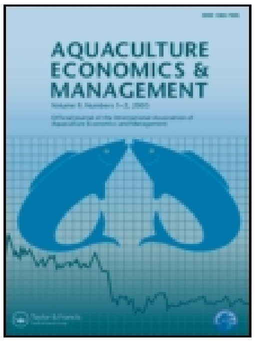

Aquaculture Economics & Management

ISSN: 1365-7305 (Print) 1551-8663 (Online) Journal homepage: https://www.tandfonline.com/loi/uaqm20

Production Economic Analysis of Black Sea Bass Juveniles to Support Finfish Mariculture Growout Industry Development in the Southeastern United States

Wade O. Watanabe, Christopher F. Dumas, Patrick M. Carroll & Christopher M. Resimius

Aquaculture Economics & Management, 19:226–250, 2015

ISSN: 1365-7305 print/1551-8663 online
DOI: 10.1080/13657305.2015.1024347

PRODUCTION ECONOMIC ANALYSIS OF BLACK SEA BASS JUVENILES TO SUPPORT FINFISH MARICULTURE GROWOUT INDUSTRY DEVELOPMENT IN THE SOUTHEASTERN UNITED STATES

Wade O. Watanabe,[1] Christopher F. Dumas,[2] Patrick M. Carroll,[1] and Christopher M. Resimius[1]

[1]*Center for Marine Science, University of North Carolina Wilmington, Wilmington, North Carolina, USA*

[2]*Department of Economics and Finance, University of North Carolina Wilmington, Wilmington, North Carolina, USA*

□ *A pilot-scale finfish mariculture hatchery was established at the University of North Carolina Wilmington. In 2011, research-based hatchery protocols were scaled up to produce 37,000 advanced (1–5 g) black sea bass fingerlings. Based on engineering, biological, and cost data from operating the pilot hatchery, an economic analysis of a hypothetical commercial scale black sea bass hatchery operation was conducted. The financial performance of two alternative facilities that produce 97,200 5-g and 388,800 1-g fingerlings per year over a 30-year project life showed cumulative net present value (NPV) of $445,000, and $3,168,000, modified internal rates of return (MIRR) of 6.52% and 10.52%, and per unit breakeven prices of $1.67 and $0.47, respectively. Sensitivity analyses showed that final stocking density was critical to financial performance. Fingerlings were supplied to startup growers in NC and in VA, and market-size fish from these growout facilities were distributed (live or whole on ice) to premium-value markets on the eastern seaboard. This pilot hatchery is enabling new farmers to access fingerlings, establish growout technology and understand market value and demand.*

Keywords black sea bass fingerlings, marine finfish hatchery, production economic analysis

INTRODUCTION

Black sea bass *Centropristis striata* is a high-value marine finfish that inhabits continental shelf waters from Maine to the Florida Keys and is a member of the family Serranidae comprising true sea basses and groupers. Previous studies identified two distinct stocks of black sea bass (McCartney

Address correspondence to Christopher F. Dumas, Department of Economics and Finance, University of North Carolina Wilmington, 601 South College Rd., Wilmington, NC 28403-5945, USA. E-mail: dumasc@uncw.edu

et al., 2013); the Mid-Atlantic stock located North of Cape Hatteras has been listed for some time as not overfished, while the South-Atlantic stock located to the South of Cape Hatteras has been heavily exploited and has been under a federally-managed rebuilding plan since 2006.

The abundance of black sea bass along the US East Coast has been declining since the 1950's. Commercial landings north of Cape Hatteras, North Carolina peaked at 10,000 mt (valued at US $2.2 million ex-vessel) in 1952 (Shepherd, 2006), but declined to 591 mt by 1971 and have since fluctuated between 1,954 mt and 909 mt. The current managed quota is around 1,636 mt valued at $8.8 million ex-vessel (ASMFC "Fisheries Focus" 2009; Shepherd, 2006). In North Carolina, commercial landings from 1972–1990 averaged 467 mt ($713,675), peaking at 599 mt in 1974. From 1991–2012, commercial landings averaged 286 mt ($1,075,487), falling to a low of 216 mt ($687,905) in 2012 (NCDMF, 2013).

Stringent quotas on harvests of wild populations and the potential for limited future market supplies and higher prices of ocean-caught black sea bass are important economic incentives to investigating the feasibility of black sea bass production via aquaculture to help meet market demand. Techniques for spawning adult black sea bass in captivity (Berlinsky et al., 2005; Watanabe et al., 2003), raising larvae through juvenile stages in a hatchery (Berlinksy et al., 2000, Carrier et al., 2011; Copeland & Watanabe, 2006, Rezek et al., 2010), and for growing juvenile fish to market sizes (Copeland et al., 2003, 2005, Watanabe, 2011) have been developed in the eastern United States for black sea bass, and there is now sufficient developed technology to support commercial-scale hatchery operations.

Based on research funded in North Carolina by federal and state agencies and a private-public business development organization, premium market size black sea bass are now being produced in marine recirculating aquaculture systems at UNCW's Aquaculture Facility (Wrightsville Beach) as well as at a startup farm in Virginia. This has enabled the distribution of ultra-fresh cultured black sea bass to niche ("upscale") restaurants serving seafood throughout the state of NC as well as to U.S. metropolitan markets (NY City, Philadelphia, Miami and San Francisco) (Dumas & Wilde, 2009; Wilde et al., 2008) to evaluate market potential. These studies have demonstrated a significant demand for farm-raised black sea bass in upscale niche markets at prices that may be profitable to startup growers.

A critical variable cost in the development of a commercial black sea bass aquaculture industry is the price of fingerlings that can be grown out to a marketable size using recirculating aquaculture system (RAS) technology (Copeland et al., 2005; Ibarra-Castro et al., 2013; Kam et al., 2002; Lee et al., 1997). The goals of this project were to support the development of the finfish mariculture industry in the southeastern United States by establishing a pilot marine fish hatchery at UNCW that will supply fingerlings to start-up commercial operations and to develop an economic model of black sea bass fingerling production based on laboratory research as well as on engineering and biological parameters derived from operation of the pilot hatchery. Specific objectives were as follows: (1) Establish a pilot commercial scale marine finfish hatchery facility, and scale-up research-based hatchery methods developed for black sea bass; (2) Conduct an economic analysis of black sea bass fingerling production using empirical data from these pilot trials; and (3) Supply fingerlings produced in this hatchery to commercial mariculture companies for their pilot growout project.

METHODS

Description of the Pilot-Scale Marine Finfish Hatchery at UNCW

The University of North Carolina Wilmington Aquaculture Facility is situated on a 0.456 ha (1.2 acre) site on Harbor Island (Wrightsville Beach, NC, USA). The facility has direct access to high-quality 32–34 ppt seawater from Bank's Channel, a protected channel that is continually flushed from a natural ocean inlet.

Controlled Environment Broodtank System

Controlled environment recirculating broodtank systems for black sea bass include twelve outdoor, circular fiberglass tanks (dia. = 1.85 m; depth = 1 m; vol. = 2.6-m^3) supported by a water recirculating system and heat pump for temperature control. Timer-controlled lighting and heat pumps were used to manipulate photoperiod and temperature to simulate artificial seasons to control rates of gonadal maturation and timing of spawning. The recirculation system consisted of a 0.28-m^3 propeller-washed bead filter (Aquaculture Systems Technologies, New Orleans, LA, USA), 195-W UV sterilizer (Emperor Aquatics, Inc., Pottstown, PA, USA), 3-hp centrifugal pump, foam fractionator, and a 3-hp heat pump (Aqua Logic, Inc., San Diego, CA, USA). Each tank was provided with a conical fiberglass cover fitted with a timer-controlled fluorescent fixture to control photoperiod.

