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Land-Based Aquaculture Production Systems, Engineering and Technology: Opportunities and Needs

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INTRODUCTION

The farm gate value of the aquaculture industry in the United States was 978 million dollars according to the 1998 USDA Census of Aquaculture. Of that total, the Northeast region accounted for 13% or $127,393,000 generated from a total of 436 farms of which 275 utilize freshwater and 160 using saltwater including 145, which lease natural waters. Cultured products from the NE region are diverse, ranging from a variety of food fish and shellfish species, ornamental fish and plants, sport or game fish, frogs, restoration plant species, algae and marine plants for food (Table 1.)

Table 1. Aquaculture species and sales in the Northeast region.

Species	**Number of Farms**	**Value (dollars)**
Salmon	16	64,729,000
Mollusks (clams and oysters)	150	26,758,000
Trout	132	8,760,000
Hybrid Striped Bass	27	7,276,000
Other (frogs, algae and sea vegetables)	20	5,590,000
Aquatic Plants (ornamental and restoration)	10	5,500,000
Ornamental Fish	34	5,130,000
Tilapia	30	4,150,000
Crustaceans (crawfish, shrimp and others)	22	2,361,000
Sport and Game Fish	37	550,000
Baitfish	62	<500,000
Catfish	24	250,000
TOTAL	436	$127,393,000

In addition to the variety of culture species in the Northeast region, there is a similar diversity of production technology utilized. The most commonly used culture system is ponds which is also the predominant technology used in the US. This may seem surprising given the cooler climate in the NE, and therefore shorter growing season, but ponds, and their culture management practices, were the earliest technology to be developed and used by research and commercial entities. Figure 1 shows how the NE region compares to the US in use of various technologies. With the exception of ponds, the NE aquaculture industry utilizes more of the other types of culture technology, i.e., flow-through raceway and tanks, prepared bottom leases, recirculating tank systems, cages, and net pens.

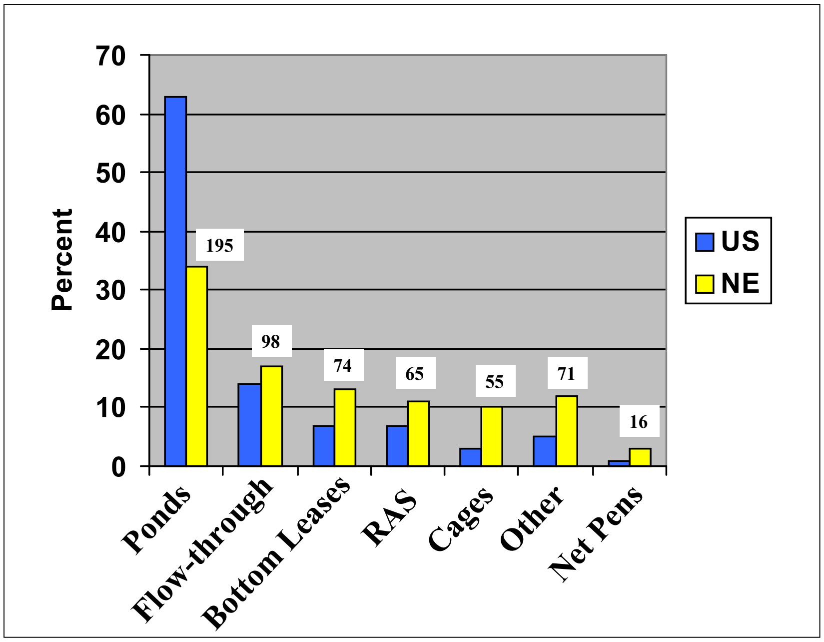

Figure 1. Comparison of the culture technology use of US and NE industry and number of operations in the NE.

As far as the sales generated for each type technology, net pens and bottom leases are the top two technologies with approximately 51 and 21 percent respectively (Figure 2). Both of these culture technologies utilize natural coastal water bodies and are discussed in another NRAC white paper: Open-Water Aquaculture Production Systems, Engineering and Technology.

