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ARTICLE

Comparative Cost Analysis of Hybrid Striped Bass Fingerling Production in Ponds and Tanks

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Abstract
Year-round production of hybrid striped bass (female white bass *Morone chrysops* × male striped bass *M. saxatilis*) fingerlings would allow food fish growers to sell their product throughout the year, which would improve the consistency of market supply and cash flow for the farm. However, pond production of fingerlings is seasonal and precludes year-round supply. Tank culture methods have been developed to produce hybrid striped bass fingerlings indoors throughout the year, but the associated costs have not been estimated or compared with pond production costs. Economic engineering techniques were used to estimate production costs for phase I hybrid striped bass fingerlings in ponds (0.4, 1.2, or 2.4 ha) and tanks (945, 2,457, or 5,670 L) for production scales of 50,000, 100,000, 250,000, 500,000, 1,000,000, or 2,000,000 fingerlings per year. The results demonstrated that there are economies of scale in terms of the volume of production and the size of the production unit. Overall, pond production per 1,000 fingerlings was substantially less expensive than tank production, even accounting for the increased number of annual production cycles in tanks. Production costs were sensitive to survival rates and can be reduced by 7–14% and 5–11% for each 5% improvement in survival in ponds and tanks, respectively. Substituting microcyst brine shrimp for rotifers *Artemia* spp. in the diet may have the potential to reduce the tank costs of producing hybrid striped bass depending on fingerling survival beyond 14 d posthatch. Additional research is needed to improve overall fingerling survival both during the early fry rearing stage and after training to dry feed.

Hybrid striped bass (i.e., sunshine bass: female white bass *Morone chrysops* × male striped bass *M. saxatilis*) production in the United States increased from US$28.2 million in 1998 to a plateau of $31.5 million in 2005 (USDA 2006; Carlberg et al. 2007). Growth of the industry in earlier years has been attributed to advancements in production technology (Ludwig 2004) and to market development. Additional advancements are needed to overcome current industry constraints and stimulate further growth and development.

One such constraint to further development of the hybrid striped bass industry is the seasonal nature of fingerling production. Climate conditions in the area where fingerlings are currently produced (Arkansas, Florida, North Carolina, and South Carolina) preclude year-round production even though spawning technologies now allow for fry production throughout the year (Ludwig 2006). Presently two crops of fingerlings are possible per year in ponds in the geographic area where most are produced. Year-round availability of hybrid striped bass fingerlings would allow hybrid striped bass growers to sell food fish year round. Spreading sales throughout the year would improve cash flow patterns, spread the risk of price fluctuations across the year, and would probably increase profits. The targeted

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market for hybrid striped bass fingerlings over the cooler months would be those with indoor tank systems that currently cannot find fingerlings year-round.

The technology to raise hybrid striped bass from fry through the first 14–21 d posthatch (dph) in indoor tanks has been developed (Denson and Smith 1997; Ludwig 2006) as have tank systems for larval fish production of a wide variety of species, such as grouper (Serranidae) (Tucker 2005), snappers (Lutjanidae) (Watanabe et al. 2005), lingcod *Ophiodon elongates* (Rust et al. 2005), and hybrid striped bass (Ludwig 1994a, 2003, 2005, 2006). Indoor tank systems to culture rotifers as first-feed sources for tank production indoors have also been developed (Pfeiffer and Ludwig 2007).

A number of studies have focused on feeds, feeding strategies, and stocking density for the early larval stages of hybrid striped bass production. Sunshine bass fry have been cultured successfully in tanks when fed with freshwater rotifers *Brachionus calyciflores* only (Ludwig 1994b), with a combination of freshwater rotifers and salmon starter feed (Ludwig 1994a), or a sequence of enriched rotifers, brine shrimp nauplii, and high-protein dry feed (Ludwig 2006). Ludwig and Lochmann (2000) used a drum filter to collect zooplankton with a 60-μm-mesh filter. Fry fed at 30 zooplankton/mL had the highest survival, but it averaged only 24%. Ludwig (2003) obtained greater total biomass and survival with similar growth by feeding three times a day. Ludwig and Lochmann (2007) compared stocking densities of larval sunshine bass in tanks, obtaining a maximum yield when fish were stocked at 87 larvae/L.

These tank culture methods offer the potential for year-round production. However, rotifer culture is difficult. It requires conditions that have a high level of control (Hoff and Snell 1997) and can be plagued with unexpected crashes (Snell 1991). This is particularly true for freshwater rotifers. Ludwig and Lochmann (2009) successfully raised sunshine bass fingerlings in tanks without using rotifers. Survival was 38% when fed microcyst *Artemia* nauplii compared with 94% when fed rotifers and only 4% when fed *Artemia* nauplii for 14 dph.

Little work has been done on the economics of hybrid striped bass production and the few studies reported in the literature have focused on food fish production. Dunning and Daniels (2001) developed enterprise budgets for hybrid striped bass food fish production. Gempesaw et al. (1992a) found that costs of food fish production in ponds were lower than those in tanks. In a second study, economies of scale were demonstrated in hybrid striped bass food fish production in ponds (Gempesaw et al. 1992a). Wui and Engle (2004) used a mixed-integer programming model to compare costs of food fish production when various alternative effluent treatment options were imposed on hybrid striped bass farms. Sydorovych and Daniels (2011) later extended the analysis with additional effluent treatment options. That model was later extended to estimate costs of hybrid striped bass production when access to black carp *Mylopharyngodon piceus* for parasite control was restricted (Wui and Engle 2007). D'Abramo et al. (2002, 2004) found that phase I hybrid striped bass can be raised in a single production as economically as in the more traditional three-phase system.

Budget spreadsheet simulation analyses have been used frequently in the aquaculture economics literature (Leung 1986). Early work with budgeting simulations focused on shrimp production (Adams et al. 1980; Griffin et al. 1981). More recent examples of budget-based analyses can be found in Zucker and Anderson (1999) for land-based summer flounder *Paralichtys dentatus*, Nelson et al. (2001) for aeration regimes in catfish cages, Ligeon et al. (2004) for hybrid catfish (female channel catfish *Ictalurus punctatus* × male blue catfish *I. furcatus*) production, D'Abramo et al. (2006) for a fingerling-to-stocker phase of production for channel catfish, and Neira et al. (2009) for tilapia *Oreochromis* spp. production in Kenya.

