Comparison of Aquaculture and Broiler Production Systems

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Introduction

Natural fish populations are being decimated and rapid growth of fish farming is supplying an ever increasing fraction of the fish market. USDA statistics show the world commercial fishery landings have decreased from 101 million metric tons to 98 million metric tons in the last three years and that USA per capita consumption rates of fish have decreased in the last several years from 7.4 kg to the current level of 6.6 kg per capita, despite documented health benefits of eating fish (USDA, 1994). Of the current seafood consumption, 20% is supplied from aquaculture (Scientific American, November, 1995).

Aquaculture must continue and accelerate the current trend of supplying the increasing need for fish and seafood products. There are strong opinions in the scientific and agri-business communities as to where this increase in aquaculture production will come from-indoor or outdoor culture systems. Outdoor culture proponents argue that the costs of producing fish from indoor systems are too high to ever allow commodity levels of product to be produced from such systems. Outdoor culture proponents also maintain that their systems take advantage of provisions of nature, e.g. sunshine and algae production, and that the initial system costs are low for pond structures. Further, outdoor proponents argue that fish production should concentrate in developing countries where labor and land are inexpensive. While the arguments for outdoor culture are valid, they do not eliminate the potential of indoor culture systems as viable production units for the competitive production of fish products. The technologies available today are dramatic improvements over what was “state of the art” just a few years ago. We believe it is no longer an issue as to whether indoor systems will be the dominant form of aquaculture in the future, but rather, the speed at which this industry will grow to meet the ever increasing need for safe seafood products.

Lessons from the Poultry Industry

A strong resemblance exists between the tilapia industry as it nears the 21st century and the broiler industry of the last half of the 20th century. The broiler industry did not exist at the beginning of the 20th century but grew to become a $40 billion industry at the retail level by the end of the century. It began as a backyard hobby and grew to employ hundreds of thousands of people. Tiny specialized companies formed the basis of what became the vertical integration model and was copied by the rest of agriculture by the end of the century.

All the elements appear to be in place for the tilapia industry to follow the broiler industry model:

- ability of tilapia to utilize a low cost corn/soy diet
- rapidly dropping costs of production with new production technology
- potential for having the lowest cost fish meat on the market
- consumer demand driven by the elasticity of demand
- potential for vertical integration and economies of scale

If the tilapia industry is to duplicate the growth rate of the broiler industry, it must produce a low cost product. Chicken became the most popular meat choice because it is a low cost, tasty, and healthful product. As the price of any meat product drops, demand increases. If tilapia becomes the lowest cost fish on the market, it will not only have a commanding presence in the fish and seafood market, but also help expand the fish portion of the total meat market.

Americans are unlikely to ever eat tilapia in the way that they eat chicken, pork, or beef. Nevertheless, an additional 50% increase in the fish consumption per year or 7 pounds per capita per year within the next 20 years could be expected. That would require a production level of 2 billion pounds of tilapia by the year 2018. To reach that level, production would have to increase by 100 million pounds each year for the next 20 years! Will this happen? It should happen if tilapia can become one of the lowest cost fish meats and highest quality available.

The broiler industry required 50 years to learn three important lessons:

- vertical integration
- further processing
- branding

Learning from the experience of the broiler industry, the tilapia industry has the opportunity to telescope that 50 year process into a much shorter time period, perhaps as few as 10 years.

Vertical Integration. Vertical integration is the ownership or control of all or most of the production stages. In the broiler industry that means that a single "Integrator" owns or closely controls the feed mill, hatchery, processing plant, farms and marketing of broiler meat. Broiler integrators do not generally own farms. Instead they closely control farm production through the use of contracts. For the tilapia industry that would mean a single company would own or closely control the production of feed, fingerlings, fish, processing (if any) and marketing.

Why is vertical integration such a good idea? Vertical integration allows a company to coordinate the capacity utilization of each stage of production, establish a single profit center, and control quality from beginning to end. It is the state of the art in the organization of an agribusiness enterprise.

Further Processing. As the broiler industry brought down the cost of production, it became possible to sell further processed and value added products because the price of these products came within reach of consumers. Further processed products have two benefits to integrators: first, they provide a higher margin of profit, and second, they provide a more stable income over time. For the tilapia industry, the benefits of further processing are obvious. American consumers do not want to deal with fish bones and entrails; they want a fish filet at a reasonable cost. Low cost whole tilapia will allow the tilapia industry to sell a low cost tilapia fillet.

Branding. The final important lesson learned by the broiler industry was that a branded product provides more returns than a non-branded product. A branded product must meet both the following conditions to be successful:

- it is widely recognized by consumers
- consumers are willing to pay more for the product

A good example of branding in the broiler industry is Perdue Farms. Perdue spends approximately 5 cents per pound in advertising to increase the sales price of the branded product by 8 cents per pound. In Perdue's marketing of the branded product, Frank Perdue makes fun of unbranded poultry parts by calling them "unidentified frying objects".

Economic Comparisons

We will make a comparison among outdoor systems, indoor systems and commercial broiler production. The outdoor economics will be taken from catfish production in the USA, since complete data is available for such systems. Catfish production is a mature industry in the USA and as such, the costs of production are well documented. Effects of initial capital investment and system productivity will be predicted for indoor production costs. Projected production costs for tilapia will be made based upon the technology or management improvements expected over the next 5 years.

Analysis

Comparison to Catfish Pond Production. We will compare predicted costs of tilapia production based upon performance data collected at Cornell University with previously published data for Mississippi catfish production from large outdoor ponds. Tilapia component costs are based upon current Cornell University data and experience with an indoor 220,000 kg/yr tilapia farm recently built near Cornell University (Cayuga Aqua Ventures, LLC, or CAV). The Cornell data were obtained from a prototype 60,000 L tank system similar to the tank systems described in Tables 1 and 2. Where reasonable, component costs are kept the same between the tilapia and catfish examples, so that differences in production costs are the result of management and system costs and not subjective values used for say liability insurance.

The production levels from both systems are 590,000 kg/year. This comparison is intended to show the strengths, weaknesses and similarities of the two production systems. Prices, depreciation values, and associated economic factors are given in Table 3 for both Mississippi pond catfish production and a northeastern USA indoor system producing tilapia where the average outside air temperature is 9°C. Costs associated with catfish production are as given by Keenum and Waldrop (1988). Depreciation, repairs and maintenance for the tilapia example were calculated in a more simple fashion than used in the catfish analysis; differences in this cost component due to calculation method are minimal. Feed price is adjusted upward from that given by Keenum and Waldrop to be reflective of current feed prices; the same feed price is used for both tilapia and catfish.

Characteristics of the indoor tilapia fish farm are given in Table 2 and system cost details (capital investment) are given in Table 3. Effects of overall system costs and productivity per unit volume of water will also be demonstrated later in this paper. The parameters given in Table 2 are somewhat conservative. Cornell has operated systems with twice the densities listed and fed at rates considerably above 2% per day for sustained periods with success. The indoor tilapia system design is based upon upflow sand filters using large sands (D_{10} = 0.6 mm and D_{eq} = 1.1 mm; upflow velocity of 3.5 cm/s), double drain flow configurations to minimize the water treatment volume for suspended solids removal, and modest carrying capacities (100 kg/cubic meter).

Labor requirements. The authors' experiences with a range of tanks from 2 to 8 m are that tanks of various sizes require similar man-hours to manage. In effect, it is the number of tanks and not the size of tanks that is important in determining management hours required. Our experience indicates that efficient growers can manage a series of tanks averaging 20 to 30 minutes per day per tank system (11,000 L). Labor includes daily water chemistry measurements, fish feeding, filter maintenance, and tank cleaning. Weekly maintenance of two to three additional man-hours per tank system for major cleaning activities and preventative maintenance is also necessary. Assuming a 40 hour work week, this suggests one person could manage 7 to 9 tank systems (average of 4.3 to 5.3 man-hours per tank system per week). Since many operations on a farm require two people, a facility could be designed assuming two full-time employees/owners to maximize labor efficiency. Hourly or contract labor would be employed for special tasks, e.g. harvesting, hauling, processing, etc. This then defines the size for the basic production unit used in the present analysis as a 16 tank system. Some adjustments in labor requirements might be allowed depending upon the tank size (our analysis for tilapia production assumes 4 full-time employees). Losordo and Westerman (1994) used 8 hours per day to manage an eight tank facility with a 3 tank nursery (approximately 50% of the labor per tank used in our cost analysis).

Comparison to Broiler Production. 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 recent USDA statistics (USDA, ERS 1996 a, b, c) and the authors' 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; North (1984) provides an extensive description of all facets of commercial poultry production. 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 productivity standards of the USA tilapia industry (7 million kg per year) and the productivity per person in the fish farming business is approximately 25,000 to 110,000 kg per year. There is obvious room for improvement in the fish production business.

Results and Discussion

The predicted tilapia production costs are given in Table 4 and are compared to the production costs of catfish and broiler production on a $ per kg basis and as a percentage of total costs. 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 4 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 year of production. These investment costs are roughly 3 times the initial capital investments for broiler production of $0.49 per kg per year of production capacity.

Labor savings obtained from converting from outdoor production to indoor farming was a primary factor that drove the poultry industry to confinement housing. As mentioned earlier, the labor productivity for indoor broiler production is roughly 8 times more productive than indoor tilapia fish farming. 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 2,500 kcal/kg. The yearly meat output per unit floor area from the tilapia system is 255 kg/m^2 compared to 122 kg/m^2 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.

Projected Costs of Production for Tilapia. At this point, there is considerable information available as to what an expected cost of tilapia production could be for large scale operations and what kind of labor savings could be anticipated over the next 5 to 10 years. For example, many utilities will reduce electrical rate charges by 25% once a load of 500 kW is reached. As previously discussed, we may expect labor requirements to reduce to 50% of the current example. Catastrophic fish insurance would no longer be deemed necessary, since the farmer would begin to become self-insured. System costs would be expected to reduce by 25% over current costs due to improvements and refinements in system designs. The predicted costs based upon this scenario are given in Table 5 (broiler production costs are listed again for sake of comparison).

