Genetic Improvement of Fishes for Commercial Recirculating Aquaculture Systems: A Case Study Involving Tilapia

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Introduction

A growing sector of aquaculture produces fish not in traditional pond systems, but in recirculating aquaculture systems (RAS). Development of RAS has tended to emphasize production systems as opposed to cultured stocks. As the RAS sector matures, however, it becomes appropriate to broaden the focus to consider the genetics of cultured stocks. The profitability of aquaculture in RAS will depend, in part, on development of genetic lines suitable for growth under conditions of high density, sub-optimal water quality, and so forth.

Fish breeders have a range of choices for pursuing genetic improvement of aquaculture stocks, including: (1) selective breeding approaches, such as individual or family selection, and (2) biotechnological approaches, such as gene transfer. This technical session of the conference includes presentations of both selective breeding and biotechnology-based programs of genetic improvement of stocks for production in RAS. I will open the program with a discussion of selective breeding of tilapia (*Oreochromis* sp.) within the operations of Blue Ridge Aquaculture (Martinsville, VA), a commercial production enterprise. Scott Lindell (AquaPartners Technologies, Turners Falls, MA) discusses strain evaluation and selective breeding of striped bass (*Morone saxatilis*). Christopher Kohler (Southern Illinois University, Carbondale, IL) then will discuss strain evaluation and selective breeding of white bass (*Morone chrysops*). Loren Miller et al. (University of Minnesota, St. Paul, MN) then will present their group’s findings in selective breeding of walleye (*Stizostedion vitreum*). Over the past 15 years, increasing effort has been committed to application of biotechnological methods to aquaculture production. Elliot Entis (A/F Protein, Waltham, MA) discusses the development and imminent commercialization of transgenic Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). It is my intent that commercial producers will understand the potential of genetic improvement for enhancing productivity and profitability of their operation, and gain insight regarding practical approaches for securing or producing genetically improved stock.
Case Study: Genetic improvement of tilapia at Blue Ridge Aquaculture

Tilapias, Oreochromis sp., are highly suited for production in RAS, showing high tolerance to crowding, ready acceptance of a wide range of foods, good feed conversion efficiency, rapid growth rate, and ease of reproduction. They also are amenable to selective breeding for improvement of certain traits of production interest. I present a case study of selective breeding of hybrid tilapia, showing how selective breeding can be practiced in the context of commercial production in RAS.

Blue Ridge Aquaculture of Martinsville, Virginia is to my knowledge, the world’s largest producer of tilapia in RAS. Blue Ridge produces over one thousand tons of tilapia per year, which are sold live in markets in New York, Boston, and Toronto. Most of the buyers are Asians, who prefer either red or white fish. Blue Ridge concentrates on the market for white fish. Hence, their breeding goals are light body coloration and, of course, rapid growth rate. Working cooperatively with Blue Ridge Aquaculture, I approached these goals using the tools of classical, quantitative genetics, using within-strain selection.

Methods

Genetic resource materials. We started with a typical, commercially obtained gray tilapia strain with genetic background including the well-known Rocky Mountain white strain.

Production system. Reproducing broodstock are held in two lined earthen ponds in a greenhouse. Each 20,000 gallon pond holds approximately 90 males and 270 females. Every seven days, workers collect the broodstock and remove eggs or fry from the females’ mouths. This not only makes the females spawn sooner, but more important from the geneticist’s viewpoint, allows rearing of groups of equal-aged young fish. Some of these groups ultimately will be subject to selection for purposes of broodstock replacement. Eggs are taken year-round, with the help of supplemental lighting from August to May.