The cost of producing fish in recirculating systems is generally higher than the cost of producing the same size of fish in open ponds in the southern United States (Lutz 2000). However, the costs of tank and pond production of hybrid striped bass fingerlings have not been explicitly compared. The specific objective of this study was to estimate and compare the costs of producing hybrid striped bass fingerlings in open ponds and in recirculating tank systems indoors for a variety of production scales.

METHODS

The bioeconomic models were built to evaluate the cost effectiveness for an existing hatchery in the southern U.S. region for hybrid striped bass fingerlings of moving to year-round production of fingerlings. Thus, the pond activities modeled are those of a traditional hybrid striped bass hatchery. The production cycle for one pond is 45 d, the length of time required for fry to reach phase I size. If fingerlings are not sold immediately, they are seined from the ponds, graded, and then similar-sized fish are returned to ponds and held until sold. Other activities modeled included indoor tank production systems of various tank sizes as well as production cycles of 45 d during which time fry reach phase I size. The base model assumed one production cycle for each pond and tank size for each scale of production. Sensitivity analyses examined the effects on cost of increasing the number of production cycles for each pond and tank scenario. The growth rates assumed were based on observations reported from commercial farms for the pond scenarios and from reported literature for the tank scenarios.

An economic engineering approach that employed standard enterprise-budgeting techniques (Engle 2010) was used to develop estimates of annual costs for producing hybrid striped bass fingerlings in various sizes of ponds and tanks. The production scales that were analyzed produced the following numbers of hybrid striped bass fingerlings a year: 50,000, 100,000, 250,000, 500,000, 1,000,000, or 2,000,000. Pond sizes considered were 0.4, 1.2, or 2.4 ha in size, and tank sizes considered were 945, 2,457, or 5,670 L. While no published experimental studies have used 5,670-L tanks for larval fish production, such sizes of

TABLE 1. Number of ponds required for each production level and pond size scenario for pond production costs, together with the number of hybrid striped bass fingerlings produced. The left-hand column shows the targeted production level. (Given the particular survival rate and the varying pond sizes used in the industry, the actual number of fingerlings produced may differ slightly from the target. For example, to produce precisely 50,000 fingerlings would require a 0.386-ha pond, but with the standard pond size of 0.4 ha, 52,500 fingerlings would be produced.) The stocking rate was 370,500 fry/ha, and the assumed survival rate was 35%; na = not applicable.

	Pond size					
	0.4 ha		1.2 ha		2.4 ha	
Production level	Ponds	Fingerlings	Ponds	Fingerlings	Ponds	Fingerlings
50,000	1	52,500	na	na	na	na
100,000	2	105,000	1	157,500	na	na
250,000	5	262,500	2	315,000	1	315,000
500,000	10	525,000	4	630,000	2	630,000
1,000,000	20	1,050,000	7	1,102,500	4	1,260,000
2,000,000	39	2,047,500	13	2,047,500	7	2,205,000

tanks (and larger) are readily available on the commercial market and commonly used for food fish production (Losordo and Westerman 1994; Dunning et al. 1998). The larger tank size was included in the analysis to fully explore potential economies and diseconomies of scale in hybrid striped bass fingerling production in tanks.

This analysis focused strictly on the costs associated with the production of phase I (35–55 mm) hybrid striped bass fingerlings. Costs associated with fry production were not considered because the low number of hybrid striped bass hatcheries in the United States creates problems of confidentiality. Fry costs were assumed to be constant across scenarios. Estimating any potential differences in fry costs across the year was outside the scope of this analysis. The costs estimated were those just of the phase I production phase.

Total investment costs in land, ponds, and wells were estimated for the pond scenarios and for tanks, filters, and buildings required for tank systems. Values of long-term investment items were taken from the Wui and Engle (2004) survey of hybrid striped bass growers for pond systems. Long-term investment costs for the tank systems were based on the design and details described in Pfeiffer and Wills (2008). Vendors were contacted for costs of various components.

Equipment investment and depreciation schedules were developed for each of the 15 pond (Table 1) and 17 tank scenarios (Table 2). Equipment and buildings that probably would be used elsewhere on the farm were charged in proportion to their estimated use for the hybrid striped bass fingerling enterprise. Also, 50,000 hybrid striped bass fingerlings could be produced only in 0.4-ha ponds because the larger 1.2-ha and 2.4-ha ponds would produce substantially more fish than these target levels at the stocking rate used. Similarly, 3.2-ha ponds could not be used for the production of 100,000 hybrid striped bass fingerlings per year, and the 5,670-L tanks could not be used for

TABLE 2. Number of tanks required for each production level and pond size scenario for tank production costs, together with the number of hybrid striped bass fingerlings produced. The left-hand column shows the targeted production level. (Given the particular survival rate and the varying tank sizes used in the analysis, the actual number of fingerlings produced may differ slightly from the target. For example, to produce precisely 50,000 fingerlings in 945-L tanks would require 2.016 tanks rather than 3.) In the analysis, the targeted level was assumed to be the minimum market demand and the number of production units was set to always meet that demand. Thus, 3 tanks were used and 74,418 fingerlings were produced. The stocking rate was 75 larvae/L, and the assumed survival rate was 35%; na = not applicable.

	Tank size					
	945 L		2,457 L		5,670 L	
Production level	Tanks	Fingerlings	Tanks	Fingerlings	Tanks	Fingerlings
50,000	3	74,418	1	64,496	na	na
100,000	5	124,030	2	128,992	1	148,838
250,000	11	272,866	4	257,984	2	297,676
500,000	21	520,926	8	515,968	4	595,352
1,000,000	41	1,017,046	16	1,031,936	7	1,041,866
2,000,000	81	2,009,286	32	2,063,872	14	2,083,732

the production of 50,000 hybrid striped bass fingerlings because these production-unit sizes would produce substantially more than the target levels at the stocking rate used.

Pond production and costs.—Detailed management information is available on hybrid striped bass (Ludwig and Tackett 1991; Ludwig 1993, 2002, 2004) and white bass (Denson and Smith 1996) fingerling production in ponds. The stocking rate used in the budget analyses was 370,500 hybrid striped bass fry per hectare and the initial assumed survival rate was 35% (Ludwig 2004, 2006). The number of ponds and estimated production of hybrid striped bass fingerlings in each production or pond size scenario is indicated in Table 1. The number of ponds required ranged from 1 to 39 ponds 0.4 ha in size and from 0 to 7 ponds 2.4 ha in size.

Annual costs, including variable and annual fixed costs, were estimated for each of the 15 pond scenarios. Variable costs included 48% protein starter meal and a number 1 crumble feed. Agricultural lime, fertilizer, and salt were assumed to be used. The costs associated with bags to move fry with oxygen were included along with utilities (including pumping costs to fill the ponds before stocking), and costs associated with bird control. Annual fixed costs included insurance, legal and accounting fees, annual interest on the investment, and annual depreciation costs.