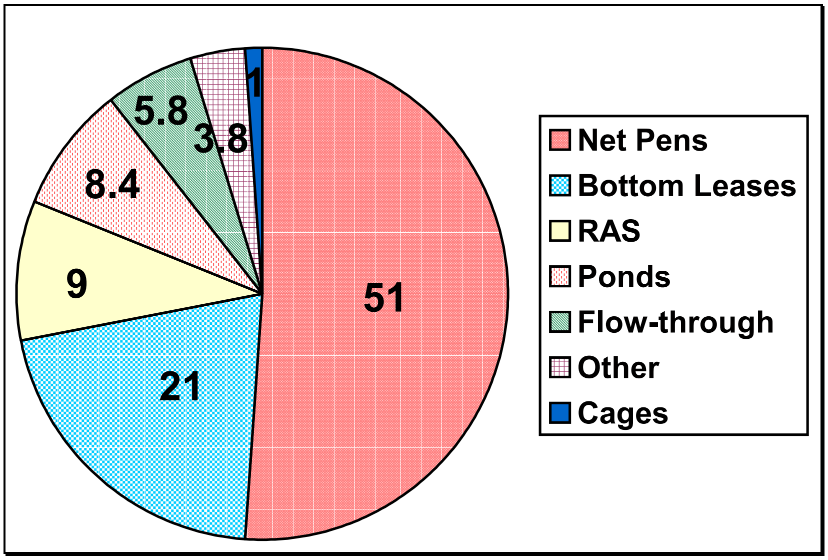

Figure 2. Percentage of 1998 sales for each aquaculture production technology used in NE region.

Land-based production technologies in the NE region comprising of ponds, flow-through raceways or tanks, recirculating aquaculture systems or tanks (RAS's), cages and other type technologies, and accounts for approximately 26% of sales or $35 million of the 1998 NE sales. Since the 1998 USDA NASS Census of Aquaculture survey there has been expansion in certain industry sectors as well as a notable decline in market prices for many species resulting in several closures of large foodfish production facilities. This white paper will present a brief overview of the status of each of the various land-based aquaculture production technologies and the opportunities and challenges of each type. In addition, recommended research needs to address those opportunities with emphasis on facilitating economic development will also be provided.

POND PRODUCTION SYSTEMS

Ponds are the most extensive culture technology used in the United States and in the Northeast region. A tremendous base of research information and commercial experience in design, construction, investment requirements and operational management exists for a variety of culture species including food, bait and ornamental fish, crustaceans and aquatic plants. Ponds also offer flexibility of use such as nursery and growout phases of production, water storage, effluent treatment and for recreation. The cooler climate in the region limits the growout period relative to the southern US where ponds are extensively used, and presents issues of competition and higher production costs.

Pond technology for food production, baitfish and ornamental fish and plants

The majority of ponds in the Northeast are used for freshwater foodfish, baitfish, ornamental fish, and to a lesser extent aquatic plants. The design characteristics including: earthen levee construction, 5-6 foot average depth, 3:1 levee slopes, flat bottom, are generally similar for most of the species produced, with the exception of crawfish and aquatic plants in which cases shallower depths are used and smaller size and choice of construction materials in the case of aquatic plants. The similar design and relative construction costs (not including land cost variability), well-established management guidelines and proven production efficiencies or track record of ponds, provide flexibility for producers and ensure that ponds will remain a useful aquaculture technology for the Northeast. These same attributes also provide opportunity and need for an analysis of which species and or market outlets result in the greatest economic return. The decrease in market prices of many food species within the past five years has necessitated operations to investigate higher value species or expand direct sales to consumers. This retail sales strategy is common in the Northeast, where pond operations tend to be small in scale, which in turn, results in higher production costs, reinforcing the need for higher value species and higher sales price of retail type markets.

Bait is typically a higher value product than foodfish, potentially offering greater economic feasibility depending on marketing strategy. Fathead minnows, golden shiners, sucker, carp and crawfish are the major bait species in the region, with the majority of production in ponds. Tanks are also used for holding, grading and conditioning on bait prior to sales. Other species of bait have potential in the region, especially marine species such as mummichog or other killifish species and spot. Where foodfish species' wholesale prices range from $0.70-2.60/pound, bait is sold at $4.00-10.00/pound depending on species, sizes and time of year. Although bait culture is relatively limited in the region, the large population and popularity of recreational fishing provide for opportunities and this is potentially a significant growth area. A current NRAC project is investigating the baitfish market and will provide essential and valuable information on where possible bait aquaculture niches exist.

Ornamental fish, mainly koi and goldfish are and have been cultured in ponds for several decades in the region and accounts for about 4% of 1998 sales. Much of the pond management practices and technology used are similar to that of foodfish species, with a few issues requiring more specialized attention such as predation. The high value of ornamental fish, increased interest in home water gardens, despite increased competition from states like Arkansas, has enabled a relatively successful industry over the years. Species diversification, improved predator control, consumer education and product differentiation are important research and development needs for this industry.

