Entrepreneurial and Economic Issues of Recirculating Aquaculture Ventures

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Introduction

Fingerlakes Aquaculture LLC was created in June of 1997 by myself, my brother, Dr. William Youngs (Professor Emeritus Cornell University Department of Natural Resources -- and my mentor in aquaculture for 15 years) and a local businessman who owned a lumber yard and built and managed apartment units. In addition, Drs. Dave Call (Dean Emeritus Cornell College of Agriculture and Life Science) and Gene German (Professor of Food Marketing, Cornell University) were members of our Board of Managers that formed the startup company. At that time, live market prices for tilapia at the farm for our location in UpState New York exceeded $2.00/lb. The original financing of the company was personal cash, bank loans that were personally secured, and the lumberyard owner building the building with his own personal funds and then renting the facility to Fingerlakes in exchange for equity ownership.

In July 1997 a second major cash infusion occurred by a successful entrepreneur with extensive experience and success in startups and also with previous success in agricultural type businesses and seafood. This cash infusion was initiated due to a negative cash flow for the first 12 months and the drop in market price from $2.00 to $1.70/ lb. The drop in market price indicated that the original capacity of the Fingerlakes farm would have to be increased if Fingerlakes was to be cost competitive. Unfortunately, the market price continued to drop for the next several months to $1.30/lb farm price for live fish in small volumes (5,000 lb per week) with an anticipated farm price of around $1.10/lb for quantities above 10,000 lb per week. This again indicated that Fingerlakes would have to further expand to be cost competitive. A new round of financing was initiated which diluted the original members significantly but did raise the capital necessary along with bank loans to allow an expansion to be initiated from the late spring of 1999. And again, the bank loans required personal guarantees. This new farm became the growout operation to receive fingerlings from the original farm (Freeville operation) and grow them to market size. Full production from this farm is expected to be reached by mid summer of 2000. Economic success is anticipated because of: a) larger scale of operations, b) trained workforce, c) improved technology, d) adequate water, e) greatly reduced electrical costs, and f) targeted marketing approach.
Could we have been successful if we immediately had embarked on this larger scale farm? I do not think so. Unless you are simply adding additional systems from a "canned" design that is already working well, I believe you will face unexpected problems that will compromise your ability to achieve the cost effectiveness that is predicted on paper. On the other hand, once you have a working system and management protocols refined at some reasonable scale, e.g. 250,000 lb/yr, I do believe "that system" or farm can be reproduced multiple times to achieve the desired production levels and obtain the economies of scale necessary to achieve an economically competitive position.

Lessons Learned

Technology

After having led a major R&D effort at Cornell University for 15 years that was completely focused on indoor Recirculating Aquaculture System (RAS) technology, the Fingerlakes principles felt very confident, maybe overconfident, that employing the full-scale systems from the Cornell R&D sites to commercial implementation would face no major obstacles. Wrong. The Cornell system was based upon microbead filters and continuous biomass loading. After approximately one year of working with high rate fluidized sand beds at the Cornell facility and being convinced that ultimately, sand beds would prevail as the most economically competitive biofilter system, Fingerlakes installed sand biofilters as the biofilter of choice. The anticipated production level of the Fingerlakes’ first facility was 400,000 lb per year but depended upon the Cornell system of continuous biomass loading, i.e. there are a mixture of size cohorts in a single tank with a harvest consisting of approximately 15% of the large fish being removed and then this number of small 75 gram fish being added back to the tank.

Pro-actively and essentially before the first fish were placed in the new facility, Fingerlakes abandoned the continuous biomass loading approach to a strict “all in all out” batch loading approach. Batch loading provides very accurate feed conversion and growth data at each tank harvest. We felt that this was in fact the most critical information we needed to generate at that time since it was these data which in reality would define the overall economics of a large scale effort. The downside to this was less anticipated production per year. But at the time, the market price was still high (October 1997). We thought we could survive the lower production levels since it was "only" an interim approach. We were over-confident that these initial results and supporting data would lead to a large scale effort in the near future, e.g. millions of pounds per year as target production levels. We also made a change from the Cornell system that relied primarily on settling basins for solids removal to one that relied primarily on mechanical screen filtration. Unfortunately, cost consideration sometimes, too often, over-ride engineering judgement. We erred by under-sizing our mechanical screen system and this contributed to high suspended solids levels in the rearing tanks, which also compromised fish performance.
Our largest error though was in not having an assured source of ground water to operate the farm. Needless to say, **never never never** start construction until you are convinced you have adequate water on site to provide at least 20% water exchange volumes per day. Also, expect that initial well recharge capacity will drop approximately 50% from its initial delivery levels (what you see over a one-week period of constant pumping during the exploratory phase) once the well is used on a continuous basis for a year. So, if you have 100,000 gallons of standing water in your system, you need a well capacity of at least 20,000 gallons per day which means your initial well capacities should be 40,000 gallons per day or 28 gpm. Just to give you an idea of our nightmare --- we drilled 5 wells at the first farm site, 4 of them after construction. Our first well provided 8 gpm of water during tests, but "dried up" during construction (well, not quite, reduced to about 0.5 gpm of flow). In my engineering egotism at the time, I believed we could successfully run the barn on about 8 to 10 gpm of continuous well flow. What is typically **not** accounted for in water needs are: a) Purging, b) Cleanup, c) Flushing during tank emergencies, d) General usage, and e) Loss of well capacity.