Total costs were calculated by summing total annual variable and total annual fixed costs. The break-even price (per-unit cost of production) was calculated by dividing the total variable (break-even price above variable costs) and total cost (break-even price above total costs) by the quantity of hybrid striped bass fingerlings produced. A complete enterprise budget for one pond production scale (1,000,000 fingerlings/year in 1.2-ha ponds) is presented in Tables A.1–A.3 in the appendix, where individual line items, their quantities, and costs are reviewed.

Tank production and costs.—The number of tanks and estimated production of hybrid striped bass fingerlings in each production–tank size scenario is shown in Table 2. The number of tanks required ranged from 3 to 81 small (945 L) tanks and from 0 to 14 large (5,670 L) tanks.

The overall design and specific details of the recirculating system used for the tank scenarios was that of Pfeiffer and Wills (2008). The system consists of round polyethylene tanks set up in rows. Filters and treatment units include a wave vortex filter from which water flows to a fiberglass sump. An open polygeyser filter, a moving bead biofilter with Kaldness media, and an ultraviolet (UV) sterilizer are used to treat the water. Excess water flows through a packed column unit filled with bio-ball media material. Liquid oxygen is supplied to the system.

The same six scales of production were modeled producing 50,000, 100,000, 250,000, 500,000, 1,000,000, or 2,000,000 fingerlings. The stocking rate used was 75 larvae/L, and the initial survival rate was 35% (Denson and Smith 1997; Ludwig 2006). The production data used were taken from studies of tank culture with sunshine bass and summarized by Ludwig (1994a, 1994b, 2006).

Annual costs were estimated for each of the 17 tank scenarios and included annual variable and annual fixed costs. The base scenario assumed that hybrid striped bass fry would be fed both freshwater rotifers and brine shrimp nauplii. Feeds included 48% protein starter meal, rotifers, and microalgae *Nannochloropsis* spp. Synthetic sea salt was added. Labor was that necessary to manage the tank system and a specially trained technician to produce rotifers. Other variable costs were utilities, repairs and maintenance, and bags and oxygen to move fry. Annual fixed costs included insurance, legal and accounting fees, interest on the investment, and annual depreciation.

Total costs were calculated by summing total annual variable and total annual fixed costs. The break-even price (per-unit costs of production) was calculated by dividing the total variable costs (break-even price above variable costs) and total cost (break-even price above total costs) by the quantity of hybrid striped bass fingerlings produced. The unit of measure used was cost per 1,000 fingerlings. A complete enterprise budget for one production scale (1,000,000 fingerlings/year in 2,457 L tanks) is presented in Tables A.4–A.6 where individual line items, their quantities, and costs are reviewed.

Sensitivity analysis.—A sensitivity analysis was conducted to evaluate the effect of the number of production cycles on costs per 1,000 fingerlings produced in either ponds or indoor recirculating tanks. Up to three production cycles in pond production were evaluated, in the event that additional research identifies a viable approach that could improve survival of hybrid striped bass fry stocked in late summer (third cycle). For the tank scenarios, up to six production cycles were evaluated, under the assumption that fry could be made available throughout the year in sufficient numbers to supply the various tank and production-scale scenarios evaluated. A second underlying assumption is that there would be adequate market demand throughout the year to sell the quantities of fingerlings produced for all production cycles analyzed.

Little research has been done on survival of hybrid striped bass fry from 14 dph to phase I fingerlings. The base scenario in this analysis used a survival value of 35%. Commercial producers of hybrid striped bass fingerlings have reported average survival rates of about 35% but with a range of 0% to approximately 60%. Ludwig (1993) showed that higher survival in experimental ponds (59%) is possible if ponds are filled with fresh well water (that does not contain predaceous zooplankton) just before fry are introduced. A sensitivity analysis was developed with survival rates that were varied from 40% to 60% in 5% increments. A similar sensitivity analysis of the effects of increased survival in tank systems was conducted owing to the lack of data on survival through the fingerling stage. Denson and Smith (1997) reported overall survival of 38% in tanks to fingerling size while Lindell et al. (2004) reported only 4% survival in tanks through to fingerlings. Survival rates in the tank budgets were increased in increments of 5% up to a survival of 90%. Increasing survival rates will increase the density of hybrid striped bass fry in both ponds and tanks. Increasing

densities may affect the growth rate and extend the amount of time required for fry to reach phase I size. However, the lack of adequate data to account for these differences precluded refining the bioeconomic levels to that extent in this analysis.

An additional cost analysis was conducted to evaluate the relative difference in annual cost of substituting microencapsulated *Artemia* for rotifers in the 4–14 dph diets of hybrid striped bass fry as described in Ludwig and Lochmann (2009). The respective changes in line items, quantities, and costs were substituted into the initial budget spreadsheets to compare the difference in total annual costs at 14 dph.

RESULTS

Pond Production

Total investment and total annual depreciation costs of both long-term real estate and equipment investment increased with increasing scales of production across the 15 pond production scenarios (Table 3). A complete set of tables for one of the 15 pond enterprise budget analyses is presented in Tables A.1–A.3 to provide details of individual line items. For example, the total long-term real estate investment cost ranged from $15,574 to $202,462 as production increased from 100,000 to 2,000,000 fingerlings/year for the 1.2-ha ponds. The total equipment cost increased from $6,631 to $79,576 for the 1.2-ha ponds as production increased from 100,000 to 2,000,000 fingerlings/year.

TABLE 3. Total investment cost and annual depreciation for the production of hybrid striped bass fingerlings in ponds at various pond sizes and production scales. All values are in U.S. dollars; na = not applicable.

	Real estate investment[a]		Equipment[b]	
Production scale	Total cost	Annual depreciation	Total cost	Annual depreciation
		0.4-ha ponds		
50,000	6,098	203	4,640	695
100,000	12,196	406	8,999	1,319
250,000	30,490	1,014	22,078	3,193
500,000	60,980	2,028	43,876	6,316
1,000,000	121,960	4,056	83,112	11,938
2,000,000	237,822	7,910	166,804	23,930
		1.2-ha ponds		
50,000	na	na	na	na
100,000	15,574	472	6,631	1,012
250,000	31,148	945	12,710	1,886
500,000	62,296	1,890	24,867	3,634
1,000,000	109,018	3,307	43,104	6,255
2,000,000	202,462	6,142	79,576	11,498
		2.4-ha ponds		
50,000	na	na	na	na
100,000	na	na	na	na
250,000	28,250	800	9,788	1,531
500,000	56,500	1,600	18,445	2,779
1,000,000	113,000	3,200	43,104	5,274
2,000,000	173,250	5,050	79,576	9,017

[a]Includes the initial acquisition cost of land, ponds, wells, and buildings that would typically be used in a business for periods of time greater than 5–7 years.