Aquatic plant production is often overlooked in the aquaculture community, yet is a significant commodity in the region with 4.5% of sales and is expanding. The majority of these sales are for ornamental ponds and aquaria, but species used for mitigation or restoration projects are in growing demand. Small, shallow above or belowground ponds of less than 2 feet are constructed from a variety of materials including plastic liner, lumber, concrete block and soil. These are easy to construct, easily dismantled or expanded and are relatively low cost production units. Although competition from southern states is a factor, the NE's significant population base and increasing regulatory requirements for mitigation projects, provides for continued growth opportunity in this sector. Major challenges for this sector include marketing, interstate regulatory complexity and constraints, development of propagation of new species, and expansion for other uses such as water quality treatment.

<u>Challenges of pond culture of food, bait and ornamental species</u>

- Competition from other states and countries affects market prices especially for food species.
- Increased regulatory concern of fed pond culture increase operational costs.
- Predation remains a significant factor for ornamental and bait production.

- Land intensive with higher cost land
- Limited growing season in region compared to south

Opportunities and needs

- High value species and markets offer the greatest potential for increasing economic gain compared to lowering operational costs.
- Extensive market analysis for alternative species (food, ornamental, bait and restoration) freshwater and marine is essential to assess potential growth of many species within these commodities. Economic assessment needs to follow market analysis.
- Integrated or polyculture systems for effluent management and product diversification is needed to offset increased treatment costs.
- What other uses of ponds, i.e. wetlands and wildlife management, and recreation can be integrated.
- Investigate predation control options.

Ponds for farm-raised fish used for recreation

The 1998 Census of Aquaculture reports that the northeast region has 2,698 acres of freshwater devoted to aquaculture production. A wide variety of fingerling and food fish are grown. Various sport and game fish were grown on 37 farms including fingerling largemouth bass, bluegill, crappie, and sunfish. About 107 acres of channel catfish were in production. Records do not show the quantity or value of pond-raised fish sold into northeastern recreational markets. Hybrid striped bass, catfish, trout, and other food fish are utilized by sporting clubs, private individuals, municipalities, parks, resorts, fee fishing businesses, golf courses, housing developments, pond consultants, fish distributors, anyone interested in managing water for positive fishing experience. Nor does the 1998 census indicates the volume of pond-raised fish imported into the northeastern recreational market. Significant quantities of live food size channel catfish and trout are transported from southern states. This market is important to northeastern businesses selling live fish because this market commands higher prices than commodity markets for food fish. Product quality in this seasonal market is not measured by shelf life, rather survival and angler satisfaction. It may be more appropriate to consider this market part of the tourism industry rather than the food industry.

Challenges

- Technology/methods to consistently deliver premium product – fish health and mortality after delivery can be a problem, especially among warm water species stocked into ponds.
- Product diversity among food size fish is low and reflects the ready supply of trout and catfish. There is demand for other species, but supply is limited and prices are high.
- Diets formulated for primary culture species like catfish and trout. Need dietary requirements for other species like bass, bluegill, etc. when produced in feedlot format.
- Regulatory barriers to transport of live fish across state lines are increasing.

- Requires service before and after the sale – continual need for education and development of educational materials.
- Ability to consistently meet demand (e.g. production strategies, tools and methods for partial harvest).

<u>Opportunities and needs</u>

- Economic assessment of profitable ways to utilize farm raised fish in recreation. Application of this information would increase awareness among recreational outlets regarding profitable strategies to use farm-raised fish.
- Assess incidence and volume of fish mortality following delivery of live fish in recreational markets. Develop protocols/methods, and educational materials to minimize stress and subsequent mortality during and immediately after distribution.
- Conduct a market survey of what the angling public values in a recreational experience. If we know demand, it would be easier to devise strategies to meet it.
- Evaluate strategies/economics to produce a more desirable product set.
    - Growing big fish.
    - Fish more appealing to the angler (e.g. color, fin shape, etc.).
    - Species diversity
- Implement new production technologies – integrated use of pond systems, flowing water systems, and/or recirculating systems.