We pursued a whole series of efforts including water recovery from the manure settling ponds and ground filtration and ozone treatment--- but these were not satisfactory. You must have water in the quantities as described above as a **minimum**. Our expansion farm went to a site that provided public water and had several hundred gallons per minute of excessive capacity.

**Capital Costs and Economic Returns.** The technology being used must support an overall economically competitive operation. You should assume something near 5 years on depreciation but more importantly, the initial cost of your start up equipment will define in part the company's anticipated internal rate of return on the investment. In round numbers, your equipment should cost not more than $0.50 per pound per year (PPY) of production and the building, land, utilities etc will cost an additional $0.50 per PPY. If these up-front investment costs are too high, your farm's internal rate of return on investment will be too low to attract outside investors.

**Management.**

I think in most cases, investors and others grossly underestimate the importance of previous management experience with RAS technology and for the intended species to be grown. Experience with salmonids in RAS is not the same as tilapia in an RAS and vice versa. The management team that was in place at Fingerlakes' inception was extremely strong: Dr. W.D. Youngs (GM, previous large scale experience, noted fisheries authority), Michael Iannello (previous GM of a large 1.0+ million lb/yr integrated salmon farm in Maine), Ken DeMunn (President, very successful local small business owner), and Scott Hoffay (successful home construction business). In effect, I felt we had about as strong of a management team that was possible. Even with this experienced management team, Fingerlakes barely survived the first 2.5 years. As I stated above, I also believe if Fingerlakes had tried a larger scale of effort than their initial farm, they would have failed categorically. Fingerlakes' first year of full production resulted in 168,000 lb of sales. Why didn't Fingerlakes reach their expected level? I would attribute
it to a lot of things, but basically, the lack of water was a severe compromise to Fingerlakes' ability to produce fish.

**Financing.**

Regardless of all we hear about government guaranteed loans for business startups, in my experience, it came down to equity infusion (self and outside investors) and personal guarantees of loans. The banks essentially will take no risk. They assume you will fail. They also assume that the value of the farm assets will be practically negligible. These are probably reasonable assumptions. The market value for used fish equipment is probably 10 cents on the dollar at best. Yes, you can probably re-sale your forklift for a reasonable salvage, but used pumps and other fish equipment are essentially of little to no value. The bank will therefore require that any loans to the company be personally guaranteed and in our case required "perfection" which means that we had to place assets in the bank's control that equaled or exceeded the value of the loans. This places the bank above other creditors in a dispersal or bankruptcy scenario.

On the original operating loan to Fingerlakes, my brother's and my personal stock assets were also only valued at 80% of face value (in case the stock market went down). Again, the bank will basically take no risk on a business start up. We followed several unfruitful experiences with lending and leasing entities and they all ended up at the same point, either provide equity guarantees or the farm (Fingerlakes) did not qualify for a loan. Also, bear in mind that these financing activities require tremendous time efforts by someone to pursue sources, develop materials, and attend meetings after meetings. Also, assume a successful loan closing will take at least 3 months before money is in your hands for use "after" the loan terms have been agreed to.

**Venture firms.** Venture firms are also supposed sources of capital. A typical venture firm will invest in less than 0.1% of the proposals that are presented to them! My experience during our initial rounds of seeking capital was that the venture firm assumed that what you had was probably not unique, that if you could do it-- so could countless others, and that the overall potential to make money in a food related business was not attractive, especially in comparison to other investment alternatives they had access to. So, unless, you have an inside track with the venture firm (some of which we did and we were still unsuccessful)-- the likelihood of obtaining equity from them is basically zero!

On the other hand, once Fingerlakes had the Phase I operation up and running and had demonstrated the ability to breed and produce fingerlings successfully, grow fish with reasonable performance values, and sell fish successfully-- we were successful in bringing in equity cash for our Phase II effort (the growout facility). Our interim investor between Phase I and Phase II, which was the first time we ran out of money, though, was closely connected with this venture firm and had a large degree of influence with them. I do not believe we would have obtained their investment otherwise.
Before You Invest.

In my role as a university researcher and extension professor, I am often involved in helping people to decide on whether or not entering aquaculture is a wise investment decision. In particular, should an investment be made. My own opinion is that very few groups or individuals are capable of raising fish using RAS technology or raising fish at all in any kind of system. I would not recommend anyone invest in an aquaculture operation until the group had successfully demonstrated their capability to successfully raise fish. Then, based upon their initial results, can the company be profitable in an expansion phase. And, the prediction of business profits should be made using realistic values for selling prices.

Species Choice.