Broodstock black sea bass (range = 296–620 g, $N = 200$) were maintained at the UNCW Aquaculture Facility under controlled day length and temperature conditions. Fish were held at a density of approximately 10–20 fish per tank. Broodstock were maintained at 34 ppt under an ambient photoperiod regime and a temperature range of 14–27°C for approximately 10 months until April 11, 2011, when spawning trials began. Photothermal conditions were then held constant at 13 hours light: 11 hours dark and 19°C until spawning ended in mid June 2011. Fish were fed three times per week to satiation commercially-prepared diets containing 48% protein and 20% lipid supplemented with Atlantic silversides *Menidia menidia*.

Hatchery System: Egg Incubation, Live Feeds Production and Larval Rearing

A climate-controlled indoor hatchery facility provided approximately 93 m^2 of floor space for egg incubation, live feed production and larval rearing. The egg incubation system consisted of two 300-L cylindroconical tanks supported by a recirculating seawater system. Live feeds system consisted of two 150-L continuous culture rotifer production systems (Bentley et al., 2008) and two 150-L enrichment tanks. The indoor hatchery facility provided approximately 6,100 L of larval rearing tank (LRT) capacity, consisting of six 350-L tanks (0.86 m dia. × 0.61 cm depth) and two 2,000-L LRTs (1.83 m dia. × 0.76 m depth).

Pilot Nursery System

The pilot nursery system was assembled in the understory of an aquaculture research laboratory, a modular structure that provided 184 m^2 (9.75 × 18.9 m) of space. The pilot nursery system consisted of three rows of insulated fish nursery tanks, one row of four small 950-L (1.22 m dia. × 0.94 m depth) tanks, one row of six medium 2,100-L (0.183 m dia. × 0.94 m depth) tanks, and one row of four large 4,980-L (2.44 m dia. × 1.25 m depth) tanks. The pilot nursery facility has a total volume of 36,320-L. The pilot nursery system was designed to raise early metamorphic stage marine fish larvae (approximately 30–50 d post-hatching) (~0.1–0.5 g) (Copeland & Watanabe, 2006) to advanced juvenile (fingerling) stages (1–5 g), approximately 90 d post-hatching, suitable for stocking into growout facilities.

Two independent recirculation systems (RAS) were installed on the north side of the modular building. One RAS supported the row of large (4,980-L) tanks, while the second supported the two rows of medium (2,100-L) and small (950-L) tanks. Both RAS consisted of a centrifugal pump, a 0.071-m^3 bubble bead filter (Aquaculture Systems Technologies) for solids removal and biological filtration, a 160-W UV-sterilizer (Rainbow Lifegard, Cerritos, CA, USA) for water disinfection, and a 3-hp heat pump (Aqua Logic, Inc.) for temperature control. One 1-hp blower provided aeration to the rearing tanks and to the biofilter. An environmental monitoring system (Sensaphone, Aston, PA, USA) monitored electrical power, water flow, oxygen levels and temperature in each RAS, with emergency dial out to staff in the event that preset parameter ranges were exceeded. Oxygen was supplied to both RAS from a 5.67-m^3 bulk storage tank in the event of power outage or pump failure.

Operation of the Pilot Hatchery Facility

Two spawning and larval rearing trials (Trials 1 and 2) were conducted in spring 2011. In April 2011, females were examined for stage of gonadal development. Fish were anesthetized (100 ppm tricaine methane sulfonate), weighed and their gonads were biopsied using a 1.57-mm o.d. × 1.14 mm i.d. polyethylene cannula. Ovarian samples were fixed in a solution of 10% formalin in seawater. Using a dissection microscope, the oocytes were photographed, and the mean vitellogenic oocyte diameter (M.O.D.) of at least 100 oocytes was measured by analyzing the digital photographs using ImageJ software. General stage of oocyte development (i.e., pre-vitellogenic, cortical vesicle, vitellogenic and atretic) was determined from microscopic appearance. Males were identified by the presence of running milt when pressure was applied to the gonadal area.

Trial 1

In Trial 1, two and three year old hatchery raised females with a M.O.D. > 380 µm were selected for induced spawning. On April 11, 2011, 10 mature females (mean wt. = 668 g) were induced to spawn using luteinizing hormone releasing hormone analog [D-Ala^6 Des-Gly^{10}]-LH-RH Ethylamide) (Sigma Chemical Co., St. Louis, MO, USA) (LHRH-a). To induce spawning, anesthetized females were implanted intramuscularly with a single 80% cholesterol-20% cellulose pellet containing (LHRH-a) at a nominal dose rate of 10 µg/kg body wt. Pellets were implanted at 1800 h into females with M.O.D. of 426 µm (range = 394-461 µm). Of the ten females implanted in Trial 1, seven (mean wt. = 710 g, M.O.D. = 430 µm) ovulated and were strip spawned on April 13, 2011, approximately 36 hours post-implantation. Sperm was collected from four males, and eggs and sperm were activated with seawater and then mixed for artificial fertilization. Floating (viable) and non-viable (sinking) eggs were transferred to graduated cylinders and quantified. Larvae were reared to the metamorphic stage (day 46 post-hatching = d46ph) using techniques established at UNCW (Watanabe, 2011; Watanabe et al., in press).

Trial 2

On June 6, 2011, 12 mature black sea bass females (mean wt. = 465 g, M.O.D. = 436 µm) were induced to spawn with a pellet implant containing LHRHa (10 µg/kg) (Trial 2). Pellets were implanted at 1800 h into females with a M.O.D. of 436 µm (range = 394–461 µm). Of 12 females implanted in Trial 2, seven (mean wt. = 453 g, M.O.D. = 451 µm) ovulated and were strip spawned on June 8, 2011, approximately 36 hours post-implantation. Sperm was collected from four males, eggs and sperm were activated with seawater and then mixed for artificial fertilization, and floating and sinking eggs were quantified. Larvae were reared to the metamorphic stage (d46ph) (Watanabe, 2011; Watanabe et al., in press).

Economic Analysis of Black Sea Bass Fingerling Production Using Data from Pilot Trials

Based on engineering, biological, and cost data from the construction and operation of the pilot hatchery facility, a production economics analysis (Copeland et al., 2005) was conducted for a hypothetical commercial scale black sea bass RAS hatchery operation. The baseline hatchery facility is located in coastal North Carolina on 0.202 ha (0.5 acre) of commercially-zoned land with salt water access. Based on estimates of potential, early-stage industry demand for fingerlings, a baseline hatchery capacity of 100,000 5-g fingerlings was considered. A 30-year project life was evaluated to allow adequate time for assessing a project with relatively large up-front capital costs and several cycles of RAS equipment replacement. RAS equipment is replaced every 10 years. All costs and prices are real (adjusted for inflation) rather than nominal (unadjusted). To reflect the most likely situation during the early stages of industry growth, it was assumed that the facility owner owns the land on which the facility is located, works as general manager of the facility, and receives all returns to management (profit).

Annual Operating Costs

Annual operating costs are those costs required to operate the facility after initial facility construction and RAS equipment installation. Operating costs are partitioned into those costs that vary with the quantity of fingerlings produced by the facility, variable operating costs, and those costs that do not vary with the quantity of fingerlings produced, fixed operating costs.

Fingerling Sales and Facility Revenue

It is assumed that fingerlings are sold to buyers who take possession of the product at the hatchery facility gate (i.e., farm gate). The sales price per fingerling is uncertain, but an estimate of $2.00 per fingerling is used in the baseline model, and other prices are considered via sensitivity analysis.

Financial Performance Measures

Financial performance of the base case facility was assessed by calculating cumulative net present value after 30 years (30 year CNPV), modified internal rate of return (MIRR), discounted payback period (DPP), and breakeven price (BE). CNPV is the value today of a future series of cash flows that accounts for discount rate, or the time value of money. MIRR is a generalization of the traditional internal rate of return (IRR) measure of investment performance. MIRR allows the reinvestment of positive cash flows to occur at a rate different from (usually lower than) the rate of return of the investment, producing a more conservative estimate of the rate of return.