[b]Includes the initial acquisition cost of equipment that would typically be used in a business for 2–7 years.

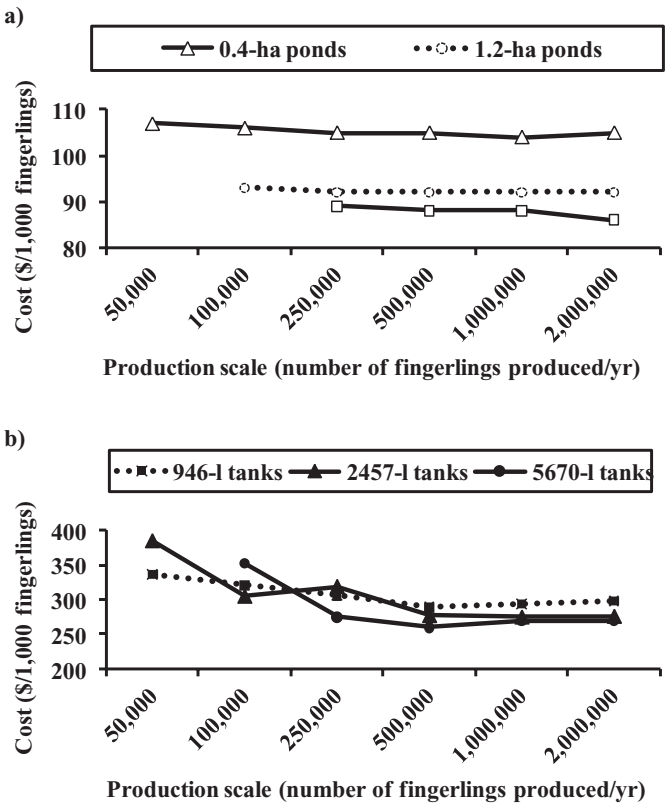

FIGURE 1. Total annual costs per 1,000 fingerlings for hybrid striped bass fingerling production in **(a)** ponds and **(b)** tanks for six scales of production that range from 50,000–2,000,000 fingerlings per year.

Total annual costs increased with increasing volumes of production (Table 4), but per-unit costs per 1,000 fingerlings (average cost of production) decreased with increasing scale of production and with increasing pond size, and thus economies of scale (Figure 1a) were exhibited. As pond size increased the average cost of production was decreased by 5–13%, while the increase in the scale of production resulted in much smaller percentage decreases in the average cost of production (1% to 3%). The cost per 1,000 fingerlings ranged from $105 to $107 in 0.4-ha ponds, $92 to $93 in 1.2-ha ponds, and $86 to $89 in 2.4-ha ponds. Variable costs accounted for 64% to 79% of the total costs of producing hybrid striped bass fingerlings in ponds. The percentage of total variable costs that made up total costs increased as the scale of operation and pond size increased. Fixed costs declined as a percentage of total costs as the scale of production and pond size increased.

TABLE 4. Total annual cost of producing hybrid striped bass fingerlings in ponds at various pond sizes and production scales. All monetary values are in U.S. dollars; na = not applicable.

	Total variable cost		Total fixed cost		Total annual cost
Production scale	$/enterprise	% of total cost	$/enterprise	% of total cost	($/year)
		0.4-ha ponds			
50,000	3,578	64	2,034	36	5,611
100,000	7,155	64	3,970	36	11,125
250,000	17,888	65	9,776	35	27,664
500,000	35,777	65	19,454	35	55,231
1,000,000	71,554	65	37,749	35	109,303
2,000,000	139,537	65	74,737	35	214,274
		1.2-ha ponds			
50,000	na	na	na	na	na
100,000	10,723	73	3,892	27	14,615
250,000	21,456	74	7,591	26	29,047
500,000	42,913	74	14,989	26	57,902
1,000,000	75,122	74	26,085	26	101,206
2,000,000	139,537	74	48,278	26	187,815
		2.4-ha ponds			
50,000	na	na	na	na	na
100,000	na	na	na	na	na
250,000	21,456	77	6,508	23	27,965
500,000	42,913	77	12,622	23	55,535
1,000,000	85,826	78	24,848	22	110,673
2,000,000	150,241	79	40,186	21	190,428

Tank Production

Total investment and total annual depreciation of the long-term real estate and equipment investment increased as scales of production increased across the 17 tank production scenarios, and ranged from $3,780 to $181,139 as production increased from 50,000 to 2,000,000 fingerlings/year for the 945-L tanks (Table 5). A complete set of tables for one of the 17 tank enterprise budgets is presented in Tables A.4–A.6 to provide details of individual line items. Increasing the size of tanks decreased the total real estate and equipment investment for any given scale of production (with the exception of equipment investment costs for the 100,000-fingerling production level).

Total annual costs increased with the scale of production within each tank-size category (Table 6). Total annual costs tended to be lower for 2,457-L tanks than for 945-L tanks for comparable production levels. However, total annual costs for the largest tank sizes (5,670 L) were lower for three of the production levels but higher for two (100,000 and 500,000 fingerlings/year). Variable costs accounted for 67–83% of total costs for the 945-L tanks, 67–88% of total costs for the 2,457-L tanks, and 82–89% of total costs for the largest tank size, 5,670 L.

The cost per 1,000 fingerlings produced ranged from $289 to $337 for the 945-L tank scenarios, from $275 to $385 for the 2,457-L tank scenarios, and from $260 to $353 for the 5,670-L tank scenarios (Figure 1b). The cost per 1,000 fingerlings decreased with the scale of production up to 500,000 fingerlings/year for the 945-L and 5,670-L tanks. For the 2,457-L tanks, the cost per 1,000 fingerlings generally decreased up to 1,000,000 fingerlings/year (with the exception of the increased cost from 100,000–250,000 fingerlings/year). Cost increases at the 2,000,000-fingerling production level and from 100,000–250,000 fingerlings/year levels were due primarily to the higher interest costs on the long-term investment, in proportion to the volume of production. For production levels of 500,000–2,000,000 fingerlings, the cost per 1,000 fingerlings decreased as the tank size increased. However, there was no consistent trend in the cost per 1,000 fingerlings compared across tank sizes for production scales less than 500,000 fingerlings/year. The sizes of tanks available and associated system components available in commercial markets are not sold in proportionate sizes that allow each component to be operated at an optimal level of production. This would result in several increases in per-unit costs ($/1,000 fingerlings) as the scale of production increases.