We chose tilapia because we believe that this fish has the attributes to be the equivalent of the broiler chicken. The industry's current problems associated with low market prices in reality are not valid in relation to tilapia being a commodity product. The only fish commodity product that can be used as a comparison is the catfish industry, which produces 600 million lb per year in comparison to US production of tilapia being 18 million lb. Pond side prices paid to the farmer for catfish are generally around $0.75/lb whole fish basis. Fillet yields for catfish are 45% and tilapia yields are now at best around 33%. Thus, the equivalent farm price for tilapia would have to be $0.55/lb. Genetic improvements in carcass yield will balance the pricing, but until then, large scale tilapia farming will have to be competitive with farm prices as noted above.

A general theme for those entering aquaculture is to choose a high value species, such as perch or walleye or ornamental fish. The primary reason these fish are at high market values is that their supply is very limited. Once, aquaculture develops successfully for a particular species and the market supply dramatically increases, the market price dramatically reduces. Also, don't be fooled by these scenarios of apparently lucrative markets. There is a reason that the market is under supplied and driving the high price. Dramatic price reductions have been seen in the salmon and striped bass industries where market prices dropped by roughly 50% in less than a year's period. Similarly, tilapia prices have been falling from the high market prices of a couple years ago and I expect prices to drop further.

Scale Effects and Risk.

The primary consideration that should dictate a particular biomass fish load for an independent production system is associated with catastrophic failure. Systems fail as units and typically all fish in a particular unit will fail. Biofilters are one source of failure. In my view it is more cost effective to minimize the number of biofilters on a farm so that each can be designed with substantial redundancy and excess capacity. The counter argument is to design small biomass systems with individual biofilters so that when a system fails, the severity of the economic loss is small since an individual system represents only a small fraction of the entire system. In the last farm I designed,
I used one biofilter for a 250,000 lb per year production module. But I designed this farm to have 6 independent biofilter systems for the entire operation. I would suggest that each farm should have at least 4 independent growout systems, so that one would only lose 25% of their crop under catastrophic failure of a particular system.

**Scale of Production.**

Fingerlakes first farm targeted 250,000 lb per year as their production target. Their expanded farm is hoping to produce 1.5 million lb per year. Unfortunately, even this level of production is not nearly that necessary to be competitive with the overseas producers of fresh tilapia fillets where fillets are processed for roughly $0.03/lb and farms are in the 5 to 15 million lb/yr size. Our fillet costs using hand labor approach $1.00/lb fillet basis with expert hand cutters and trimmers being at best around $0.50/lb. However, both PICES and Baader are close to having fully automated processing equipment that can reduce fillet costs to $0.25 to $0.75 per lb. This fillet cost would allow the US producer to be cost competitive with the overseas suppliers. The problem is that the automatic filleting equipment requires volumes on the order of 5 to 10 million lb per year to justify the initial equipment expense. Other economies of scale start to emerge at this level of production as well and begin to provide alternatives related to "in-house" feed manufacturing, oxygen production, electrical generation, and fish by-product utilization.

Being in the several 100 thousand lb per year production farm level is probably the worst position to be in. You basically have to many fish to deal with to develop and serve niche local customers and you need a fairly large staff and set of fixed costs to protect your investment which contributes to high overall production costs. Either you get really big like the catfish farmers or you stay really small and basically do everything yourself.

**Labor requirements**

This will become a major choice in your operation. Fingerlakes employs 7 day a week 24 per day coverage. Other growout farms rarely employ this type of coverage. Certainly during the startup phase for the first year, I would highly recommend this type of coverage. As the system matures and built in alarm systems infrequently are activated due to loss of flow, water level, low oxygen etc--- then one could start to consider easing the coverage of the fish farm. Experience shows that alarm systems will alert to an actual problem about 50% of the time in reality. Yes, they should be much better, but this is what happens in the real world. There is a delicate balance between monitoring too many things and not enough.

**Comparison to Catfish & Broiler Production and Future Projected Costs.**

I compare in Table 1 the predicted costs of tilapia production based upon performance data collected at Cornell University and Fingerlakes Aquaculture LLC (Groton, NY) with previously published data for: a) Mississippi catfish production from large outdoor ponds, and b) chicken broiler production costs. The production levels for the fish systems
are 590,000 kg/year. Prices, depreciation values, and associated economic factors for the catfish farm are taken from Keenum and Waldrop (1988). Overall, the tilapia production costs were slightly higher than the catfish production costs, $1.62 per kg versus $1.56 per kg. The major point of the comparison provided in Table 1 is that when indoor tilapia production is practiced on a similar scale as the large USA outdoor catfish ponds, the costs of production are also very similar. Initial system costs for tilapia and catfish are similar: $1.37 (tilapia) and $1.44 (catfish) per kg per yr of production. The investment costs for fish farming are roughly 3 times the initial capital investments for broiler production of $0.49 per kg per yr of production capacity. These costs must be brought down and they will as we improve our designs. System costs would be expected to reduce by 25% over current costs due to improvements and refinements in system designs.