Furthermore, unlike IRR, MIRR allows for cash flows that alternate between positive to negative more than once over the course of the project, a situation that occurs for some scenarios considered here. The DPP is the length of time required for an investment's discounted net cash flows to cover initial investment costs. BE is the product sales price that results in a CNPV of zero for a given discount rate; BE can be compared to current market price as an additional means of assessing economic feasibility. Annual cash flows for each year of the 30-year project and a summary of financial performance measures are compared for two financing options; the owner-financed option, which assumes that the owner uses his personal funds to finance the initial investment costs, and the bank-financed option, which assumes that the owner must obtain a bank loan to finance initial investment costs.

Sensitivity Analyses

Several sensitivity analyses were conducted to investigate the impacts of changes in the following key model parameters on the financial performance of the hatchery producing 5-g fingerlings: fingerling sales price, electricity price, interest rates, feed costs and nursery tank stocking density. Finally, the financial performance of two alternative facility scales was compared: the baseline facility that produces 5-g fingerlings and an alternative facility that produces smaller, 1-g fingerlings. In both cases, the facility is housed in a 780-m^2 building on 0.202 ha of land.

RESULTS AND DISCUSSION

Operation of the Pilot Hatchery Facility

Trial 1

In Trial 1, a total of 839,480 eggs (119,926 eggs/female, 168,909 eggs/kg body wt.) were produced, of which 446,820 were floating (63,831 eggs/female, 89,903 eggs/kg body wt.). Of the floating eggs, 51% (227,603, 32,514 eggs/female, 45,795 eggs/kg body wt.) were fertilized. On April 14, 2011, a total of 108,000 late stage embryos were stocked into six 300-L larval rearing tanks at a density of 60/L and were hatched later the same day (day 0 post-hatching = d0ph). Larvae were reared to the metamorphic stages (d46ph), producing 26,895 metamorphic stage fry (mean wt. = 0.64 g) on d41ph, representing a survival rate of 24.7% from stocking (d0ph).

Beginning on d41ph and continuing through d46ph, 26,634 metamorphic stage fry (mean wt. = 0.120 g) were transferred to six 1.85-m diam. (2,100-L) nursery tanks (4,442 per tank, 2.8 fish/L). In nursery tanks, fish were fed commercially prepared diets (Skretting, Tooele, UT, USA), including Gemma Diamond (1.5 mm, 57% protein, 15% lipid) and then transitioning to Europa (3 mm, 55% protein, 15% lipid). On d62ph, approximately 26,000 black sea bass fingerlings reached a mean weight of 0.59 g for a survival rate of 97.6%. On September 30, 2011 (169-dph), fish from Trial 1 reached a mean weight of 13.9 g. Fingerlings quality as assessed by physical appearance and resistance to handling stress was excellent.

Trial 2

In Trial 2, a total of 568,680 eggs (81,240 eggs/female, 179,337 eggs/kg body wt.) were produced, of which 541,600 were floating (77,371 eggs/female, 170,797 eggs/kg body wt.). Of the floating eggs, 65% were fertilized, producing 352,040 fertilized eggs (50,291 eggs/female, 111,019 eggs/kg body wt). On June 10, 2011, a total of 108,000 late stage embryos were stocked into six 300-L larval rearing tanks at a density of 60/L and were hatched later the same day (d0ph). Larvae were reared to the metamorphic stages (Watanabe, 2011, Watanabe et al., in press), producing 11,479 metamorphic stage fry (mean wt. = 0.64 g) on d54ph, representing a survival rate of 11% from stocking (d0ph).

On d54ph, fry were transferred to five 1.85-m diam. (2,100-L) nursery tanks (2,296 per tank, 1.09 fish/L). In nursery tanks, fish were fed commercially-prepared diets, including Gemma Diamond and then transitioning to Europa. On January 24, 2012 (d229ph), juveniles reached a mean weight of 30 g. Fingerling quality as assessed by physical appearance and resistance to handling stress was excellent.

Economic Analysis of Black Sea Bass Fingerling Production Using Data from Pilot Trials

Facility Site

The land has a relatively high market value of $309,405/ha due to its proximity to the coast (E. Graham, UNCW Dept. of Economics and Finance, 2009, personal communication); hence, the 0.202 ha of facility land has a market value of $62,500. Because it is assumed that the owner owns the land, the cost of land is an opportunity cost; i.e, the cost of a foregone opportunity to earn interest income on the value of the land. In the present case, if the facility owner were to sell this land for $62,500 and invest the proceeds in his best alternative investment paying an (assumed) average annual 5% return, the owner would earn $3,125/year ($260/month) in interest income. If the land is used instead for a hatchery facility, the owner forgoes the opportunity to earn this interest income. The lost interest income is considered the (opportunity) cost of using the land to support hatchery operations.

Facility Structures

The facility site supports a single 36.6 m × 21.3 m (780 m^2), rectangular, insulated metal building with concrete floor, 4.27-m ceiling, one large (3.66-m wide × 4.27-m high) exterior access door, two additional standard-sized external doors, electrical, plumbing and HVAC (for ambient air temperature control) (Figure 1). The building is constructed over 12 months at a cost of \$807 per m^2 (E. Graham, UNCW Dept. of Economics and Finance, 2010, personal communication), or \$630,000. The building occupies 780 m^2 of the 2,023-m^2 facility site. The remainder of the site supports feed bins, a waste treatment area, parking and zoning setbacks. The interior of the building is partitioned into a broodstock tank room, a live feed culture room, an egg incubation room, a larviculture room with larval rearing tanks (LRTs), a nursery tank area, a laboratory/office room and restrooms (Figure 1).

Broodstock System

The broodstock system (Figure 1) for the baseline facility consists of four 2.44-m diam. (4,982-L) fiberglass tanks with a 1.07-m water depth and the following RAS equipment: one 2-hp water pump, one bead filter, a UV sterilizer, foam fractionator, filter sump and a 3-hp heat pump to maintain water temperature. The tanks and RAS equipment support a standing stock of 48 male and 48 female adult black sea bass. Each male fish weighs approximately 0.907 kg, and each female weighs approximately 0.454 kg. The stocking density is 0.0131 kg/L. Broodstock system total investment costs are \$32,348 (Table 1).

The broodstock are divided into two equal groups, and each group is spawned once per year. The first group is spawned on approximately April 1, and the second group is spawned on approximately June 1. Each spawning female produces 13,500 yolksac larvae per spawn, for a total of

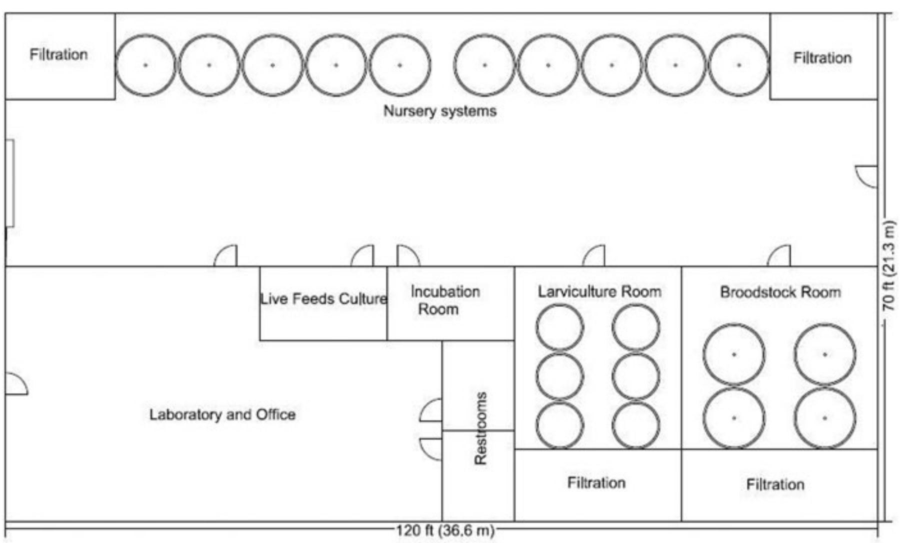

FIGURE 1 Plan view of a commercial scale recirculating hatchery for production of black sea bass fingerlings.