Conclusions

Tilapia production appears to be competitive on the commodity meat market when labor and system cost efficiencies are employed for a large scale indoor fish system. Recent improvements in system costs and labor and system efficiencies associated with larger tank sizes are largely responsible for the improvements in economic competitiveness. A comparison with catfish pond production at a similar scale of production showed that tilapia production costs were very near those of catfish ($1.62 per kg tilapia versus $1.56 per kg catfish). The costs of tilapia production are still significantly higher than commercial broiler production, e.g. $0.65 per kg for broilers. However, this difference is primarily attributed to equipment, ownership and labor costs which are much more efficient in broiler production than tilapia production, $0.073 per kg versus $0.47 per kg. The competitive advantage of indoor tilapia production is that the weight production per unit area of building per year is approximately twice the productivity of a commercial broiler house on a live weight basis and that tilapia (fish) are more efficient converters of feed into flesh.

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Table 1.
Economic parameters used for catfish (Keenum and Waldrop, 1988) and tilapia production analysis.

	catfish	tilapia
Feed cost (32% protein, $/kg)	$0.40	$0.40
Feed/gain ratio	2.00	1.40
Harvest weight, kg	0.57	0.68
Fingerlings, $/fingerling	$0.075	$0.060
Cumulative mortality, %	5	5
Electric costs, $/kWh	$0.085	$0.077
Oxygen cost, $/kg)	na	$0.19
Depreciation (straight line, zero salvage; 7 yrs equipment, 20 yrs bldg)	--	--
Interest on investment	11%	11%
Interest on operating capital (based upon 50% of total operating costs), %	10%	same
Repairs and maintenance (% of initial cost)	~5%[a]	5%
Labor ($/man year include 35% fringe benefit rate)		
1- manager	$35,000	$47,000
1- foreman	$26,000	$34,000
3- workers catfish and 2- tilapia	$36,000	$33,000
Total personnel costs	$97,000	$114,000
Total land area, hectares	131.0	2.0
Land value, $/hectare	$1,975	$2,500
Harvesting and hauling, $/kg	$0.09	$0.09

[a] Keenum and Waldrop (1988) perform a very elaborate analysis of repairs and maintenance, but from a simple practical approach, there is minimal difference from using 5% of the initial cost.

Table 2.
Production system characteristics associated with tilapia indoor system.

Size of building	1,780 m^2
Growout tank	16 tank facility (7.6 m diameter x 1.4 m deep) 60,000 L
Yearly harvest	590,000 kg
Design parameters	
Density	100 kg/cubic meter
Feeding rate (depends on fish size)	2% to 3% body mass per day
Feed conversion rate (feed/gain)	1.40 kg/kg
Supplemental oxygen	0.4 kg oxygen per kg of feed fed
Oxygen absorption efficiency	75%
Power per tank system	9 kW (3 pumps each 1,500 Lpm capacity)
Fish target size	680 g
Daily water exchange, % of system volume	5%
Temperature difference for water exchange	19.4°C
Fuel cost, $/100,000 BTU	0.62
Building infiltration, air volumes/hr	2

Table 3.
Capital cost characteristics associated with tilapia water reuse system.

Growout tank: 63 m^3 (60,000 liter)	$2,000
3- 3 kW pumps	$6,400
Oxygen and CO_2 control units	$2,500
Electronic controller	$750
Feeders (2)	$750
Sand biofilter	$4,000
Tank total cost per individual unit	**$16,400**
16 growout tanks Cost	$262,400
Quarantine hatchery /fingerling area (series of small tanks)	$9,000
Total tank costs	**$271,400**
Other Equipment	
Backup generator (2 @ 80 kW)	$32,000
Monitoring system	$10,000
Ice machine (2 ton unit)	$4,000
Feed bin and auger system	$16,000
Harvesting system	$8,000
Water heating system	$8,000
Waste catchment unit	$5,000
Ventilation system	$4,000
Water wells (2)	$8,000
Fish handling equipment	$10,000
Subtotal Other equipment	**$105,000**
Total Equipment Costs (7 year depreciation period)	**$376,400**
Building Costs	
Quarantine area	$14,400
Laboratory and office space	$6,000
Building space	$259,840
Septic/restroom	$4,000
Subtotal building Costs (20 year depreciation period)	**$284,240**
Land costs (non depreciated)	$20,000
Direct cost for complex	$660,640
Contingency costs (20%)	$132,128
Total funds required (equipment, building, land and contingency)	**$812,768**

Table 4.
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.

	$ costs per kg produced			% of Total Cost		
	tilapia	catfish	broiler	tilapia	catfish	broiler
Ownership costs ($/kg)						
Depreciation	0.14	0.11	contract	8.6	7.1	--
Interest on investment	0.07	0.10	contract	4.3	6.4	--
Catastrophic fish insurance (3%)	0.07	--	contract	4.3	--	--
Liability insurance + land taxes	0.01	0.01	contract	0.6	0.6	--
Subtotal	0.29	0.22	0.05	17.9%	14.1%	7.7%
Costs of goods services ($/kg)						
Feed	0.55	0.81	0.39	34.0	51.9	60.0
Fingerlings (chicks)	0.10	0.14	0.09	6.2	9.0	13.9
Oxygen	0.14	--	--	8.6	--	--
Subtotal	0.79	0.95	0.48	48.8%	60.9%	73.9%
Operating expenses ($/kg)						
Chemicals	--	0.05	0.06	--	3.2	9.2
Repairs & maintenance	0.07	0.04	--	4.3	2.6	--
Heating water	0.02	--	--	1.2	--	--
Heating air	0.03	--	--	1.9	--	--
Electric 0.16	--	--	9.9	--	--	
Other utilities	--	0.08	0.02	--	5.1	3.1
Management labor + fringe	0.19	0.17	0.04	11.7	10.9	6.2
Misc. 0.01	--	--	0.6	--	-	
Interest on operating capital	0.06	0.05	--	3.7	3.2	--
Subtotal	0.54	0.39	0.12	33.3%	25.0%	18.5%
Total cost of production ($/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.

Table 5.
Projected costs of tilapia production given expected improvements over the next 5 years compared to current production costs for tilapia and commercial broilers.

	Tilapia	**Projected Tilapia**	**Broiler**
Ownership Costs, $/kg			
Depreciation	$ 0.14	$ 0.10	
Interest on Investment	$ 0.07	$ 0.05	
Catastrophic Fish Insurance (3%)	$ 0.08	--	
Subtotal	**$ 0.29**	**$ 0.15**	**$ 0.05**
Costs Goods Services ($/kg)			
Feed	$ 0.55	$ 0.42	$ 0.39
Fingerlings	$ 0.10	$ 0.04	$ 0.09
Oxygen	$ 0.14	$ 0.09	--
Subtotal	**$0.79**	**$0.55**	**$0.48**
Operating Expense			
Chemicals	--	--	$0.06
Repairs & Maintenance	$ 0.07	$ 0.05	--
Heating Water	$ 0.02	$ 0.01	--
Heating Air	$ 0.03	$ 0.02	--
Electric	$ 0.16	$ 0.10	--
Other Utilities	--	--	$ 0.02
Phone	--	--	--
Management Labor + Fringe	$ 0.19	$ 0.10	$ 0.04
Misc.	$ 0.01	$ 0.01	--
Interest on operating capital	$ 0.06	$ 0.01	--
Subtotal	**$0.54**	**$0.30**	**$0.12**
Total Cost of Production ($/kg)	$1.62	$1.00	$0.65

Timing the Wave

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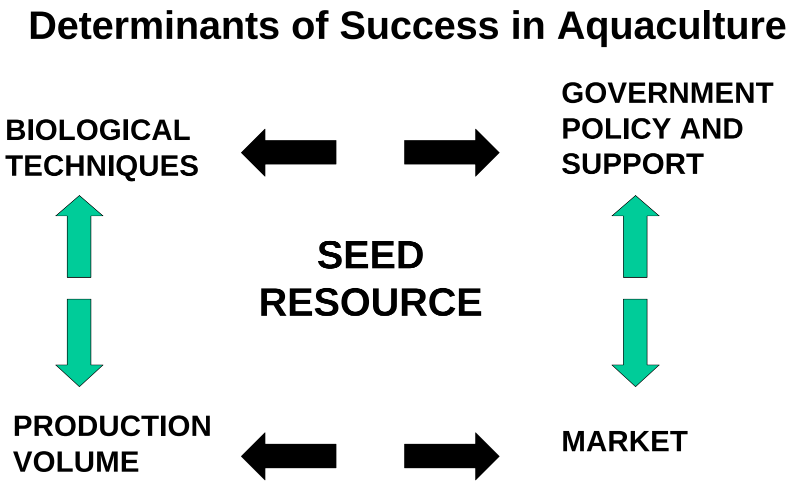
In order for a species to be successful in aquaculture, 5 key components must come together, driven and bonded by intelligent people and sufficient investment (diagram 1). Arctic charr has been a tantalizing potential success story for almost twenty years but the synchronization of these components has not yet been realized, although recent developments in some sectors makes it seem that the surge wave in arctic charr culture is pending. However, it is intriguing to try to "judge the timing of the wave" given that not all the components are yet in place.

This presentation will provide an update on the five key components, describing their current status and problems that still exist. The work will cover recent research results, market findings and production scenarios. Important to the fishfarmer considering arctic charr culture, will be the explanation of what we know and what we don't know about the fish, what systems have been tried, what disease concerns are being addressed and what costs can be expected.