Ultimately, fish production from aquaculture will have to compete with other commodity meats such as poultry. It is instructive to compare predicted costs of production for fish from indoor and outdoor facilities with those of broilers. Broiler production data is based upon USDA statistics (USDA, ERS 1996 a,b, c) and my personal knowledge gained from 20 years working in the industry. USA broiler production is now based upon vertical integration with the broiler grower being the contract farmer. The farmer owns the building, provides husbandry, and pays the majority of the utilities. For these services the farmer is paid approximately $0.09 to $0.11 per kg of broiler produced. Thus, all costs associated with building ownership, depreciation of capital equipment, labor and utilities (electric and water and generally about 50% of the fuel heating costs) are borne by the farmer. The productivity per worker has increased from 95,000 kg of broilers per year in 1951 (Watt Publishing, 1951) to 950,000 kg per year in 1991 (Perry, 1991). Similar achievements have been made in equipment, housing, and nutrition and genetics; it is interesting to note that broiler production in the 1950’s was around 5 million kg per year. The productivity per unit of worker and total broiler consumption of the 1950’s is very similar to the current production levels of the USA tilapia industry (7 million kg of tilapia per year) and the productivity per person in the fish farming business is approximately 25,000 to 110,000 kg per year.

Ultimately, indoor fish production has two distinct advantages over poultry production: feed conversion efficiency and productivity per unit area of building. Broiler production has feed conversion efficiencies of approximately 2.00 (2.09 bird weight, feed to gain ratio on feed energy levels of 3,170 kcal/kg and protein levels of 19.5%), while tilapia conversions are currently in the 1.3 to 1.5 range for feed energy levels of approximately 3,500 kcal/kg. The yearly meat output per unit floor area from the tilapia system is 255 kg/m² compared to 122 kg/m² from a broiler house. Thus, net economic productivity per year from a fixed tilapia production facility could be higher, even though the costs of production per unit weight are higher compared to broilers. The advantage for fish production systems is their higher potential rate of return per year from a fixed facility.

References

Table 1.
Comparison of tilapia, catfish and broiler production costs for farms with a yearly fish production of approximately 590,000 kg: costs shown on a per unit weight of production and percentage of total cost by category.

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<thead>
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<th>Ownership costs ($/kg)</th>
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<th>% of Total Cost</th>
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<tr>
<td></td>
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<td>broiler</td>
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<td>Fingerlings (chicks)</td>
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Total cost of production ($/kg) | 1.62 | 1.56 | 0.65 | 100% | 100% | 100%

Note: Broiler costs are broken down for comparison based upon contract grower payments and allocation of costs between grower and integrator.
University Development of Recirculating Systems:

The development of commercial recirculating aquaculture has its roots in two different worlds. The first is in biology, and the second is in wastewater engineering. I first became exposed to this new hybrid field in the latter part of the 1970’s when I became a grad student in the Aquaculture Research Laboratory at the University of Wisconsin in Madison. Here was one example of the type of Sea Grant research funded at that time to help the promise of aquaculture become a reality, and with expectations that it would happen very soon. The program, started by dairy professor Dr. Harold Calbert, was a venture that sought to find supplemental year-round income for dairy farmers who had empty barns sitting around the Midwest. The program got funding to construct three commercial scale recirculating systems inside a leased industrial building on the edge of town. This is where fish biologists and wastewater engineers came together to create something new. The goal was to raise yellow perch indoors under controlled conditions, and to show the world the promise of recirculating aquaculture. The work of the systems was done in three different configurations, involving large circulating pumps, high pressure sand filters, tube settlers, trickling biofilters, and Koch rings. Turbidity, excessive backwashing, and difficult solids removal were the first problems to be discovered. The addition of flocculants such as alum, and new settling areas helped, and yellow perch were raised to market size from fingerlings in 9 to 11 months at 21 degrees C. When the number crunching was done, the cost of production in 1979 was estimated at $8.65/ kg ($3.86/ lb). In today’s dollars that is $20.40/ kg ($9.11/ lb). At the time, the market price for Great Lakes yellow perch was $3.26 to $5.80/ lb in today’s dollars. The price of pioneering comes high. The focus of the Wisconsin aquaculture program quickly changed under the guidance of Dr. Terry Kayes, and my time there was spent studying protein metabolism and carbohydrate tolerance in rainbow trout.

Commercial Development of Recirculating Systems:

When I finally had an opportunity to start my own aquaculture facility in 1983, it was in a bankrupt chicken farm on the edge of my hometown back in Ohio. It was there, with the help of my engineer father and family, that I sought to develop a farmer approach to recirculating aquaculture. The challenge was to make it simple, make it
cheap, and make it do the job. Our first two prototype recirculating raceways were built with loosely stacked concrete blocks, two rows high, and lined with styrofoam and plastic liners. Even these 75 foot long structures looked small in our 350 foot long chicken barn. The main lesson I brought back from Wisconsin was the crucial need for solids removal. This was done with settling areas behind penned section of trout, and with a filter section made of cut-up plastic field tile. The removal of suspended solids allowed our main biofilters to remain clear of organic residues, and the submerged pea-gravel filters were found to operate 8 to 10 years before need of cleaning or replacement.