FLOW THROUGH SYSTEMS

Trout are an important component of inland aquaculture production in both the food and recreation markets. NASS reports that 132 farms were located in the northeast region and sales at those farms totaled over $8.7 million in 1998. The most reliable cost effective way to produce trout is in gravity flow flowing water systems. Raceways utilizing springs or coldwater streams are a proven technology for both public and private production of trout. These systems manage risk well. Production and water quality are quite predictable. These systems work as an aquatic feed lots where small fish are fed high protein diets that are converted into flesh. Large volumes of water flow through the system and carry with it low concentrations of fish waste.

<u>Challenges</u>

- Effluent management has become a critical issue as agencies regulate the volume and concentration of waste products discharged into public waters from flowing water aquaculture systems. Regulations continue to be developed and there is uncertainty regarding specific requirements facing managers in this well-established industry. Many facilities were not designed for waste management. The basic strategy to treat effluent has been to remove solid waste prior to discharge. Solid waste is allowed to settle in quiescent zones and settling basins. Practical cost-effective treatment of a large continuous discharge of dilute effluent presents an engineering challenge. Given continued assertiveness of effluent regulation for aquaculture, it will be necessary to devise and evaluate strategies for existing as well as new facilities.

- Fish Health – Flow through systems are not isolated from the environment. Pathogens can be freely exchanged between the production facility and the environment. Vaccination should be an important strategy in these systems.

Opportunities and needs

- Effluents: Rather than discard a proven technology because it is old fashioned, it makes sense to seek ways to modify the technology to meet current goals. Several different strategies are being developed to reduce the amount of waste in the effluent. One way is to reduce the amount of waste from each pound of fish grown. High-energy diets have been developed and are in common use. These diets may reduce waste for each pound of fish grown by as much as 50%. Research continues on diets to further reduce the amount of phosphorous and other nutrients in water from trout raceways. Improved feeding practices are another important consideration in reducing the amount of waste from each pound of fish grown. A second strategy to reduce waste is to find more efficient ways to remove waste from the water prior to discharge. Facility design improvements and technology could retain, and recover solids more quickly and with greater efficiency. Aquaponics is an emerging component of aquaculture that may have a role in removing nutrients while producing something of value. It is conceivable that various by products could be obtained from the waste stream.

- As water becomes limiting and more is invested in cleaning up effluents, partial water reuse may become an important strategy to increase production volume.
- Impaired water sources such as water from coalmines represent opportunities for expansion of the trout industry.

Develop tools that allow managers to optimize production. These same tools could help answer questions posed by new producers, extension personnel, and policy makers: Under what conditions are specific systems most profitable?

RECIRCULATING AQAUCULTURE TANK SYSTEMS

Recirculating aquaculture systems (RAS's) were the third most utilized culture technology in the NE region in 1998 accounting for 9 percent of sales or $11.4 million. The vast majority of these sales were from foodfish species, primarily hybrid striped bass and Tilapia. It is important to note that since the 1998 USDA Census of Aquaculture, a few large-scale foodfish RAS production operations have closed due to several reasons, most importantly decline in market prices. The closure of these facilities is not necessarily a reflection on RAS technology, which has experienced major advances in technology development and operational cost savings, and no doubt will be a highly utilized technology in the future. Instead the closures are a result of market and economic factors including: competition of lower priced foreign product and other meat sources, commonplace supply and demand fluctuations, and inherent high operational costs and low profit margin of traditional foodfish species. With the demand of seafood and population increasing, and certain operation costs increasing, RAS based businesses must strive to lower costs where possible and investigate other products and higher value market opportunities. Two major uses and applications of RAS technology will be discussed in this paper: large-scale food production and smaller scale operations.

Large scale RAS food production applications

Indoor fish production using recirculating aquaculture systems (RAS) is sustainable, infinitely expandable, environmentally compatible, and has the ability to guarantee both the safety and the quality of the fish produced throughout the year. The advantages of RAS compared to conventional aquaculture production methods in terms of land and water use are summarized in Table 2.