Diagram 1:



The Pacific Northwest Experience With Production Intensification Through Recirculation

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Introduction

The first thing that must be clarified in this paper is that it is written to describe the experience of only a small percentage of the total aquaculture industry in the Pacific Northwest. In British Columbia most of the industry by far, in terms of mass and crop cash value, consists of grow out systems that are not amenable to recirculation technologies. By this, I am of course referring to sea cage culture of salmon. Fortunately for enthusiasts of recirculation technology all is not lost on the Emerald coast. The salmon industry is a valuable commodity industry that is globally competitive. Prior to taking advantage of cheap flowing water and culture space in the ocean, expensive smolts must be produced in fresh water. The cost of smolt production is a fundamental and substantial input to the overall cost of salmon production. In an era when farm gate wholesale prices for salmon are barely above the cost of production, and are in some case below the cost of production, the economics of the salmon hatcheries can no longer be ignored. It is intended that this paper showcase some of the advantages that recirculating technology brings to the industry in this regard. There have recently been efforts at converting several large scale hatcheries in British Columbia to recirculating systems. These projects will form the basis of the numerical examples presented in the paper. The names of the projects have not been mentioned in the text to prevent unwanted disclosure of commercial activity.

General Overview of Recirculation Technology in the Aquaculture Industry in the Pacific Northwest

As noted in the introduction, the primary focus of the paper is technically based in British Columbia as opposed to the broader geographic region. There are reasons for this beyond the local preferences of the author. It had been hoped when the paper was initiated that there would have been more case examples from our neighboring states to help me offset the idea that all interesting recirculation projects are either in Europe or the eastern United States. There are of course a few good examples of fine recirculation projects in the region but the broader trends still tend to limit the number of these types of projects in the Pacific Northwest states. I am hopeful that this will change and would gladly change this opinion if someone can tell me that there are actually commercial or industrial scale recirculating system facilities hidden in the region.

As part of the background research for this presentation, we conducted a telephone survey of many notable people in the aquaculture industry in the region to gauge the potential or existence of the utilization of recirculating technology in their specific area.

Much as expected there was little focus on this subject in many of the areas surveyed. The reasons for this ranged from legislative restrictions, to environmental concerns to just plain too much free water.

In Alaska, we spoke to Raymond Ralonde at the University of Alaska. We discussed the state of the industry generally and some of the trends that appear to be underway. As is well known in the west, fish farming is technically illegal in Alaska. This does not mean that fish culture does not occur however. In fact some of the largest hatcheries in the world are in Alaska and many of them do contribute to what could be considered to be farming. Ocean ranching relies heavily on the salmon produced in these hatcheries and is responsible for 186 million salmon on the world market each year. This is a very successful form of aquaculture and huge volumes of fish are harvested as a result of this practice but it is about as far from the theme of this conference as is possible while still talking about fish. The hatcheries do have the potential to utilize recirculation technology for many of the same reasons as described in the British Columbia examples but currently most are operated on a flow through basis. This is partially due to the fact that these hatcheries focus on raising very small fish with high water quality demands and that there is currently very little restriction in Alaska on the use of groundwater and surface water for this purpose. There is more interest in recirculation technology for use in niche markets in Alaska such as in holding facilities for lobster and geoduck. There are substantial cost drivers for this given the higher costs of maintaining water quality in salt water and the large price differentials between live and dead product in these species. Geoduck is $12 a pound live compared to $3 a pound dead meat for example.

In Idaho, we spoke with Dr. Ernie Brannon at the University of Idaho. As expected, most of the aquaculture in Idaho is driven by the nature of the water resource. Much as the course of the industry in Alaska is set by their access to the open ocean, Idaho is driven by its plentiful ground water resource. It is probably true that you could not get a permit in today’s regulatory environment to do what has been done in Idaho but what’s done is done and it is very successful. Idaho produces 42,000,000 lbs of trout and several hundred thousand lbs of Tilapia each year with some of the lowest total input costs in North America. Given this state of affairs, there is little incentive to pursue true recirculation based culture systems. There is some work of interest in serial reuse technology that is potentially transferable to recirculation systems that are worth mentioning. Much of this research is in the field of dietary science. Specifically, the use of high lipid (grain product) feeds instead of fish meal based feeds. This could theoretically, result in lower phosphorous and ammonia levels in fish culture water, lower the cost of feed and reduce the industry’s dependence on fish meal industry. There is also work being done on feed formulations to reduce fecal disintegration, which would ease solids removal, by settling or mechanical filtration. All of these benefits would transfer directly to farmers using recirculation technology.

In Oregon, we were unable to find many examples of recirculation technology at work. The state government appears not to have been particularly supportive of aquaculture. There are several large hatcheries operating on flow through, but beyond this there does not seem to be much happening.

In Washington state we spoke to several people, Dr. Shulin Chen and Dr. Gary Thorgaard at Washington State University and Ed Jones at the Taylor Untied Oyster hatchery. Washington state has been home to many large aquaculture projects, specifically salmon hatcheries, in part due to funding for such work as a result of damage to wild stocks done by power projects on the Columbia River. Most of these projects have been flow through. Washington State University has a recirculation lab where they conduct genetics research. This facility uses recirculation primarily due to water restrictions on campus. Dr. Chen is doing some promising work on combined solids removal/biofiltration technologies and is refocusing his efforts on the shell fish industry. This industry is very valuable commercially in Washington State and is worth approximately 50 million dollars annually. It also holds some substantial promise for expansion into recirculation technology. Taylor United operates a successful shellfish hatchery that produces 10 species of algae and 6-8 species of shellfish at any given time. The prime reason for going to recirculation was heat conservation. Source water is at 10 C while optimum culture temperature is closer to 25 C. This is obviously too great a temperature differential to make up with heating in a flow through system. The secondary factor at the hatchery that drives the recirculation program is the fact that the shellfish make better total use of the food in the water by allowing multiple passes. The system volume here is changed out about two to three times per day. There are also several examples of closed systems in use for depuration and holding of shellfish.

In Alberta, conditions both commercial and regulatory, are similar to some US states which have experienced good growth in recirculation technology, notably Minnesota and Iowa. Here an interesting blend of tight environmental regulation on ground water use and effluent discharge are combined with a government attitude that is generally willing to support the concept of aquaculture as a reasonable option for family farm diversification. There is also a good dose of pioneer or frontier style entrepreneurial spirit here where farmers seem to be willing to explore new technologies. The current farms that utilize recirculation technologies are primarily engaged in the production of trout fingerlings for restocking programs. There is also a recirculating system in Calgary producing Tilapia for the live market niche in the province. Some particularly interesting work is gong on at Lethbridge Community College and the Eastern Irrigation District. Both of these facilities have built fully recirculating warm water facilities for the culture of grass carp. Both of these facilities would not have been able to do this work without the use of recirculation due to the fact that they are on essentially potable water supplies of limited capacity and the heat differential is far beyond what could economically be achieved by any other means. The final bit of interesting work in the province is at the Alberta Research Council facility at Vegreville. They have constructed a new closed system for conducting research into recirculating technologies particularly for cold water species such as trout. This facility is now easily as well equipped as any of the labs in the eastern US and has a mandate to develop economically feasible and environmentally sustainable technologies for diversifying rural farms in Alberta into aquaculture.

In British Columbia, the vast majority of aquaculture by value and tonnage is conducted in net pens off the coast as was previously mentioned. There is also a well developed wild salmon enhancement hatchery program and some sophisticated laboratory work at the Department of Fisheries and Oceans Biological Station in Nanaimo. There is also a large shellfish industry in the province. While not as large as the industry in Washington state, it faces the same pressures in that coastal water quality is being compromised by the encroachment of urban development. This is forcing the industry to utilize sophisticated depuration plants and to consider recirculating technologies for hatcheries. There is also some interesting work in the area of Sturgeon culture with recirculating technologies. British Columbia however has a long history of governmental interference with aquaculture so it is unlikely that a commercial Sturgeon industry will develop in the province any time soon despite the availability of the brood stock at the college. Similarly there has been a restriction on Tilapia culture in the province which has allowed the Vancouver live market niche to be satisfied by producers in Idaho. There is some current interest in relaxing these restrictions somewhat but the first facilities of a commercial scale are at least a year away. The greatest current interest to pursue recirculation technology therefore falls to the salmon hatcheries.

Historical Overview of the British Columbia Salmon Farming Industry

In order to place a discussion of technology change in context, it is appropriate to briefly review the history of the industry.

The Salmon producing industry in the Pacific North West is an industry that can be defined by the obstacles that is has had to overcome.

Beginning as a wave of entrepreneurship in the late ‘70’s, the industry had become a “gold rush” by the mid-80’s. Well over a hundred salmon farms were operating on B. C.’s west coast and mostly concentrated in the Jervis Inlet region approximately 50 miles north of Vancouver. In 1986, a harmful algae bloom and the mass mortality that it caused drew the attention of media and the public to the industry and it’s problems such as mort disposal, escapage, disease and drug-use. The government reacted with a two year moratorium on the licensing of new sites as it tried to establish some groundwork for regulations.

In 1989, a second, more intense harmful algae bloom on the Sunshine Coast hit the industry already on the ropes from low market prices caused by the rapid increase in the production of farmed salmon mostly in Chile and Norway. Many companies were pushed over the edge into receivership. The remaining companies gobbled up and conglomerated the assets of the failed ventures as they abandoned the Sunshine Coast and moved operations hundreds of miles to the north, hopefully into algae-free waters.

Increasing pressure from environmental and native groups led to five-year moratorium on new farm licenses beginning in 1992 as the government undertook an intensive environmental review. Even though the review awarded the industry with a clean bill of health, opposition to the industry from environmental, native and fisher groups has continued to intensify focusing on the production of Atlantic Salmon and risks inherent in introducing a non-native species into an eco-system.

And finally last year, the Supreme Court of B. C. ruled that “native interest on Crown Land is equal to the Crown’s interest” thus any new fore-shore leases must also be processed and approved by a Native level of government which as yet is undefined.