More refinements were incorporated into a second generation design, such as airlift pumps and aeration or “tidal” flushing of the biofilters, and the core of our business was the production of market-sized rainbow trout at a cost of $0.75 per pound. That may not be good in Idaho, but when you have markets of 1.5 million people an hour away, the ability to sell a premium fish product improves the economics. These older recirculating systems are still in continuous operation, and their production of one half pound trout per gallon of water are maintained with 95-98% recirculation.

The most important thing we have discovered at our facility is that in insulated pole barns (with supplemental solar heat) the water temperatures are easily maintained between 50 and 70 degrees F. This is very suitable for trout, and the recirculating systems, which we dubbed “WaterSmith Systems” allowed their installation in numerous other farms where water was a limiting factor. Pre-treatment of incoming water is sometimes necessary when excessive levels of iron (>0.5ppm) or ammonia (>1.0 ppm) are present in the water supply, but most well water sources are adequate. We have converted many other hog farms, cattle barns, and chicken farms since 1988, and have formed a network of growers in our area with joint feed purchases and marketing through Freshwater Farms of Ohio.

Production costs now vary between $0.82 and $1.09 per lb., and the delivered price of graded whole live trout to our processing facility is $1.65 per lb. Therefore our farmers are operating on a margin of $0.56 to $0.83 per lb., depending on the particular facility. The key here is that a WaterSmith raceway system can be installed for as little as $5,000 in renovated hog pits that are capable of producing 10,000 pounds of trout per year. No supplemental heat has ever been necessary when our solar heater system is used, and for good reason, as heating a system of this size just 1.0 degree C. can add $0.85 per pound in production costs (year 2000 dollars, Meade, 1973).

Our third generation design has been in operation over a year, and incorporates the same filter systems we have used for the past fifteen years, but incorporates time-saving and space-saving improvements. In a space of 13 feet by 20 feet we build modules with conical bottom polyethylene tanks set in the gravel biofilters for support. This approach allows three times the production in the same space as our raceways, and foregoes the normal daily chore of vacuum sweeping the settling areas of raceways (20 minutes per day per raceway). The system consists of two tanks per filter module, with a combination of sizes available, usually 950 gallon or 1500 gallon tanks. The latter requires ceiling heights over 12 feet, or with below-grade excavation, 10 feet. We also
have projects in the planning stages that will incorporate these 1500 gallon tank modules in retrofitting hog barns with 8 foot deep pits, with existing slats providing access to the tank tops. One converted cattle barn has had these same modules in production for over a year, and capacity at time of harvest was 1500 pounds of trout per module. We seem to reach an oxygen transfer limitation at levels above that, and modifications to incorporate the use of bulk liquid oxygen are being examined.

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Introduction

Most of the world’s commercial seafood species are either declining or on the verge of over exploitation. Approximately 93% of known wild stocks of fish are used at or above their optimum sustainable yield (DOC, 1993). In the Southeast U.S. of the 15 species listed as of “major” importance, 11 were listed as “over” exploited, three were “fully” exploited, while one species was listed as “unknown” status (DOC, 1993). In the November 1998 report to Congress on the status of marine stocks, NOAA Fisheries reported that 100 species reviewed are overfished or are approaching an overfished condition, while an additional 200 species are not overfished (NMFS, 1998).

The world’s edible fisheries supplies have stabilized at approximately 80 million metric tons, but the world’s projected demand for seafood will be 110 to 120 million metric tons by 2010. As the upward trend for seafood increases, the U.S. must develop alternative seafood supplies or suffer increasing trade imbalances in fishery products (Garrett et al., 2000). Nevertheless, the demand for high quality seafood is expected to continue to increase over the next several years, exceeding that which can be supplied by commercial harvest of wild fisheries (Garrett et al., 2000).

In the face of declining wild catches and increasing prices, there has been a decline in total seafood consumption from a high of 16.2 lbs. in 1987 to 14.9 lbs./person in 1998 (NMFS, 1999). As a goal, the National Fisheries Institute has set a consumption goal of 20 lbs./person by the year 2000 (Anon., 1990). The trend for reliance on seafood imports has been steadily increasing for the past 10 years to the extent that the U.S. now imports more than 50% of its total consumption of seafood from more than 172 countries (NMFS, 1999). As a result, the U.S. is now the world’s second largest importer of seafood. World fisheries have undergone dynamic changes. The value of international trade in fish and fishery products has increased from US $2.2 billion in 1968 to more than US $43 billion in 1998. In 1998, the U.S. exported $2.3 billion in edible fishery products and imported $8.2 billion resulting in a trade deficit in edible fishery products of $5.9 billion (NMFS, 1999).
As the upward trend for seafood demand continues, the U.S. must develop alternative seafood supplies or suffer increasing imbalances in fishery products. Aquaculture is one of the fastest growing areas of agriculture. Throughout the world, aquaculture provides approximately 20% of the world’s seafood harvest, increasing more than 85% between 1984 and 1992 (Anon., 1995).

