separators, a drum screen filter, a trickling biological filter, UV sterilizer, heat pump, protein skimmer, and oxygen cone. Each tank contains a center double drain fitted with an 11-L swirl separator (Eco-Trap, Aqua-Optima, Trondheim, Norway). The swirl separator retains larger solids (> 100 µm), allowing them to settle out. Approximately 5% of the effluent from the double drain contains the settleable solids, which are sent to the swirl separator. The remaining 95% of the effluent is reunited with the clarified water from the swirl separator in a standpipe well. The effluent then passes through a rotating drum screen filter with a 60-µm screen (PRA Manufacturing, British Columbia, Canada) to remove fine solids. The filtered water is then distributed over a biological filter by a drip plate. The biological filter media consists of 0.53 m^3 of 3-mm polystyrene microbeads. The treated water is then pumped out of the biological filter by a centrifugal pump (Jacuzzi Piranha, Little Rock, Arkansas, USA) and passed through a heat pump (Aqualogic, San Diego, California, USA). A small portion of the flow is diverted to a foam fractionator (Top Fathom, Eugene, Oregon, USA) and returned back to the biological filter. Water from the heat pump is treated by an ultraviolet (UV) sterilizer (Emperor Aquatics, Pottstown, Pennsylvania, USA) and then passes through an oxygen cone before re-entering the culture tanks through inlet manifolds. Carbon dioxide stripping is accomplished by

TABLE 1. *Base case biological parameters.*

Biological Parameters	Quantity
Initial number of fish per cycle[a]	4,022
Initial weight per fish (g)	350
Initial length per fish (cm)	24.2
Initial biomass per cycle (kg)	1,408
Survival over cycle (% of initial number of fish)	0.9
Ave. daily growth rate over cycle (g/d)	3.25
Desired average harvest size per fish (kg)	1
Final biomass per cycle (kg)	3,620
Harvestable weight per cycle (kg)	3,620
Biomass production per cycle (kg)[b]	2,574
Harvest density (kg/m3)	59.8
Feed conversion ratio (FCR = kg feedlkg production)[c]	1.5

[a]*Based on target final biomass density of 60 kglm³ or 0.5 lblgal.*
[b]*Biomass production = final biomass - initial biomass.*
[c]*kg feed used per kg biomass production.*

TABLE 2. *Base case engineering parameters.*

Engineering Parameters	Quantity
Land required for facility (ha)	0.101
Number of tanks	4
Tank size (L)	16,656
System volume (L)	66,623
System volume (m^3)	66.6
System capacity per tank (kg fish/m^3)	58
Length of growout (d/cycle)	200
Length of turn-around (d/cycle)	15
Length of total cycle (d)	215
Months/cycle	7.07
Years/cycle	0.59
Cycles/yr	1.70
Water flow rate (L/min)	22.5
Oxygen consumption rate m^3/cycle[a]	885.4
Feed consumption per cycle (kg/cycle)[b]	3,861
Electricity consumption (MJ/cycle)	234,000
Bicarbonate (kg/cycle)	959.8
Water temperature (C)	23
Fresh water input rate (L/mo)	56.8

[a]*Oxygen consumption rate = lbs. feed * 0.30 * 12.05.*
[b]*Feed cousumption per cycle = biomass production FCR*

air diffusers placed at the bottom of the biological filter and a degassing column located between the water distribution drip plate and the biological filter media (Carroll et al. 2005). Table 1 and Table 2 list the base case scenario biological and engineering parameters, respectively. Each tank can hold 1,000 black sea bass with an initial size of 350 g raised to 1 kg in 200 d. All four tanks are stocked and harvested at the same time (batch process), resulting in 1.7 production cycles per yr. The RAS system produces a harvestable weight of 3,620 kg (8,108 lb) of fish per cycle, or 6,154 kg (13,784 lb) of fish per yr.