While there is a generally held perception that RAS based production is either non-competitive for food-fish production or reserved for producing high value species, there are now numerous farms in North America employing this technology. Over 10 million smolts will be produced using RAS technology in 2003 in North America and such technology is being rapidly developed by Chile. Canadian farms are exploring large-scale land-based systems for smolt growout due to the increasingly negative public attitude towards intensive net-pen farming. Dramatic improvements in RAS technology have been made over the last 10 years, but

Table 2. Water and land requirements to produce specific seafood species

	Production Intensity	Water required	Ratio = Land or Water Use to RAS Use	
	(kg/ha/y)	(Liter/kg)	Land	Water
O. niloticus (Nile tilapia) ponds	17,400	21,000	77	210
I. punctatus (Channel catfish) ponds	3,000	3,000-5,000	448	400
S. gairdneri (Rainbow trout) raceways	150,000	210,000	9	2,100
Panaeid shrimp pond (Taiwan)	4,200-11,000	11,000-21,340	177	160
O. niloticus (Nile tilapia) RAS	1,340,000	100	1	1

continued improvements in cost efficiency are still required to allow the production of food fish on an economically competitive basis with traditional large-scale outdoor systems.

As future research needs are considered for land based production farms, it is instructive to review the relative costs of current commercial operations for tilapia, salmon and chicken broilers (see Table 3). This table serves to show the large improvements in economic efficiency needed for land-based aquaculture to be competitive with other forms of meat production. While tilapia production costs are already lower than salmon, the low fillet yield of tilapia makes the fillet price high relative to salmon. However, note that if the broiler chicken was only used to produce a fillet (breast meat), then the fillet cost would be twice as high as salmon. For this reason, the broiler industry has very effectively made use of the entire broiler carcass and moved to marketing a much higher percentage of harvest as a further processed product.

Reducing the costs of production RAS technology is paramount and needs to address the various components of the systems. The equipment used to perform these individual unit processes all contribute to overall capitalization costs. Economically competitive food fish production will depend upon collectively reducing capitalization costs to be at least nearly as efficient as the salmon industry, e.g. $0.18 per pound ($0.40/kg) per year of system capacity production. Inventive new ideas of how to combine unit operations or to reduce costs associated with present technologies must be developed. Probably more than any other factor that can contribute towards this goal is to increase the scale of the production operations. Just as dairy, hogs and poultry have increased production per farm and therein improved labor efficiency and other cost of goods components, the aquaculture RAS based industry must also do so.

Table 3. Comparison of production costs ($/kg) for net pen salmon (current and most efficient operations), large scale RAS produced tilapia, and commercial broiler production

	Cost/kg			
	Tilapia	Salmon	Efficient Salmon	Broilers
Cost of Operations				
Direct Labor & Benefits	$0.17	$0.20		
Feed	$0.46	$1.26		
Oxygen	$0.11	$0.00		
Other Operating Costs	$0.04	$0.31		
Utilities - Heat	$0.22	$0.00		
Utilities - Electric	$0.09	$0.00		
Fingerlings	$0.18	$0.35		
Insurance	$0.00	$0.11		
Health Treatments	$0.00	$0.02		
COGS ($/kg fish produced)	$1.27	$2.25	$1.76	$0.66

A primary disadvantage of RAS technology is that water must be moved from the culture tank to the different unit processes that restore used water to acceptable levels of quality for fish growth. As a rule-of-thumb, 5 gpm of flow is required per pound of feed fed per day (for supplying oxygen and required nitrification. Table 4 illustrates the cost of pumping using various flow rates and water lifting heights.

Table 4. Cost of pumping per unit of fish produced (lb) assuming electricity, $0.10 per kWh, efficiency of pump @ 70% and feed to gain ratio of 1.00. Note: WHP = Q x TDH x SG / 3,960 where WHP = HP and Q in gpm and TDH in ft.

Q, gpm	TDH, ft	BHP	kW	kWh/lb (see note)	Cost/lb
1	1	0.0004	0.0005	0.012	$ 0.001
2	1	0.0007	0.0010	0.023	$ 0.002
3	1	0.0011	0.0014	0.035	$ 0.003
4	1	0.0014	0.0019	0.046	$ 0.005
5	1	0.0018	0.0024	0.058	$ 0.006

For example, if the TDH needed to run the RAS system were 15 feet, e.g. for a fluidized sand bed, and the feed to gain ratio for the system is 1.5, then the cost of pumping would be assuming 5 gpm of flow per lb of feed fed per day:

$$\frac{Cost}{lb} = 0.058\frac{kWh}{ft\ TDH} \cdot 15\ TDH \cdot 1.5\, fg \cdot \frac{\$0.10}{kWh} = \frac{\$0.130}{lb\ \ fish}$$

Thus, it can be seen that production costs for pumping are proportional to:

- Pumping pressure (total dynamic head the pump works against)
- Feed to gain ratio
- Electricity cost

Future research should be addressed at lowering all three of these contribution factors to pump operating costs.