Estimated U.S. aquaculture production in 1997 was 348 thousand metric tons consisting primarily of baitfish, catfish, salmon, trout, clams, crawfish, mussels, oysters, fresh and saltwater shrimp, and other species such as striped bass (*Morone saxatilis*), tilapia, etc. Imported aquacultured seafood is responsible for most of the $5.9 billion U.S. trade deficit in edible fishery products (NMFS, 1999). In shrimp alone, for example, large quantities are imported from Mexico, Ecuador, Indonesia, Pakistan, and Thailand. Other principle U.S. imported species include tuna, lobster, groundfish, and salmon (NMFS, 1999).

U.S. domestic landings are not expected to increase, and any near- and long-term additional increases in seafood products will have to be produced through domestic aquaculture operations in order to meet future demand and reduce U.S. reliance on imported seafood.

**Potential Risks**

This trend for reliance on imports will probably increase, along with additional Federal and state environmental regulations to protect wild aquatic stocks, habitat, and water quality. The U.S. aquaculture industry has the potential to help reduce this trend. However, the culture of non-native species poses potential threats to native aquatic animal species, native aquatic plants, and the environment. Nevertheless, with few exceptions, such as those for bacterial and viral diseases in salmonids and catfish, there is no risk management strategy in place to provide protection against the introduction of exotic species or disease pathogens that could decimate our natural wild species (Garrett et al., 2000).

Most disease transfer from cultured to wild species occurs in conjunction with introduction of non-indigenous species. The absence of a logical risk management approach to control these hazards presents a major challenge to the aquaculture industry. Countries around the world have neglected such disease control procedures and have suffered dramatic negative consequences. One example is the introduction of the “crayfish plague” in Britain by farmed crayfish imported from the U.S. (Thompson, 1990). Farmed fish and shellfish have also been implicated as reservoirs of disease organisms (Monro and Waddell, 1984). Weston (1991) reviewed the literature and reported that 48 species, which were parasitic on freshwater fish, were transferred among continents via importation of live or frozen fish.

Some of the more recent episodes in the U.S. include the introduction of the shrimp Taura virus, yellow head, and white spot viruses into South Carolina and Texas shrimp farms. Recent studies indicate that native wild white shrimp may also be susceptible to
these exotic viruses (Anon, 1995). Without an appropriate risk management strategy, these diseases have the potential to eliminate the shrimp and aquaculture industries in South Carolina and Texas.

The potential for transmission of exotic diseases, specifically shrimp viruses, into native wild stocks has been recognized by the Texas Parks and Wildlife Department (TPWD) as the single most serious resource management issue (McKinney, 1997). The South Carolina Department of Natural Resources (SCDNR) has developed a risk management approach to permitting importation of non-native stocks (Stokes and Browdy, 1997). Other states such as Texas and Minnesota, have written regulations concerning possession and transportation of exotic species. This is a good start, but a more comprehensive risk management approach needs to be incorporated into state and Federal plans.

Disease outbreaks within an aquaculture facility are a common occurrence that, if unchecked, can wipe out an entire year’s crop (Schwarz, personal communication). The detrimental effects of disease are even more apparent in intensive recirculating aquaculture operations. To control disease, many aquaculture companies rely heavily on the use of chemotherapeutics. Currently there are only five approved antibiotics for use in aquaculture, and these can only be used for certain species and certain life stages. Inappropriate and/or misuse of such chemicals is not only illegal but can pose potential food safety hazards to consumers (Garrett et al., 1997). Similarly, the transmission of *Streptococcus iniae* from whole fish to human fish cutters illustrates the complex interaction of animal, human and environmental safety issues associated with aquaculture (CDC, 1996; Garrett et al., 2000).

In addition to diseases and exotic pathogens, the aquaculture industry also faces major challenges concerning escapement of exotic species and subsequent displacement of wild native species from their natural environment. An example of this is the escapement of 100,000 pen cultured Atlantic salmon into the Puget Sound (Brennan and Keene, 1997). There are numerous other examples of escapement of exotic species from aquaculture operations into the wild, potentially displacing native species and altering gene pools.

**Application of Haccp Principles for Risk Management**

The Hazard Analysis Critical Control Point (HACCP) system is a risk management approach that has been accepted on a worldwide basis to prevent major food safety hazards. The Codex Alimentarius Commission has recognized the benefits of HACCP for use as a global food-control system (Garrett et al., 1997). In addition to food safety, HACCP principles can be used to control a variety of non-food safety related hazards. At a National Marine Fisheries Service (NMFS) “Workshop on Integrated Assessment of Shrimp Pathogens,” the HACCP concept was proposed as a potential risk management tool to control exotic shrimp viruses in shrimp ponds and processing facilities (Jahncke, 1996). The Food And Agricultural Organization (FAO)
and the World Health Organization (WHO) also recommended that the HACCP concept be applied to fresh water aquaculture programs in Asia to control foodborne digenetic trematode infections in humans (Son et al., 1995; Santos, 1997). The results in Vietnam showed that application of HACCP principles to silver carp culture in North Vietnam was effective in preventing and controlling *Clonorchis sinensi*. Similarly, the application of these principles to fresh water aquaculture ponds in Thailand and Laos to control *Opisthorchis viverrini* infections was also successful (Son et al., 1995; Santos, 1997).