The eggs are hatched in classical McDonald hatching jars. The fry are transferred to 1200 gallon tanks for rearing to one gram. Fish intended for production are fed methyltestosterone-treated feed to achieve sex-reversal under an INAD. Fish that are broodstock candidates do not receive hormone-treated feed, so that we’ll have both sexes. Fish of one gram are transferred to lined earthen ponds in another greenhouse for growth to 30 grams. Fish of thirty grams are transferred into RAS in the main production building, to 56,500 gallon tanks for grow-out to 500 grams. Blue Ridge Aquaculture has 42 of these RAS. It takes about a year to bring a fish from egg to market size. Fish are graded at least three times through the grow-out period (Figure 1). Roughly the bottom 10-30% of fish are discarded through the production process depending on the number of fish in the batch. Blue Ridge Aquaculture regards the removal of slow-growing fish as cost-effective. These culling steps also are practiced on the broodstock replacement candidates.
Selection. When they reach market size, broodstock candidates are sorted by sex. We know we will need 500 males and 1400 females as broodstock for the next generation. Knowing how many broodstock replacement candidates of each sex are on hand, we can determine what proportion to retain, in other words, what our selection intensity should be. A sample is taken to determine the minimum weight criterion for selection for each sex. Then, we check every fish, selecting as broodstock only the light-colored, rapidly growing individuals. For example, in the second generation, we selected 40% of the males and 60% of the females grown out. I hasten to add that this final selection step comes after at least three gradings as described above, so our selection intensities actually are much higher, roughly 13% for males and 37% for females. We are now in our fourth generation of selection.

Throughout the entire process of rearing broodstock replacement candidates, prospective broodstock is maintained as two genetic lines, the “A” and “B” lines. At spawning time, males from one line are mated only with females of the other, and vice versa. The young then are considered part of the male parent’s line. This is a simplified application of the rotational line-crossing scheme developed by Kincaid (1977). The practice of making matings only between the lines reduces the likelihood of matings among relatives, and minimizes the rate of inbreeding accumulation.

Results and discussion

Body coloration. The typical coloration of the tilapia at the beginning of the selective breeding program included grey saddle marks over the back, and grey coloration along the back. We’ve made clear progress on body coloration. A typical fish from the third generation is silvery white and beautiful (Figure 2), well accepted at the market.

Response to selection. Since the commercial grower was not interested in producing fish from a control line that did not undergo selection, we had no direct means of quantifying improvement of growth rate, i.e., no contemporary comparison of select and randomly-bred lines. However, I do have data (Table 1) showing that our select line performs well at Blue Ridge Aquaculture. Compared to the DS line from another source simultaneously under production at Blue Ridge Aquaculture, our line showed higher growth rate (2.30 vs 1.91 grams/day).

Certain other traits also were improved in response to selection. These traits apparently are positively correlated with growth rate in this line. These select line exhibits a better feed conversion ratio (1.53 vs. 1.92) than the reference DS line, an FCR that continues to improve. Though mortality initially was higher than in the reference line, it has improved with each generation. Overall, Blue Ridge Aquaculture is highly satisfied with its select line.

Selective breeding as an investment. This selective breeding represents what I regard as the minimum scale needed for achieving successful in-house selective breeding. It represents a commitment to grow equal-aged groups of fish and to maintain and evaluate broodstock replacement candidates. It represents a commitment of dedicated tank space
and human effort. This commitment must be regarded as an investment. On my estimate, we increased Blue Ridge’s revenues by on the order of $200,000 a year, on a research investment of on the order of $50,000 a year. Though it was regarded as a risk at the outset, Blue Ridge Aquaculture maintains the selective breeding program because it is justified as a business decision. The cost of committing space and effort to the breeding program led to a positive return on investment.

**Should your enterprise undertake a genetic improvement program?**

The presentations in this technical session on genetic improvement collectively provide a number of case studies on genetic improvement of lines for production in recirculating aquaculture systems. They show that there are many technical possibilities for approaching genetic improvement. Some producers may prove interested in the possibility of starting their own genetic improvement program. I urge such readers to first do two things.

First, invest time in becoming familiar with the principles of fish breeding. I recommend that you read Tave (1993), *Genetics for fish hatchery managers*, or another suitable book on genetic improvement of fishes. As you gain a broad, general background, you also should read the technical literature on genetic improvement of your species of interest. The literature cited section of your fish breeding book is a good place to start. For readers interested readers in gaining a more in-depth grounding in the theory underlying selective breeding, I recommend Falconer and Mackay (1996), *Introduction to quantitative genetics*.