Effective and cost efficient biofiltration is one of the keys elements to cost effective indoor aquaculture production. Examples of biofilters that are common to the wastewater treatment and aquaculture industry include trickling filters, rotating biological contactors, sand biofilters, bead biofilters, and neutral-buoyant packing material biofilters. The choice of biofilter will impact the dynamic head that the pump system must work against. Fluidized sand beds will work against 15 to 30 feet of head, while trickle type filters can be operated at much shallower depths. Floating bead biofilters are similar in head requirements to trickle filters and provide large surface areas for nitrification comparable to fluidized sand beds. All biofilters have advantages and disadvantages, and for small-scale systems, e.g. feeding around 100 lb of feed per day, the choice of biofilter is probably irrelevant. Timmons et al. (2000) summarized costs for various biofilter choices (see Table 5).

Table 5. Capital Costs Estimates Associated With Biofilter Choices for a Tilapia Farm Producing 1,000,000 lb (454 MTON) Annually. Cost is listed as $ per PPY, i.e., pound per year

Biofilter Type	Farm Cost	Cost, $ per PPY
Rotating Biological Contactor	$668,000	$0.68
Trickling Biofilter	$620,000	$0.62

Bead Filter (not Aquafilter type)	$296,000	$0.30
Conventional Fluidized-Sand Biofilter	$124,000	$0.12
CycloBio^{TM} Fluidized-Sand Biofilter	$76,000	$0.08

The choice of species will affect the choice of equipment and biofiltration technology employed. The costs of production as affected by capitalization and water quality maintenance must be kept in the forefront if successfully based RAS production is to be created.

RAS systems can require concentrated efforts to remove dissolved carbon dioxide and to supply sufficient oxygen to maintain fish productivity. Controlling CO_2 stripping rates can be used to control water pH and pH control can be used to mitigate problems associated with high ammonia. Engineering of such systems for practical implementation are needed. Additional effort must be made to improve the efficiency of and to reduce capital costs for gas control in RAS.

The effective control of solids in RAS is probably the most critical parameter for long-term economic success. Poor solids removal destroys water quality and hence fish performance and compromises biofilter performance. Currently the most generally used method for solids removal is mechanical screens using 60 to 120 micron mesh sizes. Unfortunately, mechanical screening for solids removal is now the most expensive component of the entire RAS system. Dramatic cost improvements in methods to effectively remove solids from culture tanks are needed.

Environmental sustainability is probably the most important criteria that must be met as systems are developed for the future. Ultimately and near term, systems that are viewed as exerting negative effects on the natural environment will not be allowed by the public. The net pen industry is beginning to experience this already. Some sites that have been licensed in the past are failing to receive renewal permits even when these same sites are performing as predicted and as permitted. Research into cost effective waste disposal is needed. Some systems are successfully using wetlands for waste treatment and moving towards 100% recycle of water. More research is needed in this area.

Feeding systems, alarm and control systems and all component equipment items in RAS farms must be improved. These systems must be designed and developed for high labor efficiency and large-scale applications. Such systems do not currently exist. Rather, systems borrowed from other animal industries are applied with limited success.

Other areas where cost reductions with RAS's can be achieved are genetic and nutritional improvements. The key ingredient behind the success of the chicken and catfish industries was that there were concerted efforts by state governments to foster these industries, particularly the support that Mississippi provided for the catfish industry. The Northeast has numerous inherent advantages in the indoor aquaculture industry, including its location near a significant population density, the existing infrastructure of academic and business institutions, and the consumption patterns of its inhabitants. Successful development of a large-scale industry will be highly dependent upon improvements in the genetic stock of selected species and associated nutritional improvements in feeds for these same animals. Similar improvements could be expected in aquaculture, particularly if only two or three species were emphasized. It is amazing that the tilapia industry in the USA is doing as well as it is, since there has been no concerted effort to develop a feed for a RAS produced tilapia. Imagine trying to feed a broiler chicken a diet developed for a veal calf. This is basically what is happening when a trout feed is fed to a tilapia.

Alternative species and RAS's

While significant gains in the cost and performance of intensive culture technologies have occurred over the past decade, the rate and degree of future improvements is unlikely to dramatically improve the industry's economic situation. Now that many of the unit treatment process and their interactions are well understood, there is a sufficient technical foundation to undertake production of a far broader range of species. Indeed system designs can be tailored to meet the needs of a wide range of species produced under optimized regimes. Targeted diversification focusing on highly productive species offers a powerful means of improving the profitability of intensive systems.