TABLE 1 Broodstock System Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Tanks (2.44 m fiberglass, 1.07 m water depth, 4,982 L)	tank	2,400	4	9,600
Pump (2-hp)	pump	600	1	600
Heat pump (3-hp)	pump	6,215	1	6,215
Bead filter	unit	7,745	1	7,745
UV sterilizer and bulbs	unit	3,394	1	3,394
Filter sump	unit	700	1	700
Foam fractionator	unit	3,134	1	3,134
Female broodstock fish (0.454 kg each)	fish	10	48	480
Male broodstock fish (0.907 kg each)	fish	10	48	480
Subtotal broodstock system				$32,348

324,000 yolksac larvae produced by 24 females per spawn, with two spawning events per year.

Egg Incubation System

The egg incubation system consists of two, 322-L plastic egg incubation tanks with a 1/15-hp water pump, sump and 1/3-hp heat pump. The total investment cost of the egg incubation system is $2,156 (Table 2).

Larval Rearing Tank (LRT) System

The larval rearing tank (LRT) system consists of six, 2,002-L fiberglass tanks (1.83-m diam. × 0.81 m water depth) and the following RAS equipment: three ½-hp water pumps, foam fractionator, bubble bead filter, UV sterilizer, sump, 2-hp heat pump to maintain water temperature, automatic feeders and feeder controllers. The LRTs accommodate two cohorts (spawns) per year. For each cohort, yolksac larvae are transferred from the egg incubation system to the LRTs at 1 day post-hatching (dph) and grow to approximately 1 g at 51 dph. Each of the six LRTs accepts an initial 54,000 yolksac larvae per cohort at a stocking density of less than 30 larvae/L. With a baseline survival of 15% from 1 dph to 51 dph, each cohort produces a total of 48,600 1-g fingerlings output for all six LRTs together. LRT system total investment costs are $15,218 (Table 3).

TABLE 2 Egg Incubation System Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Egg incubation tanks (322-L) with stands	unit	440	2	880
Pump (1/15-hp)	unit	203	1	203
Sump tank	unit	78	1	78
Heat pump (1/3-hp)	unit	995	1	995
Subtotal egg incubation				$2,156

TABLE 3 Larval Rearing Tank (LRT) System Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Tanks (fiberglass, 1.83-m diam. × 0.81-m water depth, 2,002-L)	tank	810	6	4,860
Pump (1/2-hp)	pump	500	3	1,500
Foam fractionator	unit	800	1	800
Bubble bead filter	unit	2,000	1	2,000
Sump	unit	500	1	500
Heat pump (2-hp)	pump	3,500	1	3,500
UV sterilizer and bulbs	unit	1,064	1	1,064
Automatic feeders, small	unit	70	6	420
Feeder adaptors	unit	34	6	204
Feeder controller	unit	370	1	370
Subtotal LRT system				$15,218

Rotifer System

The rotifer culture system consists of four 201-L polyethylene culture tanks, enrichment tanks and sump, and a seawater storage tank. The rotifer system has a total investment cost of $2,650 (Table 4).

Nursery Tank (NT) System

The nursery system is partitioned into two identical but independent tank systems (Figure 1). Each of the two nursery systems consists of five 5,224-L (2.44-m diam. × 1.12-m deep) fiberglass tanks and the following RAS equipment: a 2-hp water pump, foam fractionator, bead filter, UV sterilizer, sump, automatic feeders and feeder controllers, and a 3-hp heat pump to maintain water temperature. The nursery tanks support 2 cohorts per year at a nominal density of 1.5 5-g fish/L. For each cohort, 1-g fingerlings are transferred from the LRTs to the nursery tanks at 51 dph. Fish grow to approximately 5 g each at 101 dph. Each nursery tank is stocked with 8,100 1-g fingerlings at 51 dph, and 7,695 fingerlings survive to reach 5-g by 101 dph for a survival rate of 95%. For all nursery tanks, 46,170 5-g fingerlings are produced per cohort, or 92,340 fingerlings per year, close to the 100,000 fingerlings per year production target. Investment costs for the nursery system total $55,242 (Table 5).

TABLE 4 Rotifer System Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Culture Tanks, Polyethylene (201-L)	tank	300	4	1,200
Enrichment Tanks and Sump	unit	575	1	575
Seawater Storage Tank (1,893-L)	tank	550	1	550
Wood Frame, Fittings, Valves, Tubing	unit	325	1	325
Subtotal rotifers				$2,650

TABLE 5 Nursery Tank (NT) System Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Tanks (fiberglass, 2.44-m diam.* 1.12-m water depth, 5,224-L each)	tank	2,400	10	24,000
Pump (2-hp)	unit	585	2	1,170
Foam fractionator	unit	3,034	2	6,068
Bead filter	unit	2,600	2	5,200
Sump	unit	400	2	800
Heat pump (3-hp)	unit	6,410	2	12,820
UV sterilizer and bulbs	unit	1,252	2	2,504
Automatic feeders, large	unit	160	10	1,600
Feeder adaptors	unit	34	10	340
Feeder controller	unit	370	2	740
Subtotal nursery				$55,242

Other Hatchery-Wide Equipment

The facility has direct access to seawater. A 2-hp pump is used to pump seawater through a sand filter and a UV sterilizer to two reservoir tanks (primary and back-up) on site. The facility has a backup generator to maintain a reliable power supply. Regenerative blowers, a liquid oxygen delivery system, and an oxygen monitoring system maintain oxygen levels in the tanks, while an emergency sensaphone system automatically phones management in the event of power disruption, pump failure, or a low oxygen event. Due to the water reclamation features of the RAS equipment and the relatively small standing-stock biomass of a hatchery facility (in comparison with a grow-out facility), the amount of liquid waste effluent is sufficiently small to avoid waste disposal permit requirements. Geotube dewatering technology (TenCate, Pendergrass, GA, USA) is used to dewater and collect solid wastes for disposal in a landfill. The Geotube is located on a concrete pad outside and adjacent to the hatchery building. Office and laboratory equipment is provided in office/lab room of the facility building. The total investment cost for this hatchery-wide equipment is $40,913 (Table 6).

Total Initial Investment Cost and Financing Terms

Total initial investment costs of facility construction and RAS equipment installation are $778,527. The interest rate on the facility's initial construction and equipment loan with a 10-year term (repayment period) is 6.5%.

Annual Operating Costs

Variable Operating Costs

Variable operating costs include: broodstock feed, feed for fingerlings in the LTRs, feed for fingerlings in the nursery tanks, algae paste necessary

TABLE 6 Other Hatchery-Wide Investment/Equipment Costs

Item	Unit	Price ($)/unit	# Units	$ Cost
Seawater Source Pump (2-hp)	unit	600	1	600
Seawater Reservoir Tanks (1893-L)	unit	550	2	1,100
Sand Filter (for makeup water)	unit	806	1	806
Sand media for sand filter	100 lbs	116	1	116
UV Sterilizer (for make-up water)	unit	1,040	1	1,040
PVC Pipe and Valves	unit	10,000	1	10,000
Electricity Backup Generator	unit	5,000	1	5,000
Oxygen Monitor	unit	5,000	1	5,000
Sensaphone Monitoring	unit	491	1	491
Regenerative Blowers	unit	675	2	1,350
Lab Equipment	unit	2,451	1	2,451
Office Equipment	unit	1,250	1	1,250
Misc. Equipment	unit	4,297	1	4,297
Equipment Set-Up Labor	unit	5,412	1	5,412
Sludge Bag Filter plumbing/pad equip	unit	2,000	1	2,000
Subtotal				$40,913

to grow rotifers (the live feed required by the fish larvae), hormones and other chemicals used to control broodstock spawning, bicarbonate used to control water alkalinity, electricity used to run pumps, lights, etc., liquid oxygen used to control the oxygen level in the water, freshwater supply (in addition to seawater supply), Geotube bags and chemical polymers, labor expenses, allowance for office overhead expenses, and interest on the line of credit bank loans used to pay operating costs between harvests. The facility's operating costs are financed through a revolving line of credit with a bank at an annual interest rate of 10%. Labor expenses include 2 part-time laborers at $11 per hour and one hired, full-time facility manager at $30,000 per year. Labor expenses include payroll taxes, and the facility pays no benefits to workers. Variable operating costs total $71,426 per year at full facility capacity under baseline conditions (Table 7).