Second, take the time to reach well-considered answers to the series of questions below highlighting key issues regarding genetic improvement of a fish stock. On a basic level, the question is a simple choice: is it worthwhile to develop your own genetically improved stock, or alternatively, is it more worthwhile to choose the best existing stock for your system? To make this decision, consider the following questions carefully:

- **What are your breeding goals?** Most likely, rapid growth will be a leading goal. You must decide on one, or possibly two breeding goals. Should you attempt genetic improvement of many goals simultaneously, you are likely to achieve little genetic progress towards any of them. Also, you must not change your breeding goals frequently.
- **Do you produce your own seed stock?** Selective breeding can go forward only in the context of a production program encompassing the entire life cycle.
- **Do you have the infrastructure to hold and performance test your broodstock candidates?** In other words, do you have the means to produce and grow a group of fish of equal-aged upon which to practice selection?
- **Can you do all this and also maintain your production?** Commercial producers profit by selling fish, not by engaging in genetic improvement per se. Do you have sufficient infrastructure and money to support one or more workers whose effort will be dedicated to the genetic improvement program?
If you have answered “yes” to all the questions above, then the decision to go forward with an in-house genetic improvement program may be justified. If you are seriously considering such a commitment, then I pose two additional questions:

- **Have you secured the cooperation of a professional geneticist?** Given your breeding goals and the inevitable economic and logistical constraints, a geneticist can help you design the breeding program that’s most appropriate for your enterprise. The collaboration of a geneticist will ensure a well-designed program and help avoid foreseeable errors of experimental design or execution.

- **Do you plan to maintain a control, randomly bred line?** Maintaining a control line provides a baseline for comparison to determine whether and to what degree you have achieved genetic progress. However, maintaining a control line does consume resources. You must make a clear-minded decision on whether or not to maintain a control line.

If you conclude that developing your own genetically improved line is *not* appropriate for you, and I anticipate that this will be the conclusion for most producers, then what are the options? It is likely to prove advantageous simply to base your production on the best stock available to you. How, then, would you determine, what stock performs “best” under your production conditions? You would compare the performance of two or more stocks in your production system at the same time under identical conditions. Each stock should be produced in replicated systems, and the results analyzed statistically. A geneticist can help you design an appropriate experiment for your facility. Then, of course, you would compare the production and costs on your enterprise budget spreadsheet. The advantage of identifying and producing the best stock is considerable (Lindell et al., this volume; Kohler et al., this volume). Choosing the best line can lead to an improvement in production equal to one or more generations of selective breeding (Kinghorn 1983).

**Genetic improvement as part of your business strategy**

Commercial growers should think of genetic improvement as a part of long-term strategy, like raising production efficiency or improving marketing. Think for a moment how much of the intensification of the broiler industry came from genetic improvement. Over the 34 years before 1991, selective breeding contributed an estimated 86% of the improvement in weight-at-age (Havenstein et al. 1994).

Since we frequently are working with species that are not very domesticated or improved, the gains can be dramatic. We can exploit great phenotypic variation and high fecundity. Gains in growth rate from selective breeding have been high, for example, 10% per generation in rainbow trout (Kincaid et al. 1977), 10% per generation in coho salmon (Hershberger et al. 1990), and 10-30% per generation in Atlantic salmon (Gjedrem 1979). A key point is that you need a long-term commitment in order to realize these benefits. Each of the successes cited above is the result of a long-term commitment, each with its own background, each a different model of how to go forward.
- Harold Kincaid works for the US Fish and Wildlife Service, which proved a reliable source of research support for many years.
- Genetic improvement of Atlantic salmon is the result of a breeding cooperative that Norwegian farmers started, and that the government entered later. This program has gone forward for over 30 years.
- Genetic improvement of coho salmon is an example of cooperation built on commitment between the University of Washington, DomSea Farms – a commercial producer, and Sea Grant – a program of the U.S. Department of Commerce.

The key point is that success in breeding often depends on support and collaboration over the long term between partners from industry, university, and government. Team-building can be key to success.

Conclusions

The key points of this review are:

- Use of a genetically improved line has the potential to boost your production and profits.
- It may be or may not be worthwhile for you to pursue genetic improvement at your own farm.
- Becoming well acquainted with genetic principles, securing the collaboration of a geneticist, and bringing together the infrastructure and money you'll need are key steps for achieving success in genetic improvement of an aquaculture stock.

Acknowledgements

I gratefully acknowledge support for my genetic improvement research from the CFAST (Commercial Fish and Shellfish Technologies) program, the Virginia Aquaculture Initiative, and the U.S. Department of Agriculture Hatch Program. I also am grateful for mutually beneficial cooperation with Darrin Prillaman, Rocky Holley, and Bill Martin of Blue Ridge Aquaculture.