The lack of a standardized metric to evaluate the productivity of candidate species has lead to research and commercialization efforts for products that have later proven to have limited profit potential. Indeed, many species are selected based principally on their desirability within a particular market, with very limited consideration for their underlying bioeconomic characteristics. We propose to use *annual gross margin contribution / M^3 of culture volume* as a standardized metric to evaluate the economic potential of various candidate species.

Assuming similarly reproductive and health status, bioeconomic modeling indicates that the following are most influential factors in determining a candidates annual gross margin contribution / $M^3$of culture volume:

VI. High Specific Growth Rate - reduces inventory levels / unit output

VII. Fewer Days to Market - increases No. batch's / yr.

VIII. High Culture Density – reduces time-based operating costs / unit output

IX. Strong Demand Elasticity – improves pricing stability

In evaluating the major species currently produced within intensive systems against these criteria, it is evident that they fall within a relatively narrow range. Table 6, below, compares the performance against these criteria for several current and candidate species, and shows how they influence the gross margin contribution / M^3 of culture volume:

Table 6. - Summary of Major Bioeconomic Characteristics of Current vs. Candidate Species.

	Current Species			Candidate Species		
	Increasing Growth Rate →			Increasing Growth Rate →		
	Yellow Perch	Hybrid Striped Bass	Tilapia	Pompano	Tambaque	Cobia
Typical Production Criteria						
Mean growth (grams-d)	0.5	1.9	2.6	1.9	6	20
Market Wt (grams)	150	750	650	450	1,800	6,000
Days to Market (5 grs to market)	275	400	250	240	300	300
Max Culture Density (kg/M^3)	35	50	100	50	50	50
Economic Indices						
Output: Kg/M^3 culture volume	24	52	137	101	122	100
Market Price ($/kg)	$ 6.15	$ 5.75	$ 3.10	$ 7.25	$ 4.40	$ 6.15
Revenue / M^3 culture volume	150	300	425	729	535	617
Inventory Value as % of sales	58%	40%	31%	19%	16%	19%
Margin Contribution - $ / M^3	$ 43	$ 82	$ 109	$ 243	$ 161	$ 208

It is evident from the analysis presented in table 6 that significantly higher levels of margin contribution/M^3 are possible given a more favorable combination or bioeconomic characteristics. Further, high inventory levels and associated carrying costs are major economic impediments for intensive producers. This occurs because sustaining the product is quite costly relative to other forms of protein production, and often occurs over significantly longer periods. Reducing inventory levels / unit output could make aquaculture business far easier to finance and grow, given limited availability of investment and operating capital.

At present, intensive systems are most frequently used to produce low to modest value products, with only moderately fast growth rates. These species are generally tolerant of a broad range of environmental conditions, and are therefore subject to high levels of competition from both domestic and imported producers. The future could look quite different. High technology systems could leverage their control as a means to reduce inventory levels and production risk, focusing on much faster growing species which offer high annul margins per of unit culture volume.

Small-scale applications of RAS's

In addition to the commodity food approach for RAS technology for production of traditional or alternative species, which requires significant capital investment and specific business goals and type of investors, smaller scale RAS applications do exist and do provide opportunity for expansion. The majority of aquaculture businesses in the NE region are relatively small scale, providing supplemental or full income for individuals and families or small businesses. RAS technology lends itself to these type businesses due to their applicability to a variety of locations, fresh or marine water potential, flexibility in scale and uses including: food, bait, ornamental fish, hatcheries, aquatic plants, and biotechnology product production.

Throughout the US, and to a lesser extent, the NE aquaculture industry, RAS's are in place producing a wide variety of products. Those operations producing ornamental fish, particularly marine fish species and live rock, hatchery products such as sport fish for recreational markets, bioassay or laboratory specimens or biotechnology products, experience the highest return on investment. Though typically smaller in scale than food systems, their success is highly significant and may provide greater opportunity for expansion or new investment in the region. Given the relatively high capital investment and operational cost of RAS's, identifying those products and associated markets which offer the greatest potential return on investment is a logical and sound approach and one that will contribute greatly to application of RAS technology, but more importantly, viable aquaculture and expanded economic impact. The northeast's diverse population and their buying habits presents significant market opportunities for those aquaculture businesses that are innovative and constantly adapting to consumer preferences and market trends.