Economic Simulation Model

Field trial production and marketing data are used to develop a base case computer spreadsheet[1] economic simulation model of a black sea bass RAS facility located in eastern North Carolina. Table 2 and Table 3 list engi-

[1]*The model was developed using Microsoft Excel 2002 software (Microsoft Corporation, Redmond, Washington, USA).*

TABLE 3. *Base case economic parameters.*

Item	Price
Market value of site land ($/ha)	123,553
Fingerling cost ($/kg/cycle)	3.14
Feed cost ($/kg/cycle)	0.94
Electricity cost (kwh/cycle)	0.065
Oxygen gas cost ($/100$m^3$)	10.6
Oxygen tank rental (S/mo)	80
Bicarbonate cost ($/kg/cycle)	0.426
Fresh water cost ($/mo)	10
Electrical demand charge ($/mo)	100
Misc. overhead costs ($/mo)	100
General insurance ($/mo)	208
Farm gate product price ($/kg)	10.1
Interest rate on 10-yr secured bank loan (%/yr)	0.11
Return on owner's next-best investment (%/yr)	0.05
Project lifetime (yr)	10

neering and economic parameters, respectively, for the base case scenario. It is assumed that the necessary 0.101 ha (1/4 acre) of land is owned by the facility owner/operator. The market price of similar land is $123,553/ha ($50,000/acre) (Table 3). The opportunity cost of using the 0.101 ha of land for aquacultural production is the income that could have been earned if the land had been sold and the proceeds invested, or $52.08/mo ($625/yr)[2] (Table 4), assuming that the annual interest rate paid by the owner's next-best investment in a similar risk class is 5%.

Table 4. *Components of annual costs of black sea bass RAS.*

Component	Annual cost ($)	% annual cost
Variable Costs		
Fingerlings	7,494	17.4
Electricity	7,173	16.6
Feed	5,300	12.3
Water, Bicarbonate, Oxygen	1,910	4.4
Fixed Costs		
Depreciation	8,451	19.6
Interest Paid (Annual Ave.)	7,273	16.9
Insurance	2,500	5.80
Misc. (overhead, fuel, marketing, etc.)	1,200	2.78
Electrical demand charge	1,200	2.78
Opportunity Cost of Land	625	1.45
Total Annual Cost	43,125	100

A facility budget for the base case scenario is presented in Tables 4, 5 and 6. The base case scenario assumes a 10-yr planning horizon. Capital costs, defined as the costs of initial facility construction and fixed equipment, are based on field trial cost data from the UNCW black sea bass RAS facility. Capital costs of $84,506 are financed over 10 yr through a se-

[2] *$52.08/mo. = (1/4 acre)·($50,000/acre)·(5%/12mo.).*

Table 5. *Initial system construction and equipment costs black sea bass marine RAS.*

Equipment type	Expected lifetime (yr)	Units	Unit cost ($)	10-year cost ($)	Annual depreciation ($)
Equipment Tanks	10	4	2,689.00	10,756.00	1075.6
Tank covers	10	4	1,395.00	5,580.00	558
Biosump w/insert	10	2	2,020.00	4,040.00	404
Biosump install	10	2	345.00	690.00	69
Particle trap	10	4	844.00	3,376.00	337.6
Drum screen filter	10	2	4,187.00	8,374.00	837.4
Biological filter	10	2	386.61	773.22	77.322
Oxygen cone	10	2	700.00	1,400.00	140
Pumps	5	4	350.00	2,800.00	280
Blowers	10	2	632.00	1,264.00	126.4
Tank piping/valves	10	1	4,736.96	4,736.96	473.696
Heat pump	10	2	4,640.00	9,280.00	928
Foam fractionator	10	2	779.00	1,558.00	155.8
Standpipe well	10	2	223.53	447.06	44.706
UV sterilizer	10	2	1,728.00	3,456.00	345.6
UV bulbs	1	8	88.00	7,040.00	704
Oxygen system	10	2	242.00	484.00	48.4
Seawater intake piping	10	1	2,500.00	2,500.00	250
PT4 oxygen monitor	10	1	3,836.48	3,836.48	383.648
Misc.	10	1	4,114.28	4,114.28	411.428
Labor Construction labor	10	1	8,000.00	8,000.00	800
Subtotal				84,506.00	8,450.6

TABLE 6. *Sensitivity of financial performance measures to changes in biological and economic parameters.*