Literature Cited


**Table 1.** Performance of the Blue Ridge Aquaculture Select strain (BRA-S), with comparison to DS strain.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Tanks</th>
<th>N Stocked</th>
<th>Mortality</th>
<th>Weight At Stocking</th>
<th>Weight At Harvest</th>
<th>Gain/Day</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS</td>
<td>A2, A3</td>
<td>59,676</td>
<td>2.8%</td>
<td>8.3 g</td>
<td>495 g</td>
<td>1.9 g</td>
<td>1.92</td>
</tr>
<tr>
<td>BRA-S1</td>
<td>A4, A6</td>
<td>62,113</td>
<td>5.3%</td>
<td>14.0</td>
<td>484 g</td>
<td>2.3</td>
<td>1.48</td>
</tr>
</tbody>
</table>
Figure 1. Production and selection of tilapia broodstock replacement candidates at Blue Ridge Fisheries includes three or more rounds of culling through the production cycle.

Figure 2. Selection for light body coloration resulted in a silvery white production stock.
Fins Technology has created the world’s largest collection of performance tested \( F_1 \) through \( F_3 \) domesticated striped bass and white bass. In 1995, we initiated a strain evaluation program to establish founder stocks of striped bass for future selective breeding. We systematically evaluated over 5,000 prospective striped bass and 3,000 white bass broodstock from 70 families and 12 distinct strains over four year-classes. Fish were individually tracked via physical and/or microsatellite markers. No single strain ranked highest in all economically important characteristics evaluated (growth rate, survival, and feed conversion efficiency). Growth rates of individuals (assignable to families and strains in replicate tanks) were compared by year-class. Survival and feed conversion efficiencies were tracked by family and strain respectively in replicated tanks. There was considerable variation in family performance within strains across year-classes, suggesting that strain alone is an insufficient basis for selection. Based on these results, we initiated a selective breeding program that combines family and within family selection, and crossbreeding of different strains to exploit their superior attributes. Use of microsatellite markers is expected to increase selection differential by allowing us to unambiguously identify top performing individuals from large numbers of communally reared families.
Performance Comparison of Geographically Distinct Strains of White Bass to Produce Sunshine Bass

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\textsuperscript{1}Fisheries and Illinois Aquaculture Center, Southern Illinois University, Carbondale, Illinois 62901-6511 USA

White Bass (\textit{Morone chrysops}) broodstock were obtained from three locations encompassing the native range of this species: Arkansas River, Arkansas; Lake Erie, near Cleveland, Ohio; and Lake Poinsett, South Dakota. In spring 1996, white bass eggs of each strain were fertilized with fresh semen from the same strain or with extended striped bass (\textit{M. saxatilis}) semen pooled from nine males collected from the Arkansas River. Each strain of white bass and sunshine bass was stocked at 500,000/ha as 4-d post hatch larvae into quadruplicated earthen ponds recently filled and fertilized. The fish were offered fry meal (~50\% crude protein) 21-d post stocking. Phase I fingerlings were harvested 35-d post stocking. Sunshine bass mean survival rates (12.5\%) were significantly higher than white bass (2.6\%). No difference in survival existed within the white bass or sunshine bass groups. Phase II sunshine bass were subsequently stocked in triplicated ponds at 25,000/ha. The fish were fed to satiation twice daily with a 40\% crude protein diet and harvested 100-d post stocking. Lake Erie sunshine bass mean weight (90.2 g) was significantly greater than Arkansas fish (58.4 g), but not South Dakota fish (69.0 g). Phase III sunshine bass were stocked in triplicated ponds at 5,000/ha and fed in the same manner as in Phase II. In fall 1997, ponds were harvested and all fish reached marketable size with Lake Erie sunshine bass averaging 647 g, followed by Arkansas fish at 638 g and South Dakota fish at 566 g. These weights were not significantly different (P > 0.05). However, Lake Erie and South Dakota fish had significantly (P < 0.05) higher dessouts (37.3\% and 37.8\%, respectively) than Arkansas fish (34.6\%). These results demonstrate the feasibility of raising sunshine bass to market size in earthen ponds in the Midwest. Lake Erie white bass might offer some advantage as a source of broodfish relative to the strains compared and under the conditions in which they were raised in this study.
Production of YY Male Tilapia

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Robert, LA

Abstract not available at time of printing.
Issues in the Commercialization of Transgenic Fish

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Abstract

The properly regulated use of genetically modified fish in aquaculture can allow for a rapid increase in the amount of fish protein available for consumption at lower costs than presently possible while limiting environmental dangers associated with fish farming. The commercial introduction of these fish will encourage the use of recirculating tank systems, save on the use of coastal waters, and create a more sustainable industry. Consumer acceptance, however will not be easy, and requires companies to be committed to policies of openness and education.