Application of HACCP principles at aquaculture sites has the potential to control transmission of exotic animal and human pathogens, and escapement of exotic species. However, except for the application of HACCP principles to control human pathogens in Asia, no additional research on the use of HACCP Principles for these purposes has been conducted.

References


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Report from Southern States

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Abstract not available at time of printing.
Introduction
Recirculating aquaculture systems (RAS) offer many advantages including reduced water consumption and environmental impact, and enhanced siting flexibility. Well-designed RAS provide high levels of control over water temperature and other parameters that can positively affect the biological performance of the species being cultured which in turn drives the economics of the business.

A review of numerous commercial projects developed over the last decade suggests that despite these advantages, RAS have not fulfilled their commercial potential due to three persistent problems: (i) higher than projected capital costs, (ii) prolonged start-up and debugging, and (iii) the inability of the life support system to consistently maintain adequate water quality while sustaining intensive feed input. These factors tend to reduce output and increase unit production costs. Our economic analysis makes it clear that even well designed RAS can only be economically competitive if they overcome certain inherent operational costs by consistently achieving superior biological performance in term of fish growth, feed conversion efficiency and survival.

How Can Superior Biological Performance Be Achieved in Commercial Systems?
Although a great deal has been learned about the underlying unit processes from which RAS are constructed, achieving consistently superior biological performance represents a far broader and more significant challenge. Over the past decade, we experienced a disturbing gap between our understanding of the system components and the full range of practical considerations essential for commercial implementation.

As designers of commercial RAS, we are challenged to meet a number of seemingly contradictory objectives. First, selection and integration of appropriately scaled unit processes is required to make efficient use of feed, oxygen, electricity, and other inputs. Second, implementation of the physical systems must be sufficiently robust to meet the demands of commercial production, minimize maintenance-related downtime and offer very low cost. Optimally, the system should also link some degree of reserve treatment capacity to monitoring and control devices capable of minimizing the impacts of feeding and fish activity in real time. Finally, the configuration of the physical facilities should be thoroughly integrated with a well-designed management regime. Failure to appreciate the risks of imprecise management can results in poor utilization of system capacity and
increase the potential for bottlenecks as successive batches progress toward market. In our view, these key success factors remain largely under appreciated.

**Background on Technical Development**

Fins Technology, (formerly AquaFuture, Inc.) is one of the world’s largest and longest operating recirculating aquaculture facilities. The company pioneered many of the basic process technologies that have become the standard for RAS in the U.S. Fins Technology has integrated three major elements in its technology platform: (1) high-performance life-support hardware, (2) process optimization methods, and (3) Fast-Track breeding to produce genetically superior fingerlings. Beginning in 1988, AquaFuture developed its *first generation* technology within a 4,000 square foot pilot plant in Turners Falls, Massachusetts. The Company’s production of hybrid striped bass (HSB) demonstrated that significantly faster fish growth could be achieved within a controlled environment.

In 1990, based on the success of its pilot operation, AquaFuture, Inc. undertook an 80-fold scale-up of its process by building 10 independent, 3 MGD *second generation* systems within a 40,000 Sq. Ft. facility. In 1993 and 1997 the plant was expanded to better integrate nursery activities and currently recirculates over 150,000 cu meters of water/day (28,000 gpm). Fish sales were initiated in 1991 with continuous weekly shipments.

Despite two years of pilot experience and the breadth and depth of our technical team, many parameters specific to production of HSB within RAS remained poorly defined through scale-up. These parameters included HSB’s tolerance for NO\(_3\), CO\(_2\), TSS, high temperature and culture density. Because the majority of research on HSB had focused on pond production of juveniles, it was necessary to undertake significant in-house process evaluation to generate data necessary to continue the evolution of the system.

Fins Technology patented fluidized bed bioreactor was a key development that provided vastly increased bio-treatment per unit of filter volume. This device allows biosolids concentrations 5 to 10 times greater than can be achieved with conventional bioreactors. The reactors surface area allows for shorter process retention times and substantial reduction in the size and cost of treatment facilities. The filter balances microbial growth with continuous cleansing of the media. This significantly increases process stability while reducing maintenance requirements and lowering operational costs. For striped bass, high oxidation rates and excess surface area reduce diffusion limits providing the capability for rapid response to changes in water quality. This is an important consideration for practical management of commercial systems which has not been widely described in the literature.

**Integration of Fish Health Management Systems**

In 1993, an expansion of the company’s facilities over-extended the available water resources and reduced our ability to maintain culture temperature within acceptable limits during summer months. This caused significant elevation in mortality associated with opportunistic bacterial infections. This forced us to implement a broad based health intervention plan which included improvements to internal water disinfection, routine
fish health sampling, vaccination, probiotics, INAD’s, and increased access to make-up water to better control temperature. Perhaps more importantly, it reinforced the need to think of and understand the system as a whole; gaining an appreciation for how seemingly small changes in condition might result in large differences in outcome. This was a critical management lesson that would be reinforced again and again over the years.