Parameter	% Change	Value	BEP[a]	ARM[b]	NPV[c] (10-yr life)	IRRD[d] (%)	DPP[e] (yr)
Product Price ($/kg)	-25%	7.560	$7.02	$3,333	$25,734	16.0	7.4
	-10%	9.070	$7.02	$12,624	$97,482	29.0	4.1
	Baseline	10.08	$7.02	$18,819	$145,313	37.0	3.2
	+10%	11.09	$7.02	$25,013	$193,145	45.0	2.6
	+25%	12.60	$7.02	$34,305	$264,892	56.0	2.1
Fingerling Cost ($/kg)	-25%	2.350	$6.69	$20,815	$160,729	40.0	3.0
	-10%	2.820	$6.89	$19,617	$151,479	38.0	3.1
	Baseline	3.140	$7.02	$18,819	$145,313	37.0	3.2
	+10%	3.450	$7.15	$18,020	$139,147	36.0	3.3
	+25%	3.920	$7.34	$16,822	$129,898	35.0	3.4
Elec. Cost ($/kwh)	-25%	0.049	$6.71	$20,729	$160,067	40.0	2.99
	-10%	0.059	$6.89	$19,583	$151,215	38.0	3.11
	Baseline	0.065	$7.02	$18,819	$145,313	37.0	3.19
	+10%	0.072	$7.14	$18,054	$139,412	36.0	3.29
	+25%	0.081	$7.33	$16,908	$130,560	35.0	3.43
Initial Weight (kg)	-25%	0.263	$7.28	$15,300	$118,140	32.6	3.7
	-10%	0.315	$7.12	$17,307	$133,639	35.2	3.4
	Baseline	0.350	$7.02	$18,819	$145,313	37.2	3.2
	+10%	0.385	$6.91	$20,498	$158,277	39.3	3.0
	+25%	0.438	$6.75	$23,399	$180,684	43.0	2.7
Feed Cost ($/kg)	-25%	0.706	$6.79	$20,230	$156,214	39.0	3.0
	-10%	0.847	$6.93	$19,383	$149,674	37.9	3.1
	Baseline	0.941	$7.02	$18,819	$145,313	37.2	3.2
	+10%	1.035	$7.11	$18,254	$140,953	36.4	3.3
	+25%	1.176	$7.25	$17,407	$134,412	35.3	3.4
FCR	-25%	1.125	$6.78	$20,267	$156,496	39.0	3.04
	-10%	1.350	$6.92	$19,398	$149,786	38.0	3.13
	Baseline	1.500	$7.02	$18,819	$145,313	37.0	3.19
	+10%	1.650	$7.11	$18,239	$140,840	36.0	3.26
	+25%	1.875	$7.25	$17,371	$134,131	35.0	3.37
Final Weight (kg)	-25%	0.750	$7.08	$21,500	$166,020	40.6	2.9
	-10%	0.900	$7.06	$19,480	$150,422	38.0	3.1
	Baseline	1.000	$7.02	$18,819	$145,313	37.2	3.2
	+10%	1.100	$6.97	$18,380	$141,926	36.6	3.2
	+25%	1.250	$6.91	$17,939	$138,517	36.0	3.3
Ave. Daily Growth (g/d)	-25%	2.438	$8.09	$9,337	$72,098	24.5	4.9
	-10%	2.925	$7.38	$15,052	$116,225	32.2	3.7
	Baseline	3.250	$7.02	$18,819	$145,313	37.2	3.2
	+10%	3.575	$6.72	$22,559	$174,195	41.9	2.8
	+25%	4.063	$6.35	$28,132	$217,231	48.9	2.4
Survival (%)	-25%	0.680	$8.84	$5,702	$44,033	24.5	4.9
	-10%	0.810	$7.63	$13,572	$104,801	32.2	3.7
	Baseline	0.900	$7.02	$18,819	$145,313	37.2	3.2
	+10%	0.990	$6.52	$24,065	$185,825	41.9	2.8
	+25%[f]	-	-	-	-	-	-
Interest Rates (%)	-2%	9.000	$6.78	$20,272	$156,532	38.0	3.2
	Baseline	11.00	$7.02	$18,819	$145,313	37.0	3.2
	2%	13.00	$7.26	$17,312	$133,675	37.0	3.2

[a] *Breakeven price.*
[b] *Annual returns to management.*
[c] *Net present value.*
[d] *Internal rate of return.*
[e] *Discount payback period.*
[f] *Not calculated.*

cured bank loan at a base case annual interest rate of 11%. Depreciation on capital costs is $8,451/yr.

The base case budget assumes that tanks are stocked every 215 d with wild-caught small black sea bass (mean wt. = 350 g) purchased from a commercial fisherman at $3.14/kg ($1.40/lb) (Table 1). The fish are immediately weaned onto a 7-mm pelleted diet consisting of 50% protein and 12% lipid at a cost of $0.94 per kg of feed. Fish are fed twice daily to satiation. Based on field trial data, the feed conversion ratio (FCR) is 1.5, and fish will reach a market weight of approximately 1 kg in 200 d. At the end of each production cycle, a live-hauler purchases the fish at the farm gate and pays the owner $10.10/kg ($4.50/lb) on a whole weight basis. The facility yields 6,154 kg (13,784 lb) of harvestable weight per year (3,620 kg to 8,108 lb per cycle), producing annual revenues of $61,944/yr ($36,488 per cycle).