Fixed Operating Costs

Fixed operating costs include: the owner's forgone interest income (opportunity cost) associated with using his/her land to support the hatchery facility, electricity demand charge (a fixed monthly charge imposed by the electric utility in addition to the per unit charge for electricity), insurance (property, liability and workers compensation), oxygen tank rental fee (in addition to the cost of the oxygen gas itself), property taxes on land and RAS equipment, a small allowance for miscellaneous fixed expenses, and interest on the line of credit bank loans used to pay operating costs between harvests. The facility's operating costs are financed through a revolving line of credit with a bank at an annual interest rate of 10%. Property taxes are included as a facility cost in the analysis. A

TABLE 7 Variable Operating Costs Per Year

Item	Unit	Price ($)/unit	# Units	$ Cost
Broodstock Feed [Pellet only (7 mo); 1/2 silversides and 1/2 pellet (5 mo)]				
Artificial Pellet Feed	kg	1.31	716	938
Frozen Silversides (includes shipping costs)	lb	1.80	544	979
Nursery diet (1-mm pellet)	kg	2.20	316	695
Algae Paste	1 L	53.89	56	3,018
Artemia, high quality	can	90	1	90
Artemia, low quality	can	25	7	175
Larval Feed	unit	1,883	1	1,883
Formalin (bulk, includes shipping)	gal	5	6	30
Hormones and Matrix Materials (per g costs)	g	56	1	56
MS-222	g	0.70	30	21
ClorAm-X	lb	7.94	31	246
Bicarbonate (20% by weight of feed used)	lb	0.19	563.8	107
Electricity (0.0125 kWh per gal-day)	kwh	0.0643	103,405	6,652
Oxygen Refill	refill	10.33	3	31
Managerial Labor (1 person)	month	2,513	12	30,156
Part-Time Labor (2 persons)	month	1,733	12	20,796
Office Overhead	month	100	12	1200
Freshwater	month	10	12	120
Sludge Bag Polymer (Hyper Floc Polymer CE1950 G)	year	$95.80	0.1017864	10
Sludge Bags (Geotube bags)	year	$500.00	1	500
Interest on Above Variable Operating Funds	month	$310.25	12	3,723
Subtotal, Variable Operating Costs				$71,426

combined city and county property tax rate of 0.823 per $100 of assessed real property value is used based on property tax rates in the Town of Wrightsville Beach, NC, USA, and New Hanover County, NC, USA. This rate is applied to the value of land, structures and RAS equipment. Fixed operating costs total $23,162 per year (Table 8).

TABLE 8 Fixed Operating Costs per Year

Item	Unit	Price ($)/unit	# Units	$ Cost
Opportunity Cost of using owner's land for aquaculture	month	260	12	3125
Insurance (property, liability, workers comp) (Farm Bureau)	month	500	12	6,000
Oxygen Tank Rental (2 tanks @ $3.68)	month	7.36	12	88
Electrical Demand Charge (Progress Energy)	month	400	12	4,800
Misc. Costs	month	100	12	1,200
Property Taxes on Land	month	43	12	514
Property Taxes on Brood/Hatch/Nursery Building & Equipment	month	532	12	6,390
Interest on Above Fixed Operating Funds	month	87	12	1,044
Subtotal, Fixed Operating Costs				$23,162

Fingerling Sales and Facility Revenue

No fingerlings are produced during initial facility construction (year 0). Beginning in year 1, the baseline facility produces a total of 92,340 5-g fingerlings per year (both cohorts combined). It is assumed that fingerlings are sold to buyers who take possession of the product at the hatchery facility gate. The hatchery owner could compare the profitability of farm gate delivery with the profitability of paying the transportation costs to deliver the product to the buyer's location; however, this comparison will not be pursued here because it is really a question of which party can access lower transportation costs rather than a question of facility production efficiency or cost. The sales price per 5-g fingerling is uncertain, but at $2.00 per fingerling, the facility has sales revenue of $184,680 per year (Table 9).

Financial Performance Measures

Owner Financed Construction

Table 9 presents annual cash flows for each year of the 30-year project and a summary of financial performance measures for the owner-financed option. The owner still chooses to make use of a revolving line of credit at a bank to finance operating costs. The RAS equipment (Broodstock, Egg Incubation System, Larval Rearing Tanks, Rotifer System, Nursery Tanks, and Other Hatchery-wide Equipment) depreciates and must be replaced (at the same inflation-adjusted cost of $148,527) every 10 years. With owner financing of initial construction costs, the discounted (at 5%) payback period occurs in year 14, the 30-year cumulative nominal returns are $1,608,332, the 30-year cumulative net present value (NPV) is $445,129,

TABLE 9 Annual Cash Flows and Financial Performance Measures, 5-g Fingerling Facility, 30-Year Project Life (Owner-Financed Construction Costs)

Year	Capital Costs	Operating Costs	Revenues
0	$778,527	$23,162	$0
1 to 10	$0	$94,588	$184,680
11	$148,527	$94,588	$184,680
12 to 20	$0	$94,588	$184,680
21	$148,527	$94,588	$184,680
22 to 30	$0	$94,588	$184,680
Summary Financial Performance Measures, 5-g Fingerling Facility (Owner-Financed Option)			
30-year cumulative nominal returns			$1,608,332
30-year cumulative Net Present Value (NPV)			$445,129
Modified Internal Rate of Return (MIRR)			6.52%
Breakeven price per 5-g fingerling produced[1]			$1.67

[1]Defined as the 5-g fingerling sales price that makes 30-year cumulative NPV equal to zero.

Facility is constructed in Year 0. Replacement RAS equipment is purchased in Year 11 and Year 21 (every 10 years).

the modified internal rate of return (MIRR) is 6.52%, and the farm gate breakeven price per 5-g fingerling sold is $1.67.

Bank-Financed Construction

The second financing option assumes that the owner must obtain a bank loan to finance initial investment costs. The interest rate on the construction loan is 6.5% with a 10-year repayment term. Table 10 presents annual cash flows for each year of the 30-year project and summary financial performance measures for the bank-financed option. The owner uses a revolving line of credit at a bank to finance operating costs. The structure/building portion of the loan is paid off in 10 years, so this portion of the loan payment disappears after year 10; however, the RAS equipment is replaced (at the same inflation-adjusted cost of $148,527) and refinanced every 10 years, so the RAS portion of the loan payment endures after year 10. As a result, the monthly loan payment is $8,840 in years 1 to 10, but falls to $1,686 in years 11+.

The construction loan is interest-only during construction (during year 0), and it is assumed that construction expenditures are distributed uniformly over time in year 0. With bank financing of initial construction costs, the discounted (at 5%) payback period occurs in year 15, the 30-year cumulative nominal returns are $1,186,627, the 30-year cumulative net present value (NPV) is $360,405, the modified internal rate of return (MIRR) is 9.18%, and the farm gate breakeven price per 5-g fingerling sold is $1.75. When initial investment costs are financed by a bank, returns are lower, the discounted payback period is one year longer, and the breakeven

TABLE 10 Annual Cash Flows and Financial Performance Measures, 5-g Fingerling Facility, 30-Year Project Life (Bank-Financed Construction Costs/Replaced RAS Equipment Only

Year	Loan Payments	Facility Operating Costs	Revenues
0	$27,411	$23,162	$0
1 to 10	$106,080	$94,588	$184,680
11 to 30	$20,238	$94,588	$184,680
Summary Financial Performance Measures, 5-g Fingerling Facility (Bank-Financed Option)			
30-year cumulative nominal returns[1]			$1,186,627
30-year cumulative Net Present Value (NPV)			$360,405
Modified Internal Rate of Return (MIRR)			9.18%
Breakeven price per 5-g fingerling produced[2]			$1.75

[1]The 30-year cumulative nominal returns and NPV are lower when initial investment costs are financed by a bank relative to owner self-finance because the bank loan interest rate is higher than owner's return on his/her next-best investment. Breakeven price is higher when initial investment costs are financed by the bank relative to owner self-finance because the bank loan interest rate is higher than the owner's return on his/her next-best investment.