Introduction

The recent development of rapidly growing transgenic salmon, trout, tilapia and other finfish, has created concern among environmentalists. It is feared that genetically modified fish might pose further dangers to the health and safety of wild fish stocks than those posed by commercial aquaculture. Potential commercialization of such fish has also raised fears that their use might result in detrimental social and economic consequences for some groups (Hite and Gutrich 1998). It has been suggested, for example, that dramatic increases in aquaculture productivity, resulting from the application of genetic engineering technologies that are controlled by large corporations, could disadvantage underdeveloped countries relative to industrialized countries and could jeopardize the livelihoods of fishers everywhere (Open-ended Ad Hoc Working Group on Biosafety, Convention on Biological Diversity, 1996). Some special interest groups and countries have suggested, therefore, that the application of genetic engineering to fish farming be highly constrained if not prohibited altogether (CNI 1995; Greenpeace 1997). This paper takes the view that such draconian policies would be a grave mistake, with negative implications for the environment, the world economy and the supply of adequate amounts of fish protein worldwide. Instead, national and international policies that foster the safe development and use of biotechnology should be strongly encouraged and supported in aquaculture to increase utility and productivity.

The foundation of this belief is that harvesting wild fish for consumption, as practiced today in many areas, is not an environmentally sustainable activity, and that expanded, low-cost, environmentally friendly aquaculture would help to feed the world. Indeed, it has been suggested that aquaculture yields will have to increase seven-fold over the
coming 25 years simply to maintain current per caput fish consumption worldwide (Clayton 1995), and, according to FAO, the world is likely to see an increase of 300% in aquaculture production over the next 13 years (FAO, 1997). Improvements in the economics and environmental soundness of aquaculture are therefore required to ensure greater benefits to consumers and to the environment.

Status of Transgenic Technology

Transgenic strains of Atlantic salmon, Chinook salmon (Oncorhynchus tschawytscha) and rainbow trout (O. mykiss), grow 400% to 600% faster than their non-transgenic siblings during the early life stages and reach full market size in less than one-half the time required for non-transgenic fish of the same species (Hew et al, 1992; Devlin et al 1994; Maclean et al 1995). Preliminary evidence also suggests that food conversion rates may be improved by as much as 25%. Such transgenic Atlantic salmon can reach a weight of 3 kg in fourteen months from first feeding. In the same time period, transgenic rainbow trout routinely reach a weight of 4.5 kg. (Sutterlin 1998). Researchers working with trout, salmon, tilapia, carp and other species have all reported dramatic increases in growth rates based on using a variety of gene promoters linked to growth hormone genes. The result of this biotechnology-derived improvement will be dramatically increased harvests with reduced production costs and with diminished exploitation of scarce feed products. The attendant shift in economics will facilitate the use of more environmentally sound practices in aquaculture, as discussed below.

Environmental Concerns

Environmentalists’ fears of transgenic fish can be summarized in the form of two hypothetical and mutually contradictory dangers associated with their escape into the wild:

- transgenic fish will outcompete wild stocks and lead to a loss of genetic diversity;
- transgenic fish will be less fit in the wild, will crossbreed with wild types, and produce offspring with lower survival rates thereby reducing the total population of wild fish.