This pressure to restrict the industry’s access to the water resource is in fact, one of the key drivers in forcing B. C. Salmon farmers to consider recirculation technologies in their hatcheries. The restrictions on ocean sites has prevented the industry from gaining the economics of scale enjoyed by Chile and Norway and so production economics must be sought elsewhere. In addition, new or expanded ground water use licenses are unlikely to be issued.

Overview of the Reasons for Pursuing Recirculation in the Salmon Hatcheries

As mentioned in the introduction, the prime reason for pursuing recirculation technologies in the hatcheries is the economic benefit. Recirculation technology is an economically viable alternative for Salmon hatchery operations. This benefit has been demonstrated in other countries and on the east coast of Canada where almost all recent hatcheries have been built to incorporate recirculation technology.

In fact, moving towards recirculation technology may be the only option in a region where the various levels of government have stated that there will be no more lakes made available for rearing smolts and expect to start paying for your water. Areas previously overlooked for hatchery construction or expansion are being revisited with recirculation in mind.

The continuing pressure of environmental concerns around the issues of water pollution and energy conservation helps strengthen the case of recirculation. With the majority of the effluent being filtered, treated and then recycled through the culture tanks, only a small amount of discharge is released. The recycling of water also reduces the energy that has been traditionally spent pumping water at the well head and heating water that was only to be used once. Last of all, the move towards a greater degree of control over the water quality in recirculation systems often results in a higher water quality in which to grow fish. There are cases where the incoming make-up water is not as clean as the recirculated water even where the fish densities are extremely high.

Examples of Audits leading to Implementation of Recirculation Technologies or Plans to do so.

Water Cost

There are some cases which have very clear pay back periods or where there was no choice but to utilize recirculation technology because of very substantial water usage surcharges. When a municipal water authority audit was conducted to find the city’s largest water users, the aquaculture program at the local college was found to be in the top five total water users in the city. Water changes were assessed as “an incentive to reduce consumption”. This water bill was in excess of the total capital and O & M

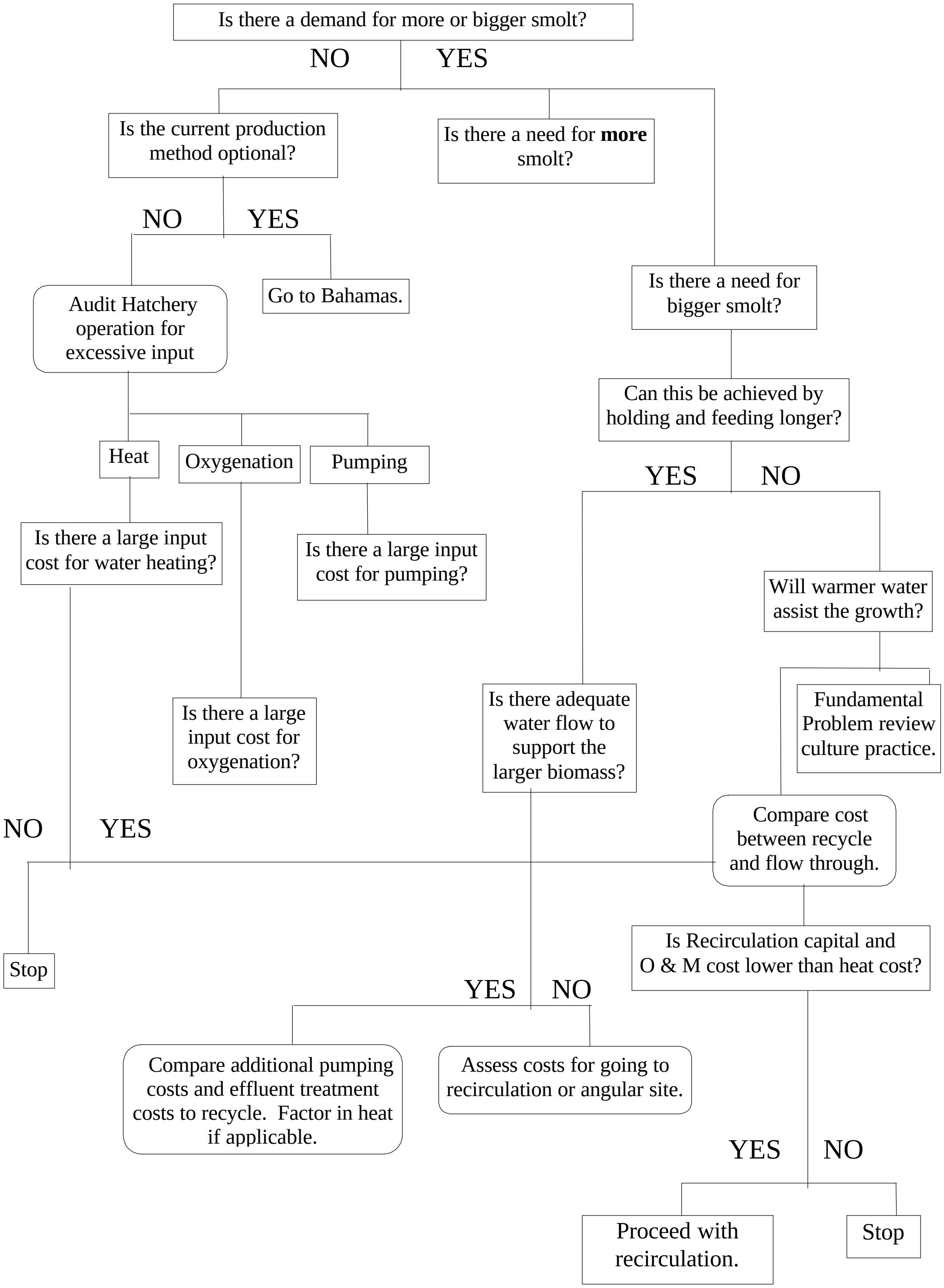

Figure 1: Hatchery Decision Tree for Intensification through Recirculation.
Note: Decision tree has been simplified by excluding feed conversion, diet, genetics and management practices from considered factors.

budget for the aquaculture program. Faced with this dilemma, the choice to proceed with conversion to recirculation was clear. The conversion of the existing facility is now complete and the staff is planning to expand into another greenhouse to work with warm water species. The capital costs of the conversion were minimized by using as much college labor, donated material and grant assisted research projects on equipment as possible. An analysis of the capital cost of this conversion is not particularly useful for designers or consultants planning green field projects or large scale conversions of existing facilities. It is however probably quite relevant to the methods and materials that might be used by an actual small scale farmer in an initial effort with recirculation. The cost of operating the system is actually quite low. In this example, the primary mechanical cost is pumping the water. They were able to use a fairly low head loss design in this facility with a total recirculation pumping head of about 12 feet. At 200 gpm and 7cents/kwhr, this cost is really very minimized at $36.00/month. This is an extreme case as the densities are very low allowing solids removal by swirl separator and setting tubes and aeration primarily by fall through packing media. Obviously the costs of operating such a simple system pale in comparison to a $3.35/1000 gal municipal water charge. To put this in perspective at 200 gpm that is a $28,944.00/month water bill Luckily, it is in Canadian dollars. Better still they don't have to face it any more.

Water Availability

In some cases, cost is not as much an issue as is water availability. When one company wanted to diversify their hatchery from Coho production to a combination of Coho and Atlantics, they were faced with the problem that their new production strategy would require operation at higher capacity during the summer. In normal operation the hatchery is fed by a blend of creek and ground water. Unfortunately, during the summer their water license limits them to groundwater alone. The ground water capacity is only barely sufficient to cover current needs. In order for the expansion to proceed recirculation would have to be utilized. Offsetting the cost of the recirculation treatment cell was the fact that going to recirculation allowed for the reduction in size of the boiler that was going to be purchased for the new area. This was a cost savings of approximately $30,000.00. The greatest savings of course is more difficult to quantify. The true benefit of this conversion is the full utilization of the site allowing for overhead costs to be spread over a larger number of smolt. There is also the business advantage of the added production and diversification that would not have otherwise been possible.

Pumping Cost

At another facility, it was thought that pumping costs were relatively high with 45 psi or 104 feet of groundwater pumping losses. With a typical recirculating system operating between 15 and 25 total feet of head loss it seemed reasonable that there could be a case made for converting one large water use area in the hatchery. This area had a drum filter already in place and a sump that would be suitable for locating the recirculation pumps. Even assuming a recirculation pumping requirement of 25 feet, there was still the opportunity to reduce pumping losses by 80 feet of head.

At $.07/Kwh, 70% pump efficiency and 90 % motor efficiency, the following calculation was done to find the monthly cost savings in eliminating this head loss differential.

$$\$/\text{month} = \frac{1000 \text{ gpm x } 80 \text{ ft. x } .746 \text{ x } .07 \text{ x } 30 \text{ x } 24}{3960 \text{ x } .7 \text{ x } .9}$$

$$= 1205.66 \ \$/\text{month}$$

This is a substantial savings for a facility of this scale but it is not adequate to justify proceeding with a conversion when taken alone.

Heat

At the facility there were additional cost factors which would lead to a more justifiable conversion argument. An energy audit was conducted and it was found that an annual heating cost difference of $86,853.75 existed between the recycle system and the flow through version.

Work on the conversion of this hatchery is waiting to proceed pending the results of similar conversions being undertaken elsewhere by this company.

Summary

In the Pacific Northwest, several factors, operating separately and in combination are impelling the aquaculture industry to seriously consider recirculation technologies. Although political and environmental forces are tightening the parameters of water use and limiting the geographical areas in which to operate, it is the cost of production, the proverbial bottom line that is the engine driving the industry towards a more cost effective use of its primary resource, water.

Definitions

In order to clarify some of aspects of the paper, I have included a brief list of definitions for words or phrases that I was concerned might have multiple interpretations.

Pacific Northwest- There are certainly several different definitions of this region, ranging from Washington and Oregon only to a much broader climatic region. I have chosen to define the region as including the states of Washington, Oregon, Idaho and Alaska. I have also included the Canadian provinces of Alberta and British Columbia.