Operational costs are defined as variable costs plus fixed costs (excluding capital costs). Variable costs are those costs that vary with the level of production and include the costs of fingerlings, feed, energy, oxygen, bicarbonate, and freshwater supply. Due to the small scale of the facility, no waste disposal permit is needed, and there are no waste disposal costs. Fixed costs are those costs that must be paid regardless of the level of production. Fixed costs may be divided into cash fixed costs and non-cash fixed costs. Non-cash fixed costs include depreciation and the opportunity cost of the owner's land. Variable costs and cash fixed costs are financed by a secured line of credit at an annual interest rate of 11%.

The sensitivity of base case scenario financial performance measures was examined in relation to changes in the following key model parameters: product price, fingerling cost, electricity cost, initial fingerling weight, feed cost, feed conversion ratio (FCR), final (harvest) weight, average daily growth rate, interest rates, and survival. Each parameter is varied by 10 and 25% above and below its baseline value and its effect on break even price (BEP), annual returns to management (ARM), net present value (NPV), internal rate of return (IRR), and discount payback period (DPP) are determined.

Results

Base Case

Initial capital costs (facility construction and equipment costs) are $84,506. The largest capital cost components are tanks and tank covers ($16,336), heat pumps ($9,280), drum screen filters ($8,374), and construction labor ($8,000) (Table 5). Capital costs are financed with a secured bank loan at an interest rate of 11% over a 10-yr term, producing a monthly loan payment of $1,164. Capital costs (including interest) account for 32% of annual total costs.

Fixed costs other than initial capital costs are rather minor (Table 4). Cash fixed costs include electrical demand charge, overhead, and insurance; these total $4,900 annually. General insurance amounts to $2,500 per year. An advantage of a RAS-type facility is the relatively small amount of land required; the opportunity cost of the 0.101 ha of required land is only $625/yr.

Variable costs amount to $12,887 per cycle, or approximately $21,877 per year, equivalent to 51 % of annual total costs. The costs of fingerlings, electricity, and feed dominate variable costs representing 17.4, 16.6, and 12.3% of total annual costs, respectively (Table 4). Note that the analysis assumes that the owner/manager supplies all required labor; no additional hired labor is purchased. Operating capital, the sum of variable costs and cash fixed costs, is financed via repeated, short-term, unsecured loans at an interest rate of 11%, with terms equal to the duration of the production cycle. Interest payments on operating capital loans are $148/mo ($1,033 operating loan interest per cycle / 7 months per cycle = $148/mo), or approximately $17,544 over the 10-yr life of the project.

As all capital and cash costs are financed via loans, annual total costs of $43,125 are equal to the sum of the annual capital cost loan payments ($13,969), the operating capital loan payments ($28,531), and non-cash fixed costs less depreciation $625. Depreciation is subtracted from non-cash fixed costs because it is covered by the principal portion of the capital cost loan payment (see Tables 4 and 6). Equivalently, annual total costs are the sum of variable costs ($21,877), cash fixed costs ($4,900), annual depreciation ($8,451), the annual opportunity cost of the owner's land ($625/yr), and annual debt service (interest paid on loans used to finance capital costs, variable costs and cash fixed costs) costs of $7,273/yr.

Annual total revenues of $61,944 less annual total costs of $43,125 leave annual returns to management of $18,819 on a before-tax basis (Table 6). This annual return amounts to a $188,187 nominal return over the 10-yr life of the project. Discounted at 5%, the 10-yr project has a net present value (NPV) of $145,313, an internal rate of return (IRR) of 37%, and a discounted payback period (DPP) of 3.2 yr. The break-even price is $7.02/kg ($3.13/lb) of harvested weight.

Sensitivity Analysis

Product price, electricity cost, and interest rates are typically volatile and beyond the control of the individual producer. Product price is influenced by changes in overall market demand and supply (including variation in wild catch), while electricity cost and interest rates are typically determined by economy-wide factors beyond the producer's control. Although changes in product price do not affect break-even price, product price changes do have a disproportionately large impact on annual returns; both a 25% reduction and increase in product price changes annual returns by approximately 82%. It is important to note that the facility would remain profitable at a product price up to 30% less (3.13/lb) than that assumed in the base case scenario. Changes in electricity cost or interest rates have moderate effects on financial performance: a 25% increase in electricity cost would reduce annual returns by 10%. If two percentage points are added to each interest rate (capital loan, operating loan, and the owner's discount rate), break-even price increases to $7.26/kg from the baseline level of $7.02/kg, and annual returns decrease by $1,507 (8%). If two percentage points are subtracted from each interest rate, break-even price falls to $6.78/kg, and annual returns increase by $1,453 (8%).