It is not the intent of this paper to argue the validity of either fear. Those wishing to examine the scientific literature will find a number of articles detailing the potential of adverse consequences resulting from the escape of farm raised fish, including transgenics. Some authors have suggested that these fears are overstated (Knibb 1997; Tave 1986) whereas others have held that the dangers are quite real, at least in localized areas (Regal 1994; Kapuscinski and Hallerman 1990, 1991; Hindar et al. 1991) The purpose of this paper is to suggest how the development of transgenic salmon with rapid growth traits can increase the economic value of aquaculture, limit its impact on the environment and enhance the well-being of wild fish.
*The Salmon Example*

Salmon farming is conducted almost entirely in open seawater cages and has resulted in a number of environmental concerns. The most frequently cited problems include the following:

- impact on wild stocks of large numbers of escapees - numbering in the millions of fish in a single growing season (NASCO 1994, 1997);
- impact of particulate, nitrogenous and other chemical wastes on local ecosystems (Gowen and Rosenthal 1993, McLay and Gordon-Rogers 1997, Ellis 1997);
- multiplication of water-borne infectious diseases associated with concentrated biomass (Goldberg and Triplett 1997);
- destruction of natural habitat due to reconfiguration of, or intrusion upon, coastal areas to support farming activity (Phillips et al. 1993; Ellis,1997).

Of continuing concern is that the projected growth of the salmon farming industry over the next 20 to 30 years (FAO 1997) would be expected to increase its environmental impact if present methods of farming remain unchanged. These problems will also apply to the farming of other species, the growth of which may be even more rapid. How then, to square the circle and to grow the larger amounts required for consumption while minimizing environmental impacts?

*The Use of Transgenics*

Based on technical progress to date, it seems probable that the application of gene modification techniques, if employed appropriately, offer one of the best opportunities for resolution of this problem.

The advent of transgenic salmon, which can attain market size in one-third to one-half the time historically required with less feed input, will allow for the commercial introduction of a new farming system based on the use of recycled-water facilities. These facilities have virtually no impact on surrounding waterbodies and can, in fact, be situated many miles from any coastal location. The critical factor allowing for the expanded use of these facilities and for subsequent reduction in deployment of open water cages, is the vastly improved economics associated with rapid-growth transgenics (Table 1). Improved feed conversion also enhances sustainability by requiring less of the world’s increasingly scarce feed proteins to support the aquaculture industry.
Table 1. Cost comparisons for transgenic vs. non-transgenic salmon production. In this *pro forma* analysis, a traditional farming operation is assumed to produce 1000 lbs of salmon per harvest over a 36-month harvest cycle; the transgenic operation has a cycle of 18 months and 20% improvement in food-conversion rates (FCRs). The cost-of-production (i.e., $1.50/lb) in the traditional operation is based on the industry average, comprising 40% for feed ($0.60/lb) and 60% for fixed costs ($0.90/lb). Both operations are assumed to be subject to a wholesale price ex-farm of $1.80/lb. Note that, the event that FCRs were not improved, production cost-per-pound for transgenic salmon would still be lower (i.e., $128/lb), resulting in total production cost of $2560, providing gross profit of $1040 (345% improvement).

<table>
<thead>
<tr>
<th>Aquaculture Operation</th>
<th>Non-Transgenic</th>
<th>Transgenic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest Size</td>
<td>1000 lbs</td>
<td>1000 lbs</td>
</tr>
<tr>
<td>Harvest Cycle</td>
<td>36 months</td>
<td>18 months</td>
</tr>
<tr>
<td>Total Cycles</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total Pounds</td>
<td>1000</td>
<td>2000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production Criterion</th>
<th>Non-Transgenic</th>
<th>Transgenic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Input-Cost (lb⁻¹)</td>
<td>$0.60</td>
<td>$0.52</td>
</tr>
<tr>
<td>Fixed Cost (lb⁻¹)</td>
<td>$0.90</td>
<td>$0.68</td>
</tr>
<tr>
<td>Production Cost (lb⁻¹)</td>
<td>$1.50</td>
<td>$1.20</td>
</tr>
<tr>
<td><strong>Total Production Cost</strong></td>
<td><strong>$1500</strong></td>
<td><strong>$2400</strong></td>
</tr>
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</table>

| Sales Revenue | $1800 | $3600 |
| Gross Profit  | $300  | $1200 |
| **Increased Profitability** | --- | **400%** |

Water recycling facilities have been available for many years, but have been ignored by salmon farmers until very recently due to their large capital investment requirements and high operating costs. The few salmon farmers who operate land-based facilities have generally been unable to compete economically with seawater cage operations and have become hatchery-nursery operations, concentrating on egg and smolt generation for sale to growout farmers.