Recirculation System- I have defined this as any system which utilizes water treatment technology to treat and continually reuse water for the culture or holding of aquatic animals.

Serial Reuse- I have not considered serial reuse systems as recirculating systems although some of the practices and research in this area could be usefully transferred to more closed systems. These systems take advantage of large volumes of flowing water to culture fish in a series of culture areas, usually raceways or ponds, and usually with the only treatment being the addition of oxygen.

Intensification- I have loosely defined this as any process by which greater aquaculture production can be achieved utilizing the same water resource.

Recirculation Rate- I have used the European convention of referring to the recirculation rate based on a percentage of flow as opposed to percentage of water volume changes per day. This allows for easier comparisons of heating and pumping costs between flow through and recirculation systems.

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The European Experience with Production Intensification

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Introduction

Aquaculture in Europe is an active and diverse industry. It operates in a wide range of environments and production systems, producing a number of species targeted towards expanding domestic and export markets. With the exception of the more remote inland and coastal regions, the land mass is highly developed and intensively populated, with high concentrations of manufacturing, service and recreational functions, and increasing value being placed on natural resource protection. An educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice.

In this context, a resource-intensive sector such as aquaculture faces particular challenges requiring a range of technical, managerial, and strategic responses. In both inland and coastal areas, aquaculture has come under increasing scrutiny, with greater constraints on water supply and discharges, land or water column occupancy, and the efficiency of use of various inputs. At the same time, competitive pressures and the potential for economies of scale have increased the commercial imperatives for expanding production within individual enterprises and at specific sites. A consequence of these pressures has been a drive towards intensifying production, and doing so in a manner that enhances production efficiency and reduces external impact. While artesian or traditional forms of aquaculture are likely to remain in Europe, and will be valued for their “natural” attributes, mainstream commercial production may be expected to become increasingly intensive.

This paper describes some of the trends in intensification in European aquaculture, using specific examples of the coastal cage culture sector, involving Atlantic salmon and Mediterranean seabream; pond or tank culture, involving turbot, rainbow trout and channel catfish; and recycle systems, involving European eel and African (*clarias*) catfish. Key trends are described, and the technical and management issues involved in developing competitive production capable of meeting regulatory and consumer criteria are considered. Finally, the potential directions for intensive aquaculture in Europe are discussed, together with the relevant issues of technology development, market and regulatory response and strategic competitiveness.

Background

Within Europe, the aquaculture sector is an active and diverse industry, operating in a wide range of environments and production systems, from traditional extensive operations to highly intensive, technologically-sophisticated units. It produces a range of species – though as in North America these are still grouped around a small number of core subsections – targeted toward developing expanded domestic and export markets, with increasing consciousness of product uniformity, quality control, and productive efficiency (Ruckes, 1994; Young and Muir, 1997). With the exception of the more remote inland and coastal regions, the land mass is highly developed and intensively populated, with high concentrations of manufacturing, service and recreational functions, and increasing value being placed on natural resource protection and enhancement. An educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice.

Table 1 provides an outline of current European finfish production in Norway, demonstrating the relative importance of species such as Atlantic salmon (55.2%) and rainbow trout (28%) in total production, though shellfish – oysters, mussels and clams – represent greater quantities in volume terms. Table 2 provides a more detailed breakdown of the major subsectors of the complete aquaculture industry, including shellfish (STAQ, 1996). The production focus on traditional salmonids is based primarily on the remarkable record of production in Norway and Scotland. Confining production to EU countries alone, excluding Norway's estimated 20,000t of salmon production in 1997**,** reduces the region's output to around 485,000 and the contribution of salmon to some 25%. Though the salmonid sectors are intensive, they are primarily based on cage culture in open coastal waters. Although the technology is increasingly sophisticated, intensification *per se* has involved very little modification of the basic holding systems, and is primarily related to the more intensive utilisation of specific site areas, the expansion of the production scale, and the derivation of scale and management-related production efficiency (Torrissen, 1996). Within the rainbow trout sector, the traditional pond-based portion-sized trout sector in the UK and mainland Europe has grown only gradually, and has more recently been supplemented – particularly in France, Norway, Finland, Sweden, Denmark and Germany – by the production of larger (>1kg) trout grown in cages in fresh and brackish waters (FEAP, 1998). The other substantial species group, apart from the traditional central European subsector of pond carp production (typically semi-intensive, using 2-3 year production cycles) is the cage culture of seabass and sea bream, using techniques similar to those of cage salmonid production in the Mediterranean region. Fuelled by good market prices and increasingly available hatchery production, the sector has grown particularly rapidly, though it is now increasingly constrained by declining market prices. In the shellfish production sector, raft and longline production of mussels (*Mytilus edulis* and *M.galloprovincialis*) has also grown notably, but has suffered recent declines in some areas due to algal blooms and increasing market saturation (Tacon, 1998).

Table 1. Overview of European aquaculture 1993-1997

Species	**1993**	**1997**	**% yr**	**Key features**
Rainbow trout	190522	227510	4.5	portion sized and larger, widely produced
Eels	5386	7675	9.3	specialised: Italy, Netherlands, Denmark
Carp	53611	57008	1.5	mainly common carp, E. Europe and Germany
Clarias catfish	900	1150	6.3	specialised: Netherlands, Belgium
Channel catfish	1750	500	-26.9	mainly Italy
Arctic char	714	1160	12.9	Sweden, Norway, Iceland, France
Sturgeon	451	652	9.7	mainly Italy, France
Atlantic salmon	252999	445612	15.2	Norway, Scotland, Ireland, Faroes, Iceland
Sea bream	12027	35326	30.9	Greece, Turkey, Italy, Spain, Malta
Sea bass	10382	24900	24.4	Greece, Italy, Turkey, France, Malta
Turbot	1424	3250	22.9	Spain, France, intensive systems
Halibut*	70	138	25.4	Norway, experimental in Scotland, Iceland
Grey mullet**	2060	2200	3.3	Italy, Spain – lagoon systems
Other mullet**	250	343	17.1	France, Greece – lagoon systems
Senola**	30	30	0	Majorca, mainly experimental
Bluefin tuna**	20	20	0	Spain, experimental
Total	**532596**	**807474**	**11**	

Source: FEAP, 1998; FAO, 1997

Table 2. Major aquaculture production systems in Europe (Source: STAQ, 1996)

System	**Species (estimated production '000t)**	**Significant locations**	**Notes**
Terrestrial			
Lagoons, parcs / salinas	Seabass, seabream, other breams, mullet (5) Oysters, clams (20)	W and S coast Portugal, Mediterranean coast of Spain, France, Italy, Greece, Algarve / SW Spain, W coast France	Traditional coastal areas, collective / artesian practices
Ponds	Common carp, other cyprinids (15) Rainbow trout (120) Eels, catfish, sturgeon (2) Crayfish (1) Atlantic salmon (0.5) Seabass / Sea bream (0.1) Turbot/halibut/sole/ other flat fish (3)	Inland France, Belgium, Germany, Austria, some UK France, Denmark, N and W Spain, N Portugal, UK, Ireland, Germany, N Italy, N Greece N/Central Italy, France, Spain, Sweden, France, UK UK (Scotland) Spain (Canarias), N W Spain, Central Portugal, France, Sweden, UK	Traditional inland areas, increasing sport fish / restocking Rowing water culture in earth ponds Eels more traditional. Also in open water bodies Now less significant Limited development

System	**Species (estimated production ‘000t)**	**Significant locations**	**Notes**
Tanks / Raceways	Eels, catfish, sturgeon (2) Tilapia (0.5) Arctic charr (neg)	Netherlands, Belgium, N Germany, France, UK (Scotland) Belgium, UK UK (Scotland), Finland	Mainly turbot, sometimes in heated effluents Usually in recycle systems Heated effluents or recycle systems Experimental – recycle systems
Immersed Cages	Atlantic salmon (80) Rainbow trout (10) Arctic charr / other salmonids (2) Sea bass/bream (25) Amberjack (0.1) Halibut (neg)	UK (Scotland), Ireland, Sweden, Denmark France, UK (Scotland), Ireland, Finland Finland, Sweden, France Greece, Italy, Spain, France Spain (Majorca) UK (Scotland)	Major production sector increasingly produced in coastal waters, also lakes France has produced coho (Pacific) salmon and sea trout Major production sector Experimental/ pilot scale Experimental only
Enclosures	Sea bass/bream (0.5)	Italy, Greece	Small scale only
Raft / longline (suspended culture)	Mussels (150) Oysters (1) Scallops (1)	NW Spain, N Italy, Greece, Ireland, UK Ireland, UK Ireland, UK	Major production sect
Pole/bed (bottom culture)	Mussels (150) Oysters (150) Scallops (5) Clams (50) Abalone (neg)	Netherlands, UK, Ireland Ireland, N & W France, S UK, Spain, Portugal, Italy W France, Spain, Portugal, UK France, Spain, Portugal, Itlay, Greece Ireland, France, Spain, Portugal	Relaying and dredging Major production sector in traditional areas Major production sector Experimental only

By contrasting these significant and active sectors with well-established technologies and markets, three other broad categories of production can be identified (see Table 2): traditional forms of aquaculture, typically extensive and semi-intensive, e.g., involving bed and bouchot shellfish culture; lagoon-based production of mullets and other breams (F-C, 1995); new species development, some of which (e.g. turbot, sole) have been in place for some time (Jones, 1994; Stephanis and Divanach, 1994; Kestemont and Billard, 1993), many of which (e.g., *Seriola* - amberjack) have changed little since original trials. Others, such as halibut and the Siberian sturgeon *(Acipenser baeri)* appear to be poised for a certain level of growth. These are primarily based on existing forms of production, commonly culture, but might also use intensive onshore production. Specialised intensive production – based primarily on eels, African *(Clarias)* catfish (Bovendeur, et al. 1987; Karnstra, 1992; Dijkma, 1992) and tilapia – using waste heat and intensive recycle systems, rely on environmental tolerance of the species chosen and their potentially high market value to provide viability for the relatively expensive production systems (Dickson, et al. 1993).