If the average initial weight of available fingerlings were to vary, but the cost per kg of fingerlings remains the same, a 25% reduction in initial weight increases break-even price by 4% and reduces annual returns to management by 19%. A 25% increase in initial weight decreases break-even price by 4% and increases annual returns by 24%. Therefore, changes in initial weight have a strong impact on financial performance by changing the grow-out time necessary to reach marketable size.

Financial performance is moderately affected by changes in feed costs. A 25% reduction in feed costs reduces break-even price to $6.79/kg from its baseline value of $7.02/kg and increases annual returns to management by $1,411 (8%).

Assuming that the price paid to the producer per kg of final weight is somewhat stable for a reasonable range of final weights around the baseline final weight of 1 kg used in the base case scenario, selling fish of smaller final weight moderately improves financial performance (Table 6). A 25% reduction in final weight to 0.75 kg (1.68 lb) per fish increases break-even price to $7.08/kg. Although returns to management fall by $2,952 per cycle, the number of cycles increases from 1.7 to 2.64 per yr, increasing annual returns by $2,681 (14%). The results in Table 6 indicate that a 25% improvement (reduction) in the FCR would have a moderate impact on financial performance, reducing the break-even price to $6.78/kg from $7.02/kg, and increasing annual returns by $1,448 (8%). A 25% improvement (increase) in the average daily growth rate has a large impact on financial performance, reducing the break-even price to $6.35/kg and increasing annual returns by $9,313 (50%). Indeed, just a 10% improvement in average daily growth rate would increase annual returns by $3,740 (20%).

Discussion

These results present financial performance including breakeven price, average annual returns to management, net present value (NPV), internal rate of return (IRR) and discounted payback period (DPP) of a black sea bass mariculture RAS facility located on the east coast of the United States. For the baseline scenario, breakeven price is $7.02/kg ($3.13/lb) of harvested weight, while recent field marketing trials have achieved prices of $13.20/kg ($6.00/lb). This annual return amounts to a $188,187 nominal return over the 10-yr life of the project. Discounted at 5%, the 10-yr project has a net present value (NPV) of $145,313, an internal rate of return (IRR) of 37%, and a discounted payback period (DPP) of 3.2 yr.

Depreciation (annualized cost of initial construction and equipment cost) is the largest component (19.6%) of annual cost. Fingerling costs are the next-largest components at 17.4%. Interest costs and electricity are the next-largest cost components at 16.9 and 16.6%, (Table 4) respectively. Fingerling cost may be reduced through better negotiation with fishermen suppliers, by buying in larger volume, or by developing hatchery facilities. Debt service costs could be lowered by using personal savings, or finding investors. Costs would decrease according to the difference between the interest rates charged by lenders and the facility owner's or investors' interest rate on their next-best investment. Feed costs account for 12.3% of annual costs (Table 4). The high cost of feed is due to the high protein content (50%) (Copeland et al 2002). A dietary protein content of 42% produced growth rates comparable to those achieved with a 50% protein diet and would reduce feed cost by approximately 20%.

While the cost of land will likely rise in the future, the costs of mariculture equipment and fingerlings may decline as the industry grows and suppliers achieve economies of scale in production. The small footprint of RAS facilities mitigates the impact of land costs on production—indeed, the base case facility requires only 0.10 ha of land. As recent experience has shown, interest rates and energy costs can vary greatly from year to year and are notoriously difficult to predict. However, sensitivity analysis results indicate that variations in these volatile production parameters have relatively small impacts on the financial performance of the black sea bass RAS facility.

Sensitivity analysis results point to product sales price, survival, and average daily growth rate as the most important determinants of financial performance. Field marketing trials indicate that product sales price can fluctuate greatly. It is assumed in this study that the product is sold to a live-hauler "middle-man" who transports the fish to market. By selling directly to the final consumer and eliminating the live-hauler, known as "direct sourcing" (Lockwood 1999), the owner could capture a larger share of the final sales price. However, the owner would then bear increased transportation and customer administration costs.