**Process Evaluation Leads to Further Improvements Technology**

After stabilizing mortality, the company was able to implement improvements to its treatment process that had been developed as a result of the process evaluation effort. Development, testing and installation of upgraded filtration systems enabled increased feeding intensity while improving key water quality parameters by as much as 70%. This upgrade shifted the principle constraint from the culture environment to the capability of the fish themselves.

**Breeding Program Introduced**

Having addressed the major limitations of the culture system, our research efforts were redirected toward breeding superior fish. In 1995 the company initiated a domestication program. Our goal was to establish a founding population of performance tested broodstock in order to produce superior performing fingerlings. Since 1995, the Company evaluated over 7,000 individually and/or genetically tagged fish from 70 families and 12 distinct strains. The top performing families resulting from this effort reach market 40% more quickly than commercially available hybrids. Ongoing efforts are underway to produce stable lines of superior hybrids for commercial production.

**Overview of Technical Accomplishments**

In 1998, after a decade of focused effort, AquaFuture developed its third-generation technology. This system optimizes the balance between fish biomass, feed input and filtration capacity, achieving a 50% increase in average daily feed input and nearly doubling production per filter module. The improved system offers a 70% reduction in capital cost per unit output and a 20% reduction in unit production costs while improving oxygenation and CO₂ removal and needing less manpower to operate. We then incorporated leading edge technologies including waste feed detection, a patented sump for segregating and removing mortalities and improved control systems. A comparison of first, second and third generation systems is shown in Figure 1.

**Integration and Experience**

A decade of commercial experience has underscored the need to broaden our development efforts to manage critical areas interrelated with, but beyond the controlled environment central to RAS. Achieving consistently superior biological performance requires well developed approaches to managing nutrition, health and genetics tailored to the species and culture system (see figure 2, below). Gaining access to effective metrics, tools and approaches has been both illusive and costly. On the positive side, some aspects of the controlled environment established in RAS have proven to be excellent platforms for making sustained gains in these critical areas.
### Figure 1: Comparison of First, Second & Third Generation Systems

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<tr>
<td><strong>Production</strong></td>
<td></td>
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<tr>
<td>Pounds Output Per Module</td>
<td>10,000</td>
<td>65,000</td>
<td>100,000</td>
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<tr>
<td>Average No. Fish Per System</td>
<td>6,500</td>
<td>40,000</td>
<td>60,000</td>
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<tr>
<td>Average Feed Input (Lbs/day)</td>
<td>50</td>
<td>330</td>
<td>500</td>
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<tr>
<td>Daily Fish Growth (Lbs/day)</td>
<td>30</td>
<td>200</td>
<td>300</td>
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<tr>
<td><strong>Operations</strong></td>
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<tr>
<td>System Volume (gal)</td>
<td>18,000</td>
<td>160,000</td>
<td>120,000</td>
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<tr>
<td>Recirculation Flow (GPM)</td>
<td>400</td>
<td>1,800</td>
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<tr>
<td>Energy Use: (kW/pound)</td>
<td>4.3</td>
<td>2.8</td>
<td>1.6</td>
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<tr>
<td>Water Use: (gal/pound output)</td>
<td>238</td>
<td>110</td>
<td>72</td>
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<tr>
<td><strong>Economics</strong></td>
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<tr>
<td>Capital Investment Per Module</td>
<td>$160,000</td>
<td>$350,000</td>
<td>$150,000</td>
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<tr>
<td>$ Capital / Ton Output</td>
<td>$18,000</td>
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<td>$3,300</td>
</tr>
<tr>
<td>Output Per Employee (tons/yr.)</td>
<td>5</td>
<td>21</td>
<td>60</td>
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### Figure 2: Key Disciplines Required For Successful Production within Commercial RAS

- **MIS Systems:** Monitoring Analysis & Process Control
- **Health Management Systems**
- **Nutrition & Feed Management**
- **Genetics & Breeding**

**Benefits:**
- Better Feed Conversion
- Lower Mortality
- Faster Growth
- Siting Flexibility
- Consistency in Quality
- Cost Reduction

**Controlled Environment RAS (with excess capacity to provide robustness)**

**Precise Control Creates a Platform for Consistent Quality and Improved System Performance**
Although valuable knowledge has been acquired about the issues that affect the success of commercial RAS, to date very limited information is available to help prospective users identify or address the practical issues of (i) project siting, (ii) managing the cost and quality of implementation, and (iii) developing robust though workable management systems. For us, identification of the unit processes that meet the opposing demands of robustness, efficiency and low cost was a critical first step. Proper implementation and cost containment represented a significant secondary challenge that many new users of RAS will undoubtedly find extremely problematic. Finally, accessing and integrating appropriate tools and strategies into the management regime is perhaps the most critical factor to achieving superior biological performance essential for commercial success. A decade of dealing with these challenges has taught us to anticipate how changes to one parameter might affect biological or economic outcomes. We’ve found no substitute for the value of long-term operational experience to develop realistic expectations necessary for developing successful projects in an increasingly competitive market environment.