In addition to these ongrowing categories, an increasingly sophisticated hatchery sector can be identified, gradually using more intensive approaches to provide the requisite level of control over reproduction timing, seed quality and market opportunity (STAQ 1996). Though insignificant in biomass terms, this sector continues to hold a disproportionate share of value, and represents a far higher concentration of technology investment.

As in North America, the European aquaculture sector has had an active engagement in technology development. In many respects, European aquaculture has undergone similar processes and cycles of technology expectation, production cost, and performance limitation, misplaced (or premature) technology investment, and a gradually maturing recognition of the potentials and certain technology approaches (Muir et al, 1996). The changes in technology that occurred during the last two decades have been incremental rather than in a breakthrough pattern. Improvements have occurred in fundamentals, such as genetic base, health management and feeding efficiency, and the particular benefits of well targeted sources and applications of technology.

Current issues and constraints

With the exception of its more remote inland and coastal regions, in which some of the aquaculture sector is located, the European land mass is highly developed and intensively populated. With the correspondingly high concentrations of manufacturing, service and recreational functions, and relatively high per capita incomes, opportunities exist for expanding markets for quality products. Increasing value is placed on natural resources and the maintenance of their quality (EC, 1995). Issues such as biodiversity (Beveridge et al, 1994) are increasingly important. As a result, an educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice. This dynamic is compounded by increasing buyer concentration; though differentials exist between European countries, supermarkets increasingly dominate retail sales of fish products. Given their concerns for image and reputation, fish products will be subject to criteria similar to those applied to other food sales, and may well represent higher-profile targets for raising the “green” credentials of competing chains (Young and Muir, 1997).

In this context, a resource-intensive sector such as aquaculture faces particular challenges, which have required from the industry a range of technical, management and strategic responses. In both inland and coastal areas, aquaculture activities have come under increasing scrutiny. Greater constraints have been applied to aquaculture water supplies and discharges, land or water column occupancy, and on the efficiency of use of the various inputs to production (EC, 1995; Muir and Beveridge, 1994). At the same time, competitive pressures in expanding sectors and the potential for economies of scale in many operations have increased the commercial imperatives for expanding production within individual enterprises and at specific sites (Muir and Young, 1997). A natural consequence of these pressures has been a corresponding drive towards intensifying production, but, as far as is possible, doing so in a manner which both enhances productive efficiency and reduces external impact. Artesian or traditional forms of aquaculture are likely to remain in Europe, and will be particularly valued for their "natural" attributes. However, mainstream commercial production, by far the most significant component of the industry, may be expected to become increasingly intensive. While more challenging technical approaches, such as offshore aquaculture and onshore recycle systems are under consideration, the most common circumstance is that of intensifying existing sites and systems (Prickett and Iakovopoulous, 1994).

A notable accompaniment of expanded production has been the fall in market price and the drive to reduce production costs. Improvements in growth rate, food conversion, maturation management, and disease control can all contribute, and, as in the case of the pioneering Atlantic salmon sector, costs for more efficient operators have dropped from approximately US$5.00 kg^{-1} in the late 1980s to current levels of US$2.00 kg^{-1}. In the Mediterranean, seabream production costs have dropped from around US$9.00 kg^{-1} to US$6.00 kg^{-1} over the same time (Muir & Young, 1997). These compare with even lower production costs internationally; in the US, average 1996 farmgate price of channel catfish was US$1.70 kg^{-1} (*Fish Farmer*, 1997), with tilapia production costs as low as US$1.00 kg^{-1} quoted for new large-scale tropical projects (Little, 1997; *pers. comm.).*

The emergence of the European Union as a more coherent regional political and economic group has also brought its own consequences. At a strategic level, a range of policies have been adopted in an attempt to stimulate domestic food (and fish) production, to promote economic growth in disadvantaged regions, to create a free market within member states, to open trade to poor countries, and to standardise legislative environments (STAQ, 1996). The impact of these policies may be confusing and contradictory at best, but may bring both positive and negative impact to bear. With respect to aquaculture and its intensification, current issues include the relative availability of investment support for quality upgrading, the unification of environmental management philosophies, funding policy for industry-linked research, and the relatively open competition from non-EU suppliers.

The role of technology

From the foregoing, it can be seen that the technology of intensification has a significant but variable role in the European aquaculture sector, and careful application of selective technologies is a matter of increasing importance in more strongly competitive environments. The increasing scale of many aquaculture operations also leads to a more widespread use of bulk handling technology, larger scale monitoring and control systems, and automation. As elsewhere, a mix of technologies can be identified. These technologies have evolved around specific systems, and a range of relatively standardised elements, such as aerators, fish pumps, cage modules, tank units, and feeder systems.

The origin of aquaculture technologies within Europe has patterned those found in other sectors. Technologies have been borrowed from marine engineering, oil industry technology, the water treatment industry, materials sciences, and the agricultural, chemical and food processing sectors. A small but increasing degree of intra-sector research and development has occurred as the industry grows, with more Europe-wide sales prospects, justifying specialist attention. Systems such as the UK "Technology Foresight," ROPA ("Realising our Potential" Award) and "Teaching Company" programme, and the EU "CRAFT" also offer routes for combining academic research with commercial enterprise, particularly in the small and medium enterprise sector. These research and product development systems have been available to aquaculture, though the bulk of such work has to-date been concerned with biological science in fields such as reproduction, genetics, and health management.

Developments are commonly carried out on an *ad hoc* basis within production, supply, and service companies. Because product development and trial periods vary, producers accept a certain degree of risk when accepting relatively untried technology, particularly, though not exclusively, in the recycle system and offshore cage sector (STAQ, 1996). The response to demands of existing sectors has not been revolutionary; instead systems developers have introduced gradual improvements. In this respect, changes towards intensification are often brought about through a process of dialogue between developers and producers, with external pressures an ultimate element in commercial decisionmaking. Thus, while there may be incentives for change, the decision of how or how much to modify an existing production system (e.g., should some supplementary aeration or oxygenation be added, or a pond layout modified, or should the production system be modified radically) will still depend on the technical confidence and the commercial judgements of the producer (Muir, 1993). As elsewhere, a certain collective mentality may also apply, at least at a national level with industry leaders influencing others. To this might also be added the potential role of the multinational aquaculture company, and the related tendencies to apply similar technologies, using standard suppliers, at all production sites. However, this has not been a significant phenomenon to-date, partially due to historical circumstances, as with the takeover of established and equipped national enterprises with local supply and service contracts.

Current approaches

The key problems concerning the mainstream aquaculture sector in Europe have been noted, and the response of intensification identified. Clearly, intensification alone is not the typical development response, and it has to be carried out within a defined context. The most critical of these is not surprisingly the "cost envelope," i.e., the available range within which any production system might be viable, modified as appropriate by the perceptions of technical or commercial risk (Stephanis, 1995; 1996). As elsewhere, declining margins and a higher degree of competition have limited the range of options, and have also tended to favour incremental rather than radical investment. Unlike much of North America and many other parts of the world, energy costs have traditionally been high in Europe. Although market deregulation and tariff reductions for certain user categories have reduced actual prices for many aquaculture producers, prices remain significantly higher (typically \$0.1 - 0.15 kWh^{-1}) in most of Europe. A possible exception to the incremental approach is the occasional "new venture aquaculture" development, increasingly rare as the pioneering phase of aquaculture production has passed, and more common in terms of export promotion, particularly for package recycle systems and offshore aquaculture.

Another increasingly critical factor is that of quality management, i.e., the need to plan and control production flows and to record the production circumstances of all stocks through the system (Muir and Bostock, 1994). This tends to favour more precisely managed systems, in terms of water and waste management, feed systems, inventory and monitoring processes. Therefore, intensive production systems tend to be favoured where investment is applied. The importance of feeding efficiency itself tends to drive management towards more closely graded operations, hence, a higher degree of stock control, grading, and “fine-tuning” to meet the needs of specific stock batches. In addition, the gradually increasing pressure for so-called “green” products has lead to greater attention being devoted to rearing conditions and handling procedures.

There is also a growing, if not completely enthusiastic awareness of sustainability issues, particularly at inland and nearshore coastal sites (Folke and Kautsky, 1992; Stewart, 1995), though to-date this has not proceeded much beyond the intention to reduce physical disruptors, demonstrate some degree of harmony with surrounding ecosystems, and if not to support, at least to avoid diminishing biodiversity and cultural diversity. Though the wider principles of ecosystem engineering are yet to become established, physical features, layouts, use of restorative space, and control of external interactions are becoming slightly more common. Though unjustifiable in broader sustainability terms, the concept of a self-enclosed production system, possibly supporting some local conservation objectives, is appealing.

At the technical level, therefore, producers and system developers have taken up a number of changes (STAQ, 1996) including:

1. More closely managed stock control, with simplified systems of stock pumping and transfer, as well as improved monitoring, better precision in feed input (Bjordal and Juell, 1993; Blyth et al, 1993), and inventory programming.

2. Move from simple settlement devices to more closely engineered swirl concentrator or screen filter designs. Self-backwashing rotating disc and drum screen filters targeting known particle sizes and using water or air washes are increasingly common, and recent developments have included conveyor belt filters which can more readily remove finer particles.

3. Closer attention devoted to tank or raceway hydraulics, and to inlet and outlet designs, oxygen and metabolise profiles, and feed and stock distribution; dual outlets are increasingly being considered, separating solids into two streams, though it is still sometimes problematic to adapt inlets and outlets to meet a range of stock sizes.

4. Closer assessment and design of heat budgets, particularly in association with recycle systems and the potential effects of system heating through pumps, aerators and biomass.