Sensitivity Analysis

Results of the sensitivity analysis conducted to compare the effect of varying numbers of annual production cycles on the

TABLE 5. Total investment cost and annual depreciation for the production of hybrid striped bass fingerlings in tanks at various tank sizes and production scales. All values are in U.S. dollars; na = not applicable. See Table 3 for additional information.

Production scale	Real estate investment		Equipment	
	Total	Annual depreciation	Total	Annual depreciation
		945-L tanks		
50,000	3,780	192	33,609	4,269
100,000	5,654	283	38,726	4,988
250,000	11,926	558	51,197	6,815
500,000	27,483	1,117	91,147	11,907
1,000,000	67,400	2,183	177,175	23,167
2,000,000	181,139	4,225	347,421	45,536
		2,457-L tanks		
50,000	3,780	192	33,263	4,145
100,000	5,654	283	37,485	4,681
250,000	9,429	459	48,530	6,080
500,000	18,400	817	66,391	8,334
1,000,000	42,980	1,583	127,368	16,182
2,000,000	117,843	3,175	255,056	32,256
		5,670-L tanks		
50,000	na	na	na	na
100,000	4,561	233	39,229	4,947
250,000	9,429	459	46,068	5,792
500,000	16,863	766	61,852	7,762
1,000,000	38,900	1,483	114,842	14,569
2,000,000	102,772	2,926	224,947	28,535

cost per 1,000 fingerlings in ponds and tanks are presented in Table 7. Increasing pond production to two cycles per year decreased per-unit costs of production by approximately 11% to 18%. Adding a third production cycle resulted in an additional 4–8% decrease in per-unit costs. Increasing the number of production cycles in the tank scenarios decreased the per-unit costs of production from 8% to 17% for the 945-L tank scenarios, from 6% to 16% for the 2,457-L tank scenarios, and from 5% to 9% in the 5,670-L tank scenarios as the number of production cycles increased from one to two per year. Additional increases in the number of production cycles further decreased the cost per 1,000 fingerlings, but at successively lower rates of decrease.

Overall, the lowest cost (per 1,000 fingerlings) was in pond production in 2.4-ha ponds at 2,000,000 fingerlings/year with three production cycles per year. This cost was more than three times lower than the lowest cost in tanks (500,000 fingerlings/year in the largest tanks with six production cycles a year). However, there was little difference in cost between the 1.2-ha and 2.4-ha ponds across scales of production with two cycles per year. The smallest pond size (0.4 ha) with two production cycles per year resulted in a per-unit cost that was similar to that of one production cycle in the largest pond size (2.4 ha).

Increased survival rates result in increased production in any given pond because more fingerlings are produced per hectare. The sensitivity analysis of increased survival rates of hybrid striped bass fry reduced production costs ($/1,000 fingerlings) for all pond (Table 8) and tank (Table 9) scenarios, and this demonstrates that, as production capacity in each pond increases the average costs of production decrease. In ponds, each 5% increase in survival decreased the cost per 1,000 fingerlings by 7% to 14%. In tanks, survival rates were increased up to 90% based on the 2-week results of Ludwig and Lochmann (2009). For each 5% increase in survival, the cost per 1,000 fingerlings produced decreased by 5% to 11% (Table 9).

The production of freshwater rotifers adds a substantial amount of cost to tank production of hybrid striped bass fingerlings. Much of this cost consists of the cost of the rotifer cysts, but rotifer production also increases the cost of skilled labor, utilities, repair, maintenance, and fixed costs in the form of annual interest on investment and annual depreciation. Purchase of live, brackish-water rotifers is an alternative to on-farm production of freshwater rotifers when cysts are used, but the overall costs are of a similar magnitude. Ludwig and Lochmann (2009) demonstrated that hybrid striped bass fingerlings can be raised without rotifers for the first 2 weeks of culture, up to a size of 17 mm by replacing rotifers with *Artemia*. The cost analysis conducted in this study showed a substantial (89%) reduction in the cost of producing 14-dph larvae. However, given that the fry were not cultured through to phase I fingerling size, data on growth and survival to fingerlings are not available to estimate and compare fingerling costs.

DISCUSSION

The decreasing costs per unit in the pond scenarios in which pond size and scale increase indicate economies of scale in pond production of hybrid striped bass fingerlings. Economies of scale are common in aquaculture and result in greater economic efficiencies when production is on a larger scale. Gempesaw et al. (1992a) demonstrated significant economies of scale in hybrid striped bass food fish production as pond size increased.

Tank production of hybrid striped bass fingerlings exhibited economies of scale as production increased from 50,000 to 500,000 fingerlings/year but then showed diseconomies of scale as production increased to 2,000,000 fingerlings/year (with the exception of the 2,457-L tank system that showed slight cost decreases from 500,000–1,000,000 fingerlings/year). Thus, with 945-L and 5,670-L tanks, the least-cost scale of production appeared to be 500,000 fingerlings/year. Larger tank sizes generally resulted in lower per-unit costs than did smaller tanks for any given scale of production. However, the largest tank size considered in this analysis is larger than those that have been used in the research on hybrid striped bass fry (Losordo and Westerman 1994; Dunning et al. 1998). Adequate cleaning

TABLE 6. Total annual cost of producing hybrid striped bass fingerlings in tanks at various tank sizes and production scales. All monetary values are in U.S. dollars; na = not applicable.

	Total variable cost		Total fixed cost		
Production scale	$/enterprise	% of total cost	$/enterprise	% of total cost	Total annual cost
			945-L tanks		
50,000	16,745	67	8,334	33	25,078
100,000	30,019	75	9,834	25	39,853
250,000	69,868	84	13,748	16	83,616
500,000	125,603	83	24,994	17	150,597
1,000,000	249,781	83	49,506	17	299,287
2,000,000	497,641	83	101,653	17	599,293
			2,457-L tanks		
50,000	16,691	67	8,113	33	24,804
100,000	30,045	76	9,340	24	39,386
250,000	69,788	85	12,397	15	82,186
500,000	125,158	88	17,693	12	142,851
1,000,000	249,442	88	34,324	12	283,766
2,000,000	497,593	87	71,737	13	569,329
			5,670-L tanks		
50,000	na	na	na	na	na
100,000	42,979	82	9,621	18	52,601
250,000	70,002	86	11,863	14	81,865
500,000	138,343	89	16,462	11	154,805
1,000,000	249,496	89	30,950	11	280,446
2,000,000	497,490	89	63,249	11	560,738

of the largest tank size may be difficult and may have adverse effects on production.