<u>Opportunities of RAS</u>

- The cost of creating and maintaining inventory is a major economic impediment for intensive aquaculture producers.
- Reducing inventory levels / unit output could make aquaculture business easier to finance and grow, particularly given the limited availability of investment and operating capital.

- Larger economic gains are likely to be available through the production of new species that offer more favorable bioeconomic characteristics, than are available through engineering improvements.
- A standardized metric, such as *annual gross margin contribution / M^3 of culture volume,* is a useful tool to evaluate the economic potential of candidate species.
- Diversification, focusing on highly productive species, offers a powerful means of improving profitability within intensive systems.
- Production of euryhaline marine species may offer important opportunities to improve contribution margins/unit of culture volume.
- RAS's offer the only environmentally responsible technology for production of non-native species.

Research needs of RAS technology

- Identify economic profitability of various aquaculture sectors products (food, bait, ornamental, recreation, restoration and biotech) using RAS technology.
- Development of systems and associated management methods whose capitalization are comparable to salmon net pen farming, e.g. less than $0.20 per lb per year of production capacity; current RAS based systems often exceed $4.00 per lb per year of production capacity
- Development of high volume low head pumps
- Establish fish performance standards as affected by water quality parameters
- Develop feeds that are suited for RAS conditions for specifically identified species, e.g. tilapia
- Improve genetics that focus on product yield
- Develop cost effective methods for waste disposal that are environmentally sustainable
- Develop biofiltration systems and gas conditioning systems that are economically efficient in terms of capital and operating costs
- Develop alternative methods of supplying low cost energy (heating and pumping)
- Develop improved utilization of all carcass parts for species cultures

CAGE PRODUCTION SYSTEMS

Cage culture technology is the least used method of aquaculture production in the NE region representing approximately 1% of sales. Foodfish such as trout, catfish and hybrid striped bass are the dominant species produced in cages. Cages are typically employed in ponds or reservoirs where open pond culture is not well suited due to excessive depths or structure that interferes with pond seining. In addition to fish production, cages are often used to temporarily hold fish for marketing purposes. Several attributes of cages including: simple design and construction, low start up cost relative to other aquaculture technologies and availability of technical publications makes cages attractive to many farmers with ponds and those beginners interested in learning more about aquaculture.

Cage culture does have several challenges that need to be taken into consideration including: increased fish stress depending on species and water circulation within pond, increased disease susceptibility compared to open pond culture, predation and theft. If these factors are addressed, then cages can provide opportunities for use of water bodies not previously used for culture, supplemental farm income where reservoirs exist, and aquaculture education activities.

SUMMARY

Inland aquaculture in the northeast is comprised mostly of small businesses striving to establish and maximize profitability. Given that all of the inland-based culture systems have experienced significant advances in technology development and production efficiencies resulting in reduced operation costs, the most important underlying issue remains that of economic viability. Future improvements in technology could be years away or have minimal impact on profitability. The greatest potential economic gain for the greatest number of operations will occur in the market place by expansion of higher value products and their uses and targeting of higher value market niches. Inland-based systems are very flexible, capable of producing freshwater and marine animals and plants for use as food, bait, ornamentals, recreation, restoration and laboratory research. Research emphasis on identifying and demonstrating those products and market strategies that offer the greatest return on investment is both obvious and paramount to further aquaculture economic development in the northeast. Table 7 summarizes the high priority research needs for pond, flow-through, and recirculating aquaculture production systems.

Table 7. Highest priority research needs for land-based aquaculture systems in the NE region (not in ranked order).

Research Need
Evaluation of market characteristics and economic opportunities of high value bait, biotechnology, food, ornamental, recreation and restoration species and products including value added products
Evaluation of cost effective effluent treatment and waste utilization options for all culture technologies
Investigate genetic improvements of fish and plant species
Assess incidence and volume of fish mortality following delivery of live fish in recreational markets. Develop protocols/methods, and educational materials to minimize stress and subsequent mortality during and immediately after distribution
Evaluation of alternative disease management treatment or practices
Identify lower capital cost technology and cost reduction of operational practices for recirculating system technology
Develop feeds and feeding practices which reduce amount of phosphorus and nitrogen in waste
Evaluation of integrated production systems to produce multiple species (plants, shellfish or fish) to reduce nutrient concentration of point and non-point source discharges
Evaluate use of alternative water sources for aquaculture production
Develop feeds that are suited for RAS conditions for specifically identified species, e.g. tilapia

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