5. Greater use of oxygenation, in association with more closely controlled temperature, feeding regimes, and activity levels, and with feedback sensors to reduce wastage. However, aerators are still widely used, but as in North America, are more carefully selected and designed to meet specific operating requirements.

6. Gradually increased use of ozone and foam fractionation devices to improve water quality and clarity, and use of ozone itself for sterilisation; flooded or trickling biological filters still represent a mainstay of production; denitrification is not commonly used, though may be partially supported in anoxic subsystems. However, current interest in higher recycle rates is increasing the case for specific incorporation of these stages.

7. Improved control and management information systems linking temperatures, stock, system and treatment process conditions, feeding systems, stock behaviour, etc.

Based on these trends and developments in intensification, a number of subsectoral changes can be observed (STAQ, 1996; Muir *et al,* 1996; STAQ 1998).

Apart from the traditional forms of eel culture in Italy, eel and catfish production has primarily built up around the basis of package recycle systems, usually based on simple solids removal, trickling biofilters and partial ozonation. This had developed particularly in Northern Europe, where in the Netherlands the sales of "fish barns" proved to be attractive for a number of agricultural farmers wishing to diversify. The technical objective was to create "plug and play" systems, though this had never been achieved in practice, and most systems required more detailed management than anticipated. A necessary element had been the environmental tolerance of the species and the potential for high biomass output related to high growth rate and stocking densities, and the implications of marketing the product had been less carefully considered. In practice, a number of technical constraints, combined with reducing market prices and increasing energy costs, has reduced the output of this sector and led to the closure of smaller units. The recent increase of eel export from China, and the potential supply of *Clarias* from other sources, such as Thailand, Philippines and Bangladesh, has further discouraged new entrants. By contrast, primarily in Italy, eel and channel catfish production has been carried out in earth ponds, traditionally fed with gravity water supplies, or more commonly supplemented by pumping. The channel catfish sector uses semi-intensive techniques with a single-year production cycle. The European industry lacks the major research and development resource which has made American catfish production so efficient. However, intensification has proceeded along the lines of that pursued in North America, with the gradual introduction of aerators and supplemental oxygenation, though future directions might be constrained by competition from imported North American producers (Neubacher, 1995). Siberian sturgeon *(Acipemer baeri)* are also being grown in ponds and tanks, mainly in France and Italy. Though still in their early stages, techniques are being developed, and more intensive systems may be feasible.

As in North America, the potential for intensive production of tilapia and carp had been considered since the 1970s. Trials in intensive and recycle carp culture, particularly in Germany, have dated from that era and had contributed significantly to the wider understanding of intensive water management and recycle system performance (Meske, 1976; Otte and Rosenthal, 1979). However, this development, though technically interesting had never proceeded due primarily to the lack of market demand for carp, particularly in the post-Perestroika period. By contrast, intensive tilapia production has been established, if at a minority level, with initial interest surrounding the use of waste heat from power stations or industrial processes. The most common are the *Oreohcromis niloticus* and *O. aureus*, or for saline waters, *O. mossambicus* or *O. spilurus*, grown at densities of up to 50 – 60 kg m^{-3} at optimal temperatures of around 24 - 30°C, taking 5 – 8 months to reach 200 – 400g. To date, the most notable and longest lasting such project has been the joint-venture operation at the Tihange nuclear power station in Belgium, producing tilapia intensively on a year-round basis, using elliptical GRC tanks and warmed intake water. A recent venture in the UK, using textile mill wastewater has just closed; though contractual problems were cited, concerns about potential profitability had also been noted. The most significant moves in intensive production of tilapia have taken place in Israel, where a range of semi-closed and complete recycle systems is currently under development and in commercial production (Simon and Kinsbursky, 1997). Two general approaches can be described:

1. A modified traditional system using Taiwanese rounded square ponds with water circulated by paddle-wheel aerators at each corner, and a central sump for waste collection and solids removal (Mires and Amit, 1992), and;

2. More complete reuse systems involving ponds or tanks, together with nitrifying and denitrifying biological filtration, with the objective of maximal water conservation (Arviv and van Rijn, 1994).

Though neither of these systems has supplanted the core sector of pond production of tilapia and carp, they are under active development and may be expected to gain interest as water management and its cost becomes a more pressing issue in the region.

The production of rainbow trout *(0. gairdnerii)* in simple earth ponds has been one of the mainstays of European aquaculture. This subsector remains a distinctive contributor to rainbow trout production along with lake- or coastal-based cage culture, and occasionally intensive tank and raceway culture. A range of intensification can be observed, including use of aeration and oxygenation of conventional trout ponds or earth raceways, redesign of earth ponds to improve hydraulics and waste removal, and conversion of earth ponds to spiral flow concrete tanks with supplementary oxygen control. The use of simple back channels (waste collection ponds) is increasingly common even in relatively simple systems, and these are not infrequently used as sumps from which water can be recycled during low water flow periods. A small subsector in rainbow trout production uses intensive tanks and raceways in highly intensive oxygen-based systems. However, since Forster *et al*, 1977 illustrated the difficulties of operating these intensive tank-based systems profitably, they have not developed strongly. Large raceway-based systems (typically 200 to l000t or more per units), using pumped or spring water are being operated successfully in Italy Spain, Portugal, and France, usually with supplementary oxygenation, though some have closed due to production inefficiency.

The onshore production of Atlantic salmon has been one of the main areas of technical development in intensive systems in Europe, stimulated in the mid-late 1980s by expectations of continued market margins and the theoretical benefits of managed onshore environments. Considerable investment had been committed, particularly in Scotland, Norway, Iceland and the Faroes, generally based on large circular or elliptical tank systems with supplementary aeration and/or oxygenation and high stocking densities, typically 40kg m^{-3} or more (Blakstad, 1993). In Portugal, a similar development made use of saline groundwater at optimal temperatures, with controlled oxygenation, photoperiod controlled smolt supply and high density tank rearing. In almost all cases, except where artificially subsidised, these systems did not prove to be competitive, and have been converted to other uses, such as marine flatfish or salmon broodstock production. Some production continues in Iceland, where energy costs are still marginally favourable, but performance will be highly dependent on the effectiveness of oxygenation and mixing regimes currently being developed.

Marine flatfish; turbot, and halibut, and also Dover, Japanese and Senegal sole have been produced in intensive systems, primarily tanks or raceways fed with saline groundwater, heated industrial or power station effluents, or directly pumped seawater. The most significant sector in terms of production is that of turbot, whose production is primarily concentrated around Northern Spain, with other producers in France and Portugal. In some cases, systems have been converted from earlier intensive salmonid systems, which had been unprofitable to turbot systems, where the higher market price of turbot was expected to help support the higher capital and operating costs. These systems have remained in operation but are increasingly concerned by pressures on market prices, and henc production margins. Intensive onshore halibut systems are also being promoted as one of the possible routes for its production, and though these are largely untested, the species appear to tolerate relatively high stocking densities. Intensive systems for halibut species are relatively simple, usually involving concrete or frame and liner raceways, in some cases organized to provide internal layers to allow the fish to “stack” more effectively. Oxygenation systems are increasingly common in reducing the costs of water exchange and maintaining optimal environments.

Seabass and seabream production; based on the traditional lagoon culture systems in the Mediterranean coastal region, a number producers have developed more intensive ponds or earth raceways for these and associated marine species. The cost of production has been kept within acceptable boundaries using relatively simple pumping and aeration systems, typically based on developing slowly circulating pond environments. Wastes are usually discharged directly, often into the main lagoon areas, where they serve to enrich productivity. Several intensive onshore systems had also developed for these highly demanded warm-water marine species, particularly in Cyprus, Italy, Spain (Canary Islands) and Portugal. The intensive onshore systems are often based on concrete raceways with directly pumped seawater and supplementary oxygenation. The cost of production has been high compared with most cage units (STAQ 1991; Blakstad, et al, 1994), producers have found it difficult to remain competitive. Key systems have been subjected to redesign to improve hydraulics, gas management and waste management.

Other species; Arctic charr have recently attracted attention, particularly because of their surprisingly high stocking dersity tolerance (active growth at up to 80 kg m^{-3}) and their potentially interesting marketability; to date, systems have been similar to those of present generation intensive trout and salmon production, i.e., tanks or raceways, aeration, solids removal, and biological filtration. The wolf-fish or sea catfish *(Anarichas lupus)* has also been examined experimentally, having similar potential for high stocking density, together with rapid growth rate. However, its marketability is uncertain, as there are still substantial wild fish landings at prices which are currently well below the potential cost of production in intensive systems. In fresh water, there is also a small amount of intensive production of sport fish – primarily fry and fingerlings, for restocking into open waters or into the increasingly common commercial put and take fisheries.

Other package systems have been developed for a range of species and are typically marketed to non-specialist investors on the basis of their complete independence from external environments, their high degree of control, their priority, and their ability to supply markets optimally. These systems are commonly based on water recycle units, usually with conventional biofilters, solids removal, oxygenation, and ozone or UV sterilisation units. In some cases filter configurations such as rotating 'Biodrums' may be used, but as these generally require more energy, they tend to be superseded by static filters. Simpler systems have standard tank or raceway configurations and sequential common flow paths, which may be split up into sub-modules. More advanced designs may have closer detail in tank hydraulics and waste flows, and will tend to use "sidestreams," i.e., partial flows being directed to specific treatment units. In some cases, additional heating and/or cooling circuits may be used (Bawden, *pers comm*, 1998). Generally, these package systems have had a variable record, and have proved most effective (in production terms) for robust species such as carp, tilapia and African catfish.