The cost per 1,000 fingerlings was variable and did not exhibit smooth trends as tank sizes and scales of production increased. This results from "lumpiness" and indivisibility of a number of different types of fixed assets (production tanks, treatment tanks, sump, and full-time technicians) in the same recirculating system production unit. When a larger size of one component must be purchased to accommodate another component part, even though it is not used at full capacity, costs can increase markedly. These same costs then decrease as scale increases further because that component is used more fully.

Additional research is needed to optimize designs of recirculating systems across the entire set of fixed assets. Improved availability of sizes of the various fixed assets that allow for full capacity utilization of each component to minimize fixed costs across the system has the potential to lower per-unit costs of production, particularly for the larger scales of production.

Ponds were the least expensive way to produce hybrid striped bass fingerlings, even with only one production cycle in ponds and six cycles in tanks. If survival rates could be increased consistently up to 60%, fingerling production costs in ponds would further decrease by more than 40%. Gempesaw et al. (1992b) also found that pond production was considerably more profitable than tank systems for food fish production of hybrid striped bass. Fixed costs were proportionately higher (29%) for hybrid striped bass reared as food fish (Gempesaw et al. 1992b) than those observed in the present study with hybrid striped bass fingerlings. Similarly, Dunning et al. (1998) showed fixed costs of 23% for food fish production in recirculating tank systems, while Losordo and Westerman (1994) found fixed costs to be 34% of total costs for food fish production.

This analysis focused on fingerling production costs and did not consider whether fry costs would differ if produced year-round. Producing fry year-round would probably reduce fixed costs per million fry by spreading fixed costs over a larger output. However, the additional temperature control costs might result in increased fixed and variable costs.

Recently, studies have found that *Artemia* could be used as a substitute for the difficult and expensive rotifer phase in the diet for hybrid striped bass fry; this could reduce tank production costs by as much as 89% for any given survival rate. However, survival rates decrease at ages beyond 18–22 dph (Ludwig 2005). Lindell et al. (2004) reported survival rates of only 4%, while Denson and Smith (1997) reported 38% in the one tank used to continue raising fry through the phase I fingerling size. Thus, the 38% survival rate achieved by Ludwig and Lochmann

TABLE 7. Effect of the number of annual production cycles on the costs per 1,000 hybrid striped bass fingerlings produced in ponds and indoor recirculating tanks. Values are US$ per 1,000 fingerlings; na = not applicable.

Production scale	Number of annual production cycles					
	1	2	3	4	5	6
0.4-ha ponds						
50,000	107	88	81	na	na	na
100,000	106	87	80	na	na	na
250,000	105	87	81	na	na	na
500,000	105	87	80	na	na	na
1,000,000	104	86	80	na	na	na
2,000,000	105	86	80	na	na	na
1.2-ha ponds						
100,000	93	80	76	na	na	na
250,000	92	80	76	na	na	na
500,000	92	80	76	na	na	na
1,000,000	92	80	76	na	na	na
2,000,000	92	80	76	na	na	na
2.4-ha ponds						
250,000	89	78	75	na	na	na
500,000	88	78	75	na	na	na
1,000,000	88	78	75	na	na	na
2,000,000	86	77	74	na	na	na
945-L tanks						
50,000	337	281	262	253	247	244
100,000	321	282	268	262	258	255
250,000	306	281	273	269	266	264
500,000	289	265	257	253	251	249
1,000,000	294	270	262	258	255	254
2,000,000	298	273	265	260	258	256
2,457-L tanks						
50,000	385	322	301	290	284	280
100,000	305	269	257	251	247	245
250,000	319	295	287	283	280	279
500,000	277	260	254	251	249	248
1,000,000	275	258	253	250	248	247
2,000,000	276	258	253	250	248	247
5,670-L tanks						
50,000	na	na	na	na	na	na
100,000	353	321	310	305	302	300
250,000	275	255	248	245	243	242
500,000	260	246	242	239	238	237
1,000,000	269	254	249	246	245	244
2,000,000	269	254	249	246	245	244

TABLE 8. Effect of varying survival rates of hybrid striped bass fingerlings in ponds. Values are US$ per 1,000 fingerlings; na = not applicable.

Production scale	Survival rate (%)				
	40	45	50	55	60
0.4-ha ponds					
50,000	94	83	75	68	62
100,000	93	82	74	67	62
250,000	92	79	71	63	57
500,000	92	82	74	67	61
1,000,000	91	81	73	66	61
2,000,000	92	81	73	67	61
1.2-ha ponds					
100,000	81	72	65	59	54
250,000	81	72	65	59	54
500,000	80	71	64	58	54
1,000,000	80	71	64	58	54
2,000,000	80	71	64	58	54
2.4-ha ponds					
250,000	78	69	62	56	na
500,000	77	69	62	56	51
1,000,000	77	68	61	56	51
2,000,000	76	67	60	55	50

(2009) at 14 dph would result in very low survival by the time fish reach fingerling size at 45 d.

Palmetto bass (female striped bass × male white bass) will accept *Artemia* as their first feed (Tuncer et al. 1990). Our study has shown that eliminating the rotifer phase of feeding for tank production of fingerlings could reduce tank production costs by as much as 89%. However, the hybrid striped bass industry has relied on sunshine bass because of the difficulty in handling the larger striped bass females, which also take a year longer to reach sexual maturity than the white bass females. It is also very difficult to induce ovulation in striped bass females when needed (Hodson et al. 1999).

Survival rates have a clear effect on the costs of hybrid striped bass fingerling production in both ponds and tanks, and rates reported in the literature are variable. Additional work is needed to consistently increase the survival of hybrid striped bass fingerlings in ponds and in tanks without using rotifers as feed in both the early larval stages and following weaning to dry feed. Additional work is needed to quantify the economic risks associated with variations in survival rates. Specialized circumstances might allow for a tank production facility to operate at a lower cost. A tank system that also produced a secondary crop, such as a hydroponics crop, might have the potential to spread the fixed costs associated with the tanks and filters across greater overall output.