The moderate impact of changes in final weight on financial performance indicates that producers should monitor carefully the relationship between final weight, price per kg, and annual returns. Recent black sea bass test marketing trials in Philadelphia revealed a market preference for smaller black sea bass (1.5 lb or less, unpublished data). Sensitivity analysis results indicate that a 25% reduction in the final weight per fish at sale increases the number of production cycles achievable per year and increases annual returns by 14%. By targeting markets with a demand for smaller fish, there is potential to increase profitability by reducing growout time and increasing the number of cycles per year.

Sensitivity analysis results indicate that average daily growth rate is a critical determinant of financial performance. While there is a considerable amount of information to indicate that subadult black sea bass can be grown quickly to market size in tank culture systems, optimal temperature and salinity regimes, nutritional requirements, and feeding regimens of black sea bass juveniles and subadults for nursery and growout production remain poorly defined, and there is considerable scope for improvement.

In North Carolina, where commercial landings since 1990 have fluctuated from 226,000 to 452,000 kg (0.5 to 1 million lb) annually, we estimate that roughly 60% (personal communication, Captain Carl Snow) comprise small fish that bring nominal prices to the fisherman.

Current harvest levels could therefore support an ongrowing industry, with little or no impact on the existing fishery. This activity could supplement wild populations by producing higher yields of marketable product and greater revenues per unit weight of fish harvested from the oceans.

Fingerling costs may be potentially reduced by producing fingerlings "in house," or if fingerlings are produced in specialized hatcheries that supply multiple growout operations. Reductions in fingerling cost have a moderate impact on break-even price and profitability (Table 6). For example, a 25% reduction in fingerling cost decreases the break-even price to \$6.69/kg and increases annual returns to management by \$1,996 (11%).

It is important to keep in mind that the financial performance results reported in this study reflect production conditions in eastern North Carolina circa 2002. The sensitivity analysis results presented here should help potential investors plan for regional differences and changes in market conditions.

Acknowledgments

We thank: Thomas Losordo and Patrick Carroll for engineering assistance; Kevin Patterson, Southeast Pond Stocking, Currie, North Carolina, USA, K. Scott Wheatley, J. Kevin Yates, and Carl and Missy Snow for technical assistance; Thomas Chau of Captain Thomas Co., Inc., Philadelphia, Pennsylvania, USA, Reiko Sugiura of Genki Japanese Restaurant, Wilmington, North Carolina, USA, Roy Castle, and Missy Snow for participating in the marketing trials; and Robert Wicklund, Tom Ellis, and Ron Hodson for helpful advice. This study was supported by the North Carolina Fishery Resource Grant Program (Grant #98-AM-19 and 00-AM-05) and the U.S. Department of Agriculture, Cooperative State Research Education and Extension Service (Grant #98-38854-6009 and 00-38854-9406).

Literature Cited

Berlinsky, D., M. Watson, G. Nardi, and T. M. Bradley. 2000. Investigations of selected parameters of growth of larval and juvenile black sea bass *Centropristis striata* L. Journal of the World Aquaculture Society 31:426–435.

Carroll, P. M., W. O. Watanabe, and T. M. Losordo. 2005. Pilot production of hatchery-reared summer flounder *Paralichthys dentatus* in a marine recirculating aquaculture system: the effects of ration level on growth, feed conversion, and survival. Journal of the World Aquaculture Society 36:120–128.

Copeland, K. A., W. O. Watanabe, and P. M. Carroll. 2002 Growth and feed utilization of captive wild subadult black sea bass *Centropristis striata* fed practical diets in a recirculating system. Journal of the World Aquaculture Society 33:97-109.

Copeland, K. A., W. O. Watanabe, P. M. Carroll, K. S. Wheatley, and T. M. Losordo. 2003 Growth and feed utilization of captive wild black sea bass *Centropristis striata* at four different densities in a recirculating tank system. Journal of the World Aquaculture Society 34(3):300–307.

Lockwood, G. S. 1999 Aquaculture driven seafood trends in the United States. Aquaculture Magazine March/April 1999.

Losordo, T. M., A. O. Hobbs, and D. P. DeLong. 2000. The design and operational characteristics of the CP&L/EPRI fish barn: a demonstration of recirculating aquaculture technology. Aquacultural Engineering 22 (1–2):3–16.

NMFS. 2003. Annual commercial landings statistics and marine recreational fisheries statistics survey query results. National Marine Fisheries Service, Silver Spring, Maryland, USA.