[2]Defined as the 5-g fingerling sales price that makes 30-year cumulative NPV equal to zero.

Facility is constructed in Year 0. Building loan is paid off after 10 years. RAS equipment is re-purchased/replaced every 10 years, so loan payment for years 11+ reflects loan payment for repurchased.

price per fingerling is higher ($1.75) relative to owner self-finance ($1.67) because the interest rate charged by the bank is higher than owner's return on his/her next-best investment.

Sensitivity Analyses

Several sensitivity analyses were conducted for the 5-g fingerling facility to investigate the impacts of changes in key model parameters on financial performance. Financial performance is very sensitive to changes in fingerling price (Table 11). At the baseline fingerling price of $2.00 per fingerling, the 30-year cumulative NPV is $445,129. A decrease in fingerling price to $1.50 lowers the 30-year cumulative NPV to negative $264,618, while an increase in fingerling price to $2.50 increases 30-year cumulative NPV to $1.15 million. A change in fingerling price does not affect the breakeven price per fingerling because a change in fingerling price does not affect the cost of production.

Table 12 presents results for a sensitivity analysis of financial performance measures to changes in electricity price. Energy prices have been quite volatile over the last decade; however, relatively large changes in electricity prices have relatively moderate impacts on financial performance. At the baseline electricity price of $0.0643 per kWh (a typical price in eastern North Carolina in 2010–2011), the 30-year cumulative NPV is $445,129 and breakeven price is $1.67. A decrease in electricity price to $0.04/kWh slightly increases the 30-year cumulative NPV to $485,936 and barely lowers the breakeven price to $1.66, while an increase in electricity price to $0.10/kWh decreases 30-year cumulative NPV modestly to $385,315 and raises breakeven price slightly to $1.73.

Table 13 presents results for a sensitivity analysis of financial performance measures to changes in interest rates. Interest rates also have been quite volatile over the last decade. Due to the relatively capital-intensive nature of RAS facilities, financial performance is very sensitive to interest rates. At baseline interest rates, the 30-year cumulative NPV is $445,129, and breakeven price is $1.67. A 50% decrease in baseline interest rates

TABLE 11 Sensitivity Analysis of Financial Performance to Changes in Fingerling Price, 5-g Fingerling Facility

Fingerling Sales Price ($ per 5-g fingerling)	Revenue per Year	30-yr Cumulative Returns	30-yr Cumulative NPV Returns	Breakeven Price per 5-g Fingerling
$1.50	$138,510	$223,232	-$264,618	$1.670
$1.75	$161,595	$915,782	$90,255	$1.670
$2.00 (baseline)	$184,680	$1,608,332	$445,129	$1.670
$2.25	$207,765	$2,300,882	$800,002	$1.670
$2.50	$230,850	$2,993,432	$1,154,875	$1.670

TABLE 12 Sensitivity Analysis of Financial Performance to Changes in Electricity Price, 5-g Fingerling Facility

Electricity Price ($ per kWh)	Revenue per Year	30-yr Cumulative Returns	30-yr Cumulative NPV Returns	Breakeven Price per 5-g Fingerling
$0.04	$184,680	$1,687,969	$485,936	$1.660
$0.05	$184,680	$1,655,241	$469,166	$1.670
$0.0643 (baseline)	$184,680	$1,608,332	$445,129	$1.670
$0.08	$184,680	$1,557,058	$418,855	$1.705
$0.10	$184,680	$1,491,603	$385,315	$1.729

TABLE 13 Sensitivity Analysis of Financial Performance to Changes in Interest Rates, 5-g Fingerling Facility

Interest Rates	Revenue per Year	30-yr Cumulative Returns	30-yr Cumulative NPV Returns	Breakeven Price per 5-g Fingerling
0.5*Baseline	$184,680	$1,729,342	$970,319	$1.500
0.75*Baseline	$184,680	$1,668,972	$675,855	$1.590
Baseline	$184,680	$1,608,332	$445,129	$1.670
1.25*Baseline	$184,680	$1,547,426	$262,030	$1.789
1.5*Baseline	$184,680	$1,486,253	$114,886	$1.895

All interest rates in the model were adjusted simultaneously for each interest rate scenario. For example, in the "0.75*Baseline" interest rate scenario, all three interest rates in the model were multiplied simultaneously by 0.75.

(all three interest rates in the model were decreased by 50% simultaneously) more than doubles the 30-year cumulative NPV to $970,319 and reduces breakeven price to $1.50, while a 50% increase in baseline rates decreases the 30-year cumulative NPV by nearly 75% to $114,886 and increases breakeven price to $1.90. Although 50% changes in interest rates are somewhat rare events, such changes have occurred over the last 30 years, and with a 30-year project life it is appropriate to consider this type of financial uncertainty.

Table 14 presents results for a sensitivity analysis of financial performance measures to changes in fish feed costs. Changes in fish feed costs have moderate impacts on financial performance. At baseline fish feed

TABLE 14 Sensitivity Analysis of Financial Performance to Changes in Feed Costs, 5-g Fingerling Facility

Feed Costs	Revenue per Year	30-yr Cumulative Returns	30-yr Cumulative NPV Returns	Breakeven Price per 5-g Fingerling
0.5*Baseline	$184,680	$1,731,418	$508,200	$1.642
0.75*Baseline	$184,680	$1,669,875	$476,664	$1.665
Baseline	$184,680	$1,608,332	$445,129	$1.670
1.25*Baseline	$184,680	$1,546,790	$413,594	$1.709
1.5*Baseline	$184,680	$1,485,248	$382,058	$1.731

costs, the 30-year cumulative NPV is $445,129 and breakeven price is $1.67. A decrease in fish feed costs by 50% increases 30-year cumulative NPV moderately to $508,200 and lowers breakeven price to $1.64, while a 50% increase in fish feed costs decreases 30-year cumulative NPV to $382,058 and raises breakeven price to $1.73.

Financial Gains from Biological Research: Discovery of a Higher Safe Stocking Density

As a result of the biological research conducted as part of this study, it was discovered that a higher stocking density for the nursery tanks of two 5-g juveniles per L was possible (i.e., safe) rather than the more conservative, lower stocking density of 1.5, 5-g juveniles per L assumed in the baseline scenario. A sensitivity analysis was conducted to determine the effects of this increase in the allowable nursery tank stocking density on the financial performance of the hatchery producing 5-g fingerlings. With the higher stocking density, the number of 5-g fingerlings produced per year by the hatchery increases from 92,340 to 123,120, resulting in an increase in hatchery revenues from $184,680/year to $246,240/year.

To support the larger fingerling output, the number of broodstock fish must be increased from 96 to 128, and the number of broodstock tanks must be increased from 4 to 6, along with the necessary increase in RAS equipment to support the additional broodstock tanks. The amount of office and laboratory space in the facility building is decreased modestly to accommodate the additional broodstock tanks. It is not necessary to change the numbers of LRTs and nursery tanks. The required amounts of feed, electricity, etc., are adjusted to support greater fingerling production. Initial investment costs increase from $778,527 to $805,435, and operating costs increase from $94,588/year to $98,537/year. The increase in annual facility revenues outweighs the increase in costs, resulting in a substantial increase in financial performance.