Pond production continues to be the least expensive way to produce hybrid striped bass fingerlings. Additional work is needed to develop culture methods to improve survival in both early fry rearing and after training fish to feed on dry feed in both ponds and tanks. The effects of risk, particularly those of varying survival rates, on the overall costs also need to be quantified.

TABLE 9. Effects of varying survival rates of hybrid striped bass fingerlings in tanks. Values are US$ per 1,000 fingerlings.

	Survival rate (%)										
Production scale	40	45	50	55	60	65	70	75	80	85	90
						945-L tanks					
50,000	295	262	236	214	197	181	168	157	147	139	131
100,000	281	250	225	204	187	173	161	150	141	132	125
250,000	268	238	215	195	179	165	153	143	134	126	119
500,000	253	225	202	184	169	156	145	135	126	119	112
1,000,000	257	229	206	187	172	158	147	137	129	121	114
2,000,000	261	232	209	190	174	161	149	139	130	123	116
						2,457-L tanks					
50,000	337	299	269	245	224	207	192	179	168	158	150
100,000	267	237	214	194	178	164	153	142	134	126	119
250,000	279	248	223	203	186	172	159	149	139	131	124
500,000	242	215	194	176	162	149	138	129	121	114	108
1,000,000	241	214	192	175	160	148	137	128	120	113	107
2,000,000	241	215	193	176	161	149	138	129	121	114	107
						5,670-L tanks					
100,000	309	275	247	225	206	190	177	165	155	146	137
250,000	241	214	193	175	160	148	138	128	120	113	107
500,000	228	202	182	165	152	140	130	121	114	107	101
1,000,000	236	209	188	171	157	145	135	126	118	111	105
2,000,000	235	209	188	171	157	145	135	126	118	111	105

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Appendix: Additional Information on Production Costs of Hybrid Striped Bass Culture

TABLE A.1. Long-term investment costs (U.S. dollars) of the real estate required to produce 1,000,000 hybrid striped bass fingerlings per year (seven 1.2-ha earthen ponds); na = not applicable. These costs include the initial acquisition cost of land, ponds, wells, and buildings that would typically be used in a business for periods greater than 5–7 years.

Item	Description	Unit	Price/unit	Quantity	Proportion of use	Total cost	Useful life (years)	Annual depreciation
Land		ha	4,942	9.56[a]	100	47,250	na	na
Ponds[b]	Seven 1.2-ha earthen ponds	ha	5,791	8.4	100	48,643	20	2,432
Wells		Each	25,000	1	52.5	13,125	15	875
Total						109,018		3,307

[a]Includes the water surface area of 8.4 ha and 1.16 ha of land for levees and the well head as well as other land surrounding the ponds.
[b]Includes water supply, drainage structures, and electrical systems.

TABLE A.2. Investment costs (U.S. dollars) of the equipment[a] required to produce 1,000,000 hybrid striped bass fingerlings per year (seven 1.2-ha earthen ponds). These costs include the initial acquisition cost of equipment that would typically be used in a business for 2–7 years.

Item	Description	Quantity	Unit cost ($)	Total cost ($)	Useful life (years)	Annual depreciation ($)
Feed bin and footing	15 ton (for 10-ton half-loads)	1	3,925	3,925	10	393
Feeder (1 ton, gas)	Trailer mounted, digital scale	1	13,000	13,000	15	867
Paddlewheel aerator	Power takeoff, sidewinder	1	3,500	3,500	10	350
Trailer sprayer	227 L, 4.1-kW gas engine, pump	1	1,500	1,500	10	150
Tractor	45 kW, 100% used for fish	1	20,000	20,000	15	1,333
Rotary cutter	4.6-m bat-wing, chain guards	1	9,700	9,700	7	1,386
Chemical kit	Water quality testing	1	246	246	2	123
Dissolved oxygen meter	Meter with probe	1	800	800	4	200
Buckets	19 L	20	5	100	1	100
Truck	1 ton, flatbed, 4-wheel drive, dual wheels	1	35,500	35,500	5	7,100
Truck	Pickup, 0.5 ton, 2-wheel drive, tow package	1	25,000	25,000	5	5,000
Fish hauling tank	Two compartments, 1,136 L each	1	5,500	5,500	10	550
Regulator, meters, hose	For use with hauling tank	1	585	585	5	117
Oxygen cylinders	7 m^3	8	220	1,760	7	251
Waders	Various sizes	4	105	420	1	420
Seine reel	2.1 m, pull-type	1	6,000	6,000	10	600
Relift pump	6,434 L/min, water transfer	1	10,000	10,000	10	1,000
Subtotal				141,351		20,373
Proportion	0.13125			18,552		2,674
Subtotal				137,536		19,940
Proportion	0.13125			18,051.6		2,617.125
Electric aerators	3.73 kW	7	3,500	24,500	7	3,500
Seines	30.5 m, 0.64-cm mesh seine	1	552	552	4	138
Total				43,104		6,255

TABLE A.3. Annual costs of and returns from producing 1,000,000 hybrid striped bass fingerlings per year (seven 1.2-ha earthen ponds).

Item	Unit	Quantity	Price or cost/unit ($)	Value or cost ($)
		Variable costs		
Feed				
48% protein starter meal	kg	1,202.73	3.954	4,756
Number one crumble	kg	1,088.2	3.91	4,255
Lime	Metric ton	10.091	2,373.8	45,318
Fertilizer[a]	total	21	204	4,284
Salt	kg	477.3	0.213	102
Labor	ha	8.4	412.5	3,465
Electricity	ha	8.4	240	2,016
Fuel (gas and diesel)	ha	8.4	325	2,730
Pumping	ha	8.4	527.5	4,431
Repairs and maintenance	ha	8.4	242.5	2,037
Oxygen	Cylinder	7.5	25	188
Fry shipping bags, 3 mil	Box	0.0626	60	3.76
Bird depredation	ha	8.4	15.62	131
Telephone	ha	8.4	42.5	357
Office supplies	ha	8.4	27.5	231
Interest on operating capital	$	74,304	0.011[b]	817
Total variable costs				75,122
		Fixed costs		
Farm insurance	ha	8.4	109	916
Legal, accounting	ha	8.4	47	395
Interest on investment				
Land, ponds, wells	$	109,018	0.1	10,902
Equipment	$	43,104	0.1	4,310
Annual depreciation				
Real estate	$			6,255
Equipment	$			3,307
Total fixed costs				26,085
Total cost				101,206
Cost/1,000 fingerlings				92
Break-even price (per fingerling)				
To cover variable costs	$/fingerling			0.068
To cover total costs	$/fingerling			0.092
Break-even yield				
To cover variable costs	Fingerlings per 8.4 water ha		Total	751,217
	Fingerlings/ha		per ha	89,431
To cover total costs	Fingerlings per 8.4 water ha		Total	1,012,064
	Fingerlings/ha		per ha	120,484

[a]Fertilizer budgeted followed recommendations in Ludwig (2004) and included rice bran and liquid inorganic (10–30–0) fertilizers.
[b]Six-week interest rate (length of phase I production cycle) based on a 10% annual percentage rate for nine 6-week periods.