This state of affairs has begun to change recently, albeit slowly, as a result of several factors. First, there is a growing realization within the industry that increasingly complex environmental regulations present a significant cost to farmers. In many locations, these regulations put a limit on production and require potentially expensive ameliorative efforts.
Second, as the salmon farming industry matures, the size and nature of the producers are changing. What was once an industry of small farmers is rapidly evolving into an aquaculture version of agribusiness: relatively large companies with multinational interests controlling an increasing share of production. These companies are less interested in least cost methods of production in the short-term than in the predictability of costs and harvest size in the long run. In any given year, a seawater cage facility may represent the most cost-effective method of production, but may also be subject to the highest degree of risk: storms, disease, predation, and changes in water temperature that can severely and unpredictably reduce yields. For large firms with the available capital, therefore, reliance on indoor systems represents a predictable alternative with greater opportunity for long-range planning and growth at diminished risk.

Third, recent improvements in the design and engineering efficiencies of modern recycled-water plants allow for higher stocking densities, less disease, fewer breakdowns and lower operating costs. The increased number of engineering firms now designing and promoting water-recycling systems ensures that improvements to filtering systems, pumping and oxygenation equipment, temperature controls and water flows will continue.

Despite these pressures and incentives to move from open water to indoor growout, the vast majority of salmon are still grown outdoors and the movement towards recirculation systems is slow. The primary reason for this is still the lower costs of growing salmon in open waters compared to growing in a capital intensive, highly engineered plant. The missing component, the single element which can drive the movement towards more environmentally sound land-based salmon farming, is the advent of fish which are significantly less expensive to raise. Rapidly growing transgenics, such as those developed in Canada by Dr. Choy Hew and Dr. Garth Fletcher (Hew et al 1992) and licensed to Aqua Bounty Farms under the tradename *AquAdvantage®*, Inc. meet this need.

The economic impact of the increased growth rates is enormous: not only is the cost-per-unit weight of production lower as a result of shortening the growout time and reducing the amount of feed required, production is essentially doubled over time because two harvests of transgenic salmon can be produced in the same time that it takes to produce one harvest of non-transgenic salmon. Preliminary economic analyses (Table 1) indicate that if a farmer were to receive the same market price for transgenics as for non-transgenics, profitability could increase by over 400%. Obviously, this will not happen, nor is it desirable. The preferable outcome will be a sharing of economic benefits between consumer and producer: lower costs of production and increased output will lead to lower selling prices and a larger market as people who presently cannot afford the product will find it in their price range (Hite and Gutrich 1998).

Even where the initial capital requirements for high-tech indoor growing systems cannot be met, transgenics will at least reduce input needs and increase output at lower costs - an invaluable benefit in a world where the price of fish makes it prohibitively expensive for many.

The first transgenic fish to be commercially available, A/F Protein’s *AquAdvantage®* salmon, are being grown in the Company’s land-based facility. Commercial grow-out in open water cages will be permitted only for sterile transgenics, all-female triploids. Aqua
Bounty Farms believes that this eliminates any direct threat to the wild fish population, even if it does not fully address certain of the other environmental concerns cited previously. The policy issue here is, is it not more acceptable to raise sterile, rapidly growing transgenic fish in open water cages than fertile, slow growing non-trangenic fish? If the commercialization of transgenic fish proceeds according to the principles of using environmentally isolated facilities or growing only sterile fish in open areas, this technology will produce a net gain for the ocean’s ecosystems by replacing systems with more severe impacts.

Conclusion

Recognizing the enormous potential benefit of biotechnology, such as the development of transgenic fish, means also recognizing that while regulatory oversight is necessary, regulations must be used to safely advance its use, not to hamper or eliminate the technology. Further, regulatory oversight should be developed in keeping with the thoughts expressed in the ICLARM-GTZ Bellagio Conference ‘Environment and Aquaculture in Developing Countries’ (Pullin 1993), that “environmental conservation and human needs must be balanced.” A sound understanding of the economic, nutritional and environmental advantages which transgenics can offer - through application of cost-benefit analysis - should be employed (Hite and Gutrich 1998; Balint et al. 1998). Examples where these guidelines to the development of policy have not been followed show that the results are negative to producers, consumers, and ultimately, to the environment as well (Ackefors and Olburs 1995).

References