With owner-financed construction, the discounted (at 5%) payback period occurs in year 7 (rather than year 14 for the baseline scenario), the 30-year cumulative nominal returns are $3.26 million (rather than $1.61 million), the 30-year cumulative net present value (NPV) is $1.28 million (rather than $445,000), MIRR is 8.27% (rather than 6.52%), and the farm gate breakeven price per 5-g fingerling sold is $1.33 (rather than $1.67). With bank-financed construction, the 30-year cumulative nominal returns are $2.82 million (compared to $1.20 million under the baseline scenario), the 30-year cumulative net present value (NPV) is $1.20 million (rather than $374,000), MIRR is 17.94% (rather than 9.18%), and the farm gate breakeven price per 5-g fingerling sold is $1.37 (rather than $1.73). These improvements in financial performance highlight the potential economic gains from biological research: discovery of higher safe stocking densities result in large potential economic gains.

These results also revealed that final safe stocking density of 5-g juveniles in nursery tanks is a much more pertinent parameter than survival per se in nursery tanks. There are two survival rates in the model, a larval tank survival rate (yolksac to 1 g, 1dph to 51dph) of 15%, and a nursery tank survival rate (1 g to 5 g, 51dph to101dph) of 95%. The stocking density constraints become binding only at the end of each growth stage. If larval tank survival were lower, more yolksac larvae could be added at very low cost to ensure the target production number and stocking density at the end of the larval tank stage. If nursery tank survival were lower, more 1 g fingerlings could be added at the beginning of the nursery tank stage; this would require increasing larval production capacity, but it would not require increasing the nursery tank production capacity. The larval rearing tanks actually operate somewhat below capacity in the model; larval production could be increased by just under 20% without purchasing more larval rearing equipment. Unless the nursery tank survival rate were much lower than the assumed rate, the costs of boosting 1-g fingerling production in the larval tanks to ensure that the nursery tanks hit their production targets would be negligible.

Production of 1-g vs. 5-g Fingerlings

The financial performance of two alternative facility scales was compared: the baseline facility (described above) that produces 5-g fingerlings and an alternative facility that produces 1-g fingerlings. Whereas 5-g fingerlings are approximately 101 days old, the 1-g black sea bass fingerlings are approximately 60–70 days old. Although much smaller, black sea bass juveniles at this early juvenile stage are nevertheless robust, able to withstand grading, and suitable for transport from a hatchery to a remote growout facility.

In both cases, the facility is housed in a 780 m^2 building on 0.202 ha of land. The two cases are different in terms of the types and quantity of RAS equipment installed and the facility operations. In the case of the 1-g fingerling facility, fingerlings would be sold as they leave the larval rearing tanks (LRTs) and would not require time in nursery tanks at the hatchery facility. The nursery tanks and related filtering equipment are removed from the facility plan. This creates space for doubling the number of broodstock tanks, egg incubation facilities, rotifer production equipment and LRTs. In addition, each LRT can now support four cohorts per year instead of only two, because the limiting factor of reconciling LRT and nursery tank transfer times has been removed. With these changes in facility equipment and operations, initial investment/construction costs increase from

$778,527/year for the baseline 5-g fingerling facility to $844,665/year for the 1-g fingerling facility, variable operating costs increase from $71,426/year to $89,852/year, and fixed operating costs increase from $23,162/year to $23,680/year.

However, the number of 1-g fingerlings produced per year increases from 97,200 to 388,800. The breakeven price per 1-g fingerling for the modeled facility is $0.47 each. The market price for 1-g fingerlings is from $0.75 to $2.00 each. Assuming a farm-gate sales price of $1.00 per 1-g fingerling, facility revenues would be $388,800/year. In terms of financial performance, the 30-year cumulative returns are $6,976,964, the 30-year cumulative NPV is $3,168,359, and the modified internal rate of return (MIRR) is 10.52% (Table 15). The financial performance of a 1-g fingerling production facility appears superior to the performance of a 5-g fingerling production facility. While, there may be more uncertainty regarding the extent of market demand for 1-g fingerlings relative to demand for large, 5-g fingerlings, buyers may prefer smaller fish due to lower cost and easier transportability to growout facilities.

Owner Needs to Purchase Land

In previous scenarios, it was assumed that the facility owner also owned the land on which the facility was constructed, such that the only cost of land was the opportunity cost of foregone interest earnings from the owner's best alternative investment, here assumed to pay 5% per year, or $3,125/year in foregone interest earnings on the $62,500 value of the land. Suppose instead that the owner does not own the land but must instead purchase it, either from his own savings, or via a bank loan. The need to purchase land has a negative, but modest effect on financial performance.

TABLE 15 Annual Cash Flows and Financial Performance Measures, 1-g Fingerling Facility, 30-Year Project Life (Owner-Financed Construction Costs)

Year	Capital Costs	Operating Costs	Revenues
0	$844,865	$23,681	$0
1 to 10	$0	$113,534	$388,800
11	$214,865	$113,534	$388,800
12 to 20	$0	$113,534	$388,800
21	$214,865	$113,534	$388,800
22 to 30	$0	$113,534	$388,800
Summary Financial Performance Measures, 1-g Fingerling Facility (Owner-Financed Option)			
30-year cumulative nominal returns			$6,976,964
30-year cumulative NPV			$3,168,359
Modified Internal Rate of Return (MIRR)			10.52%
Breakeven price per 1-g fingerling produced[1]			$0.470

[1]Defined as the 1-g fingerling sales price that makes 30-year cumulative NPV equal to zero.

In the case of 5-g fingerling production and owner self-financing, Cumulative NPV falls from $445,129 to $382,627, and MIRR falls from 6.52% to 6.27% when the owner must purchase land. In the case of 5-g fingerling production and bank-financing, the cumulative NPV falls from $360,405 to $292,444, and MIRR falls from 9.18% to 8.01%. In the case of 1-g fingerling production and owner self-financing, cumulative NPV falls from $3,168,359 to $3,097,716, and MIRR falls from 10.52% to 10.25%.

Outreach: Supply Fingerlings to Commercial Mariculture Companies for Pilot Growout Trials

In 2011, approximately 20,700 fingerlings (mean wt. = 13.9–48.0 g) reared in the pilot hatchery facility from Trials 1 and 2 were supplied to two commercial marine finfish producers in Quinby, on the eastern shore of VA, and in Wilmington, NC. At both sites, fish were raised to market sizes in 4.57–7.32-m dia. recirculating seawater tanks. The pilot hatchery facility built under support by this North Carolina Biotechnology Center (Regional Development Grant Program) project provides ample production capacity to supply 88,894 fingerlings per year, in two crops of 44,447 fingerlings each, sufficient to support a commercial demonstration farm producing 45,455 kg per year (66,667, 0.68-kg fish).

SUMMARY AND CONCLUSIONS

The construction and operation of a pilot hatchery facility at UNCW has enabled evaluation of the scale-up of laboratory culture methods for spawning black sea bass broodstock and rearing larvae to the juvenile stages at a pilot commercial scale. The use of photothermal conditioning and induced spawning methods to produce the requisite numbers of black sea bass embryos for pilot-scale production were confirmed. Survival rates of larvae to metamorphic stages during this process has been consistent with those achieved in laboratory studies at UNCW, and fingerling production output per unit volume has remained constant with increasing scale. Fingerling quality as judged by physical appearance and resistance to handling stress was excellent in both Trials 1 and 2.

Based on engineering, biological, and cost data from the pilot hatchery facility, an economics analysis of a hypothetical commercial scale black sea bass RAS hatchery operation was conducted using a computer spreadsheet model. Assuming a sales price of $2.00 per 5-g fingerling, the baseline model hatchery appears moderately profitable (NPV of $350,000-$450,000, MIRR of 6.5%–9.2%) under baseline conditions over the 30-year project lifetime, but the payback period is long by conventional standards and does not occur until year 14 or 15 for this capital-intensive project. Alternatively, if the facility were operated on a non-profit basis instead of a for-profit basis (including the addition of thirty percent paid benefits for public sector managers and workers), with a management goal of supplying fingerlings to NC fish farmers "at cost," fingerlings could be supplied at cost of $1.86 to $1.92, for a cost savings to NC farmers on the order of $0.08–$0.14 per fingerling, or 4 to 7% (depending on financing arrangements), compared to the cost of obtaining fingerlings from out-of-state hatcheries at a cost of $2.00 each.