TABLE A.4. Long-term investment costs (U.S. dollars) of real estate required to produce 1,000,000 hybrid striped bass fingerlings per year (2,457-L tanks); na = not applicable. These costs include the initial acquisition cost of land, ponds, wells, and buildings that would typically be used in a business for periods greater than 5–7 years.

Item	Description	Unit	Price/unit	Quantity	Proportion of use	Total cost	Useful life (years)	Annual depreciation
Land		ha	12,350	3.644	0.344	15,480	na	na
Building	9.3 × 9.3 m	Each	30,000	1	0.500	15,000	20	750
Wells		Each	25,000	1	0.500	12,500	15	833
Total						42,980		1,583

TABLE A.5. Investment costs (U.S. dollars) of the equipment required to produce 1,000,000 hybrid striped bass fingerlings per year (sixteen 2,457-L tanks). These costs include the initial acquisition costs of equipment that would typically be used in a business for 2–7 years.

Item	Description	Quantity	Unit cost ($)	Total cost ($)	Useful life (years)	Annual depreciation ($)
	Hybrid striped bass production					
Tanks	2,461 L, black, round, conical	16	587	9,392	10	939
Tank stand	Each	16	1,403	22,448	10	2,245
Bulkhead fitting	5 cm (2 in)	16	6	96	10	10
Swirl separator	36 vortex filter	2	1,279	2,558	10	256
Sump	4,165-L sump	2	1,359	2,718	10	272
Sump pump	Low-head propeller,0.75 kW	2	898	1,796	5	359
Polygeyser unit	With 0.71 m^3 media	2	15,000	30,000	10	3,000
Clearwater biofilter	2–6 L/s	2	2,769	5,538	10	554
Sterilizer	1,223-L UV	2	370	740	5	148
Packed air column	Each	2	1,250	2,500	5	500
Airstone	30-cm fine pore diffuser	16	24	384	5	77
Heater	50-W submersible heater	16	23	368	5	74
Chemical kit	Water quality testing	1	246	246	2	123
Feeder	Automatic vibrating	16	136	2,176	5	435
12-V DC adapter	For use with feeders	16	34	544	3	181
Timer	For use with feeders	16	181	2,896	3	965
Fry counter	Coolwater fry counter	1	3,500	3,500	10	350
Piping and fittings	Various	0.025	25,559	639	10	64
Mesh screen	200 μm, internal standpipes	4	17	68	5	14
Pressure washer	Electric	1	200	200	5	40
Utility brushes	Various sizes (two per tank)	32	20	640	5	128
Shop vacuum	Wet/dry model	2	207	414	5	83
	Rotifer culture system					
Tank	Semisquare	20	323	6,460	10	646
Tank stand	Semisquare	20	298	5,960	10	596
Algal culture tank	1,091 L, conical bottom tank	18	629	11,322	10	1,132
Plankton mesh	55-μm mesh for rotifer collection	4	37	147	5	29
Light fixtures	Each	20	19	380	10	38
Bulbs	Cool white fluorescent bulbs	18	4	72	1	72
	Actinic	18	25	457	1	457
Timer	Electronic plug-in for lights	20	29	575	5	115
Pump	Low-head propeller, 0.75 kW	4	898	3,592	5	718
UV filter	65 W	2	629	1,258	5	252
Filter cartridge	20 μm	2	76	152	1	152
Filter cartridge	5 μm	2	76	152	1	152
Pipings, fittings	Various	2	300	600	10	60
Chlorine	0.91 kg as granules	2	13	26	1	26
Dechlorinator	1.8-kg jar	2	17	35	1	35
Lab microscope	For counting rotifers	2	986	1,972	10	197
Bulbs	For microscope	2	10	20	1	20
Counting cell	Plastic cell with grid (1 mL)	2	52	104	5	21
Cover glass	Package of 12	2	31	62	1	62
	Algae culture system					
Flask	500 mL	28	19	521	5	104
Flask	1 L	54	22	1,178	5	236
Carboy containers	19 L	54	46	2,462	10	246
Total				127,368		16,182

TABLE A.6. Annual costs of (U.S. dollars) and returns to producing 1,000,000 hybrid striped bass fingerlings per year (sixteen 2,457-L tanks).

Item	Unit	Quantity	Price or cost/unit	Value or cost
		Variable costs		
Feed				
48% protein starter meal	kg	10.3	3.98	41
Rotifer cysts (per million)	Each	594	380	225,720
Rotifer diet (0.5 kg)	Each	54	21.85	1,180
Microalgae disk (*Nannochloropsis* spp.)	Each	28	13.66	382
Microalgae Grow Mass Pack	Each	2	10.02	20
Synthetic sea salt	L	617.6	0.8	53
Oxygen tank rental	$	1	450	450
Labor				
Hybrid striped bass	$/h	168	6.9	1,159
Rotifers (for 22 d)	$/week per system	12	635	7,620
Electricity				
Hybrid striped bass	$/L	2,694	1.571	4,232
Rotifers	$/L	2,289	1.571	3,596
Repairs and maintenance	$/L	4,984	0.4504	2,245
Fry shipping bags, 3 mil	Box	0.5	60	30
Interest on operating capital	$	246,728	0.011[a]	2,714
Total variable costs				249,442
		Fixed costs		
Farm insurance	ha	0.4	109	44
Legal and accounting	ha	0.4	47	19
Interest on investment				
Long term	$	42,980	0.1	4,298
Equipment	$	125,572	0.1	12,557
Annual depreciation				
Long term	$			1,583
Equipment	$			15,823
Total fixed costs				34,324
Total cost				283,766
Break-even price				242
To cover variable costs	$/1,000 fingerlings			242
To cover total costs	$/1,000 fingerlings			275
Break-even yield				
To cover variable costs	Fingerlings/system			2,494,424
	Fingerlings/L			62
To cover total costs	Fingerlings/system		Total	2,837,660
	Fingerlings/L		Per liter	71

[a]Six-week interest rate (length of phase I production cycle) based on a 10% annual percentage rate for nine 6-week periods.