Sensitivity analyses indicate that financial performance is strongly sensitive to fingerling price and interest rates, but only moderately-to-weakly sensitive to electricity price and feed costs. The impact of changes in fingerling growth rates on financial performance was not significant; as the short grow out times involved in reaching 1-g or 5-g size would not be appreciably affected by any realistic changes in growth rates. The impact of changes in fingerling survival rates on financial performance were not significant as the primary effect on costs would be small changes in the number of required broodstock fish, but broodstock fish are a very small component of total cost.

As a result of the biological research conducted as part of this study, it was discovered that a higher stocking density for the nursery tanks of two 5-g larvae per L was possible (i.e., safe) rather than the more conservative, lower stocking density of 1.5, 5-g larvae per L assumed in the baseline scenario. With the higher stocking density, sensitivity analyses reveal that the financial performance of the baseline 5-g fingerling hatchery facility improves dramatically, the 30-year cumulative NPV almost tripling, and the breakeven price per 5-g fingerling decreasing by 20 percent from $1.67 to $1.33. Final safe stocking density of 5-g juveniles in nursery tanks is, therefore, a key parameter (rather than survival rate in nursery tanks) to assess production capacity (and hence, financial performance) of a hatchery facility.

An alternative facility that produces 1-g fingerlings instead of the baseline 5-g fingerlings was found to produce a breakeven price of $0.47 each and produce greater financial returns (NPV of up to $3.2 million, MIRR of 10.5%) using the same land and building, but with an alternative RAS equipment configuration and operations schedule. These potentially larger gains must be weighed against greater uncertainty in market demand for 1-g fingerlings. However, given the potential for much greater financial returns, future research should further investigate the market and production methods for 1-g fingerlings.

By providing startup farmers with a source of fingerlings, the pilot hatchery at UNCW is enabling new farmers in the region to access small numbers of fingerlings at a reasonable (not-for-profit) cost, develop know-how for raising fish using intensive culture systems, and clearly understand the markets for their product, which is critical to developing sound business strategies for scale-up.

ACKNOWLEDGMENTS

We thank Deborah De and Randall Johnson for helpful advice, Dr. Edward Graham of the UNCW Department of Economics and Finance for expert advice on real estate values and interest rates, and the UNCW Aquaculture Program faculty and staff, including Dr. Md. Shah Alam, Troy C. Rezek, Amanda R. Myers, and Jennifer Gabel and graduate students Walker Wright-Moore, Daniel Russo, and Tyler Gibson for technical assistance.

FUNDING

We thank the North Carolina Biotechnology Center Regional Development Grant Program Grant No. 2009-RDG-4005 for funding support for this project and Marine Biotechnology in North Carolina (MARBIONC) for providing matching funding.

REFERENCES

Atlantic States Marine Fisheries Commission (ASMFC) Fisheries Focus (2009) Species profile: Black sea bass. Joint management yields rebuilt status for popular mid-Atlantic fish. *ASMFC Fisheries Focus* **18**(6), 4–8, August 2009, Washington, DC.

Bentley, C.D., P.M. Carroll, A.M. Riedel, & W.O. Watanabe (2008) Intensive rotifer production in a pilot-scale continuous culture recirculating system using condensed microalgae. *Journal of the World Aquaculture Society*, **39**, 625–635.

Berlinsky, D.L., V.W. King, & T.I.J. Smith (2005) The use of luteinizing hormone releasing hormone analogue for ovulation induction in black sea bass (*Centropristis striata*). *Aquaculture*, **250**, 813–822.

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

Carrier, J.K. III, W.O. Watanabe, M. Harel, T.C. Rezek, P.J. Seaton, & T.H. Shafer (2011) Effects of dietary arachidonic acid on larval performance, fatty acid profiles, stress resistance, and expression of Na^+/K^+ ATPase mRNA in black sea bass *Centropristis striata*. *Aquaculture*, **319**, 111–121.

Copeland, K.A. & W.O. Watanabe (2006) Light intensity effects on early life stages of black sea bass *Centropristis striata* (Linnaeus 1758). *Aquaculture Research*, **37**, 1458–1463.

Copeland, K.A., W.O. Watanabe, P.M. Carroll, K.S. Wheatley, & 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**, 300–307.

Copeland, K., W. Watanabe, & C.F. Dumas (2005) Economic evaluation of a small-scale recirculating system for ongrowing of captive wild black sea bass *Centropristis striata* in North Carolina. *Journal of the World Aquaculture Society*, **36**(4), 489–497.

Dumas, C.F. & J.D. Wilde (2009) Assessing metro niche market demand for North Carolina mariculture products. North Carolina Biotechnology Center Regional Development Grant Program. Grant No. 2008-RDG-4003 and North Carolina Sea Grant, North Carolina, USA.

Ibarra-Castro, L., F.J. Martinez Cordero, & L. Albarez-Lajonchere (2013) Financial analysis of pilot-scale egg production of spotted rose snapper, *Lutjanus guttatus*. *Aquaculture Economics & Management*, **17**(2), 171–183.

Kam, L.E., P. Leung, A.C. Ostrowski, & A. Molnar (2002) Economies of a Pacific threadfin *Polydactylus sexfilis* hatchery in Hawaii. *Journal of the World Aquaculture Society*, **33**, 410–424.

Lee, C.-S., P.S. Leung, & M.S. Su (1997) Bioeconomic evaluation of different fry production systems for mjilkfish (*Chanos chanos*). *Aquaculture*, **155**, 367–376.

McCartney M.A., M.L. Burton, & T.G. Lima (2013) Mitochondrial DNA differentiation between populations of black sea bass *Centropristis striata* across Cape Hatteras, North Carolina (USA). *Journal of Biogeography*, **40**, 1386–1398.

North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries (NCDMF) (2013) Stock status of important coastal fisheries in North Carolina, 2013. Retrieved from http://www.ncfisheries.net/stocks/index.html

Rezek, T.C., W.O. Watanabe, M. Harel, & P.J. Seaton (2010) The effects of dietary docosahexaenoic acid (22:6n-3) and arachidonic acid (20:4n-6) on growth, survival, stress resistance and fatty acid composition in black sea bass *Centropristis striata* (Linnaeus 1758) larvae. *Aquaculture Research*, **41**, 1302–1314.

Shepherd, G. (2006) Status of Fishery Resources off the Northeastern US NEFSC - Resource Evaluation and Assessment Division. Black sea bass (*Centropristis striata*). Retrieved from http://www.nefsc.noaa.gov/sos/spsyn/og/seabass/archives/16_BlackSeaBass_2006.pdf

Watanabe, W.O. (2011) Species profile: Black Sea Bass. Southern Regional Aquaculture Center. SRAC Publication No. 7207, October 2011. Texas A & M University, College Station, Texas, USA.

Watanabe, W.O., P.M. Carroll, T.C. Rezek, A.R. Myers, C.D. Bentley, & M.S. Alam (In press) *Production of Black Sea Bass Fingerlings: A Practical Hatchery Manual*. North Carolina Sea Grant, Publication No.: UNC-SG, Raleigh, NC, USA.

Watanabe, W.O., T.I.J. Smith, D.L. Berlinsky, C.A. Wooolridge, K.R. Stuart, K.A. Copeland, & M.R. Denson (2003) Volitional spawning of black sea bass *Centropristis striata* induced with pelleted Lutenizing Hormone Releasing Hormone Analogue. *Journal of the World Aquaculture Society*, **34**, 319–331.

Wilde, J.D. (2008) *Analyses of the Niche Restaurant Market For Farm-Raised Black Sea Bass Centropristis Striata in North Carolina*. MS Thesis. University of North Carolina Wilmington, Center for Marine Science, Wilmington, North Carolina, USA.