Hatcheries, for various species, but particularly for the major groups of salmonids, seabass and seabream, have shown perhaps the strongest trends towards intensification in recent years. Intensification of hatcheries has been particularly stimulated by the increasing demand for year-round production, and by increasingly competitive environment demanding higher productivity from available facilities and management inputs. Within the salmonid sector, much of the change has concerned the establishment of temperature controlled operations for year-round production, either using heat exchangers, or increasingly, using partial or complete recycle systems. In other cases (e.g., the Shetland Islands), water recycle systems were established at the outset to overcome water supply constraints, and have only subsequently been operated with temperature management as a key objective. Many of these systems are based on proprietary units in which solids removal and ozonation are used as primary treatment stages, and a certain number have been subsequently re-engineered to improve their performance and productivity (Bawden, *pers comm, 1998).* In the case of seabass and bream, intensive recycle systems have been developed in a number of locations, to compensate for inadequate or poor quality water supplies, to reduce heating costs, and/or to maintain water quality within the system. Many such systems have been developed using quite complex layouts and components, with a range of automated features, biofilter units employing specialised granular media, foam fractionaters, ozone units, and high-specification heat exchangers. However, a number of hatcheries have also developed their systems subsequently to initial installation, some of which may be more simply designed.

Future developments

Though its potential significance might still be questionable, at least in the medium term, it would appear that the more intensive, primarily land-based aquaculture sector will continue to occupy a useful role in overall production in Europe. Based on current activities and recent trends, and subject to the factors discussed earlier, a number of technological trends and developments can also be identified for the European intensive aquaculture sector, though their timing and impact will be subject to a range of other influences. These include:

- the existence of commercial and/or legislative incentives to control wastes and improve the environmental credentials of aquaculture production; though more intensive systems are rarely more sustainable in the broader context, public perceptions of the importance of controlled waste discharge and good animal husbandry conditions may well outweigh concerns for additional capitalisation or energy costs.

- the development of more comprehensive evaluation/management packages for intensive production. A range of assessment tools need to be developed to improve the ability to assess the potential for developing or re-engineering intensive systems, linking technology specification with performance and production cost criteria. This would be justified by the use of more closely targeted objectives by major producer groups, plus the need to identify clear development and operational criteria for technology packages.

- the adoption of more closed production units in open waters, involving either closed bag systems, partially enclosed systems, and/or time-linked devices for waste removal and recycling. Interest is already developing in the USA, Norway and Scotland (Institute of Aquaculture, 1998), and a number of potential systems are in the course of evaluation and pre-commercial testing. Suitably viable approaches might involve a production cost envelope of no more than 10% above current operating costs and would involve important improvements in the capture of unused or metabolised therapeutic compounds and of unused feeds.

- a move from partial to complete recycle systems. Where companies have started to invest in water treatment equipment and face continuing or increasing pressures of water supplies and/or waste management, the logic of improving water management through better control of water use and quality, and reusing treated water, starts to become more compelling (STAQ, 1998). At this stage, the advantages of more complete water quality and temperature control can be incorporated, delivering particular benefits in situations where production planning becomes more critical. Though in practice, farm managers may need to be convinced of the practicality of controlling management risks. A gradually increasing record of use and effectiveness would provide a more positive basis for change.

- the use of more intensive systems for specialised production sectors particularly the higher value new species, for organic production (Debio, 1996) and for specialised hatchery sectors. A mix of factors including the need to isolate non-indigenous species, the need to create optimised conditions for demanding efficiency targets and the need to control production for specific temporal and quality factors, will tend to justify the higher capital and operating costs entailed. In some cases, existing intensive installations may be adapted for new species; in others systems may be intensified, and in a small number of cases, new projects may be developed.

a move towards better and more integrated control packages – increasingly necessary to manage more sophisticated systems, and to deliver optimised performance in changing environments according to production targets; considerable development has already taken place, but the use of PC-based decision-support systems is likely to be increasingly common (Muir and Bostock, 1994).

Conclusions

The intensive aquaculture sector occupies a distinct position in the European aquaculture industry, but more highly intensive tank, raceway and recycle systems are relatively insignificant in overall terms, and are subject to significant cost pressures. However, the same cost pressures, together with an increasing concern for environmental management, are increasing the intensification of some of the more traditional pond and tank sectors, requiring an increased use of similar technologies, particularly for water management, feed control and waste treatment. In addition, the coastal aquaculture sector, which has contributed much of the recent growth in production, is likely to have to adapt practices and systems, to move more decisively offshore, or demonstrate improved environmental containment.

The future for the more intensive sectors will depend on a number of inter-related factors, including:

- structural changes within the industry and the strategic decisions concerning production sites, scene of operation and product image, together with strategic decisions by major retail groups.
- trade potential and access to imported products based on less complex or expensive production approaches; key areas include channel catfish, tilapia and tropical shrimp.
- the practical enforcement of environmental regulation and the acceptance by consumers of the necessary price changes.
- the extent to which technology will be available at acceptable costs, and can be applied without unnecessary risk or interruption to market supply.
- the levels of investment available for commercial and pre-commercial research and development, and the effectiveness of industry associations and technology suppliers in testing, developing and proving newer applications at suitable commercial scales.

In this context, while highly specialised systems are unlikely to occupy a significant share of future production, land-based systems can be expected to continue and possibly even expand, using similar quantities of water at higher productivity levels and returning lower levels of wastes to external environments. New species are likely to use modifications of existing systems, though highest value species may justify some intensification. Loadings in inshore coastal waters are also likely to be further controlled, and intensification and process control will become more common. All of these changes will require further investment in technology, and in the case of existing production, will require better developed skills in upgrading and delivering profitability from technology investment. The research and development sector has been moderately successful to-date, but may require better co-ordination and product targeting to maintain competitiveness in global marketplace.

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The Impact of Fish Handling Equipment

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VI. Summary

Trends in Feed and Feeding Strategies

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Introduction

Feeds and feeding strategies are often over-looked opportunities of a recirculating aquaculture system. Though feed costs represent a lesser portion of total production costs in a recirculating system than in a single pass system, feed characteristics may significantly affect production efficiency, water quality, and both operating and capitol costs of the recirculating system. Feeding strategies should deliver feed at rates which maximize growth, minimize feed waste, and supply the biofilter with a steady supply of metabolites while maintaining a “natural” environment for the fish. Profit optimization, within marketing constraints is the continuing goal of commercial projects.

Feeds

Feeds formulations specifically designed for use in recirculating systems are not commonplace, mainly because the interaction of diet formulation and system function has not been thoroughly studied. However, the waste minimization strategies for trout and salmon production in flow through systems can give insight for improving contemporary diets for recirculating systems. Current feed formulations can be improved by altering their nutritional and physical characteristics.

It has been observed and reported that feed type influences fecal consistencies. In addition, there are also differences among species in fecal consistency, tilapia are noted for a consistent fecal cast, rainbow trout have semi-cast feces, and hybrid striped bass have constant diarrhea. Fecal consistency could possibly be a factor that can be managed through diet formulation.

Dissolved solids from feed inputs have an affect on the color of the culture system water and indirectly affect fish behavior. Dark colored water would allow less light penetration, possibly providing a more suitable environment for some species and also minimize outside disturbances to the fish (i.e. human interactions). Water that is clear has the advantage of allowing easy observation of fish for management purposes. Water color and clarity could be modified to a certain extent by feed ingredients and with color additives to the feed.

Nutritionally, feeds must meet species requirements for optimal growth while preventing nutrient excess at the same time. Feeds formulated with protein content in excess of requirement or made from poorly digestible ingredients should be avoided. The protein requirement of fish is actually a requirement for essential amino acids and a nitrogen source (i.e. nonessential amino acids) used to make body proteins. Though fish can utilize protein for energy, this results in increased ammonia production by the fish increasing nutrient load on the biofilter. Net protein utilization (NPU, body protein gain divided by protein fed) can be improved by sparing protein from energy metabolism by optimizing the protein to energy ratio of the feed. Improvement of NPU can also be accomplished through feeding an "ideal protein", or a protein of high biological value. In feeding an ideal protein you are presenting a pattern of amino acids which match the species requirements, but not exceeding the requirements.

The digestibility of a carbohydrate varies among fish species, generally raw or uncooked carbohydrates are better utilized by omnivorous species (catfish and tilapia) compared to carnivorous species (salmonids) (NRC 1993). Undigested carbohydrates increase the volume of feces excreted which must be removed from the culture system by a solids separator. Digestibility of both protein and carbohydrates is affected by the processes applied to the feed or feed ingredients.

The processing method used to form the pellets, steam pelleting or extrusion, affects the digestibility of a feed and its physical characteristics such as buoyancy and durability. Temperature, pressure and duration of exposure to these elements can either enhance or reduce the digestibility of carbohydrates and proteins in a feed. The digestible energy of starch for salmonids is increased by heating through gelatinization. Excessive temperatures can cause a browning effect which can create indigestible lysine-carbohydrate linkages reducing the digestibility of carbohydrates and reducing the biological value of protein. Newer, low temperature extrusion processing methods are being developed which produce the desirable qualities of traditional extrusion processing but at significantly reduced costs.

The pellet density can cause a pellet to sink or float depending on processing methods. From the management perspective floating feeds have been preferred because observation of feeding activity is much easier. However, floating feeds can create competition for surface feeding territory and stratify the fish population with smaller fish pushed to deeper positions. Less stratification can be observed among fish fed sinking pellets. However, from a management perspective, sinking pellets do not allow observation of feeding activity.

Heating of the starches improves the durability and water stability of a pellet. Pellet durability is important in automated feed systems where conveyors may create excess fines. Feed fines are not consumed by the fish increasing the load on the solids removal system and possibly the biofilter if the fines pass through solids removal. Fines can be removed from the feed delivery system by incorporating sieves at strategic locations. Water stability of feed is mainly a concern in shrimp production where pellets may be in the water for several hours before consumption. However, water stable feed may be an advantage in a recirculating system in the event that feed is wasted and must be removed in the solids separator. Improved water stability would increase the amount of whole feed reaching the separator facilitating feed removal. The prevention of feed waste must be the primary goal of a feeding strategy.

Feeding strategies

Feeding strategies can be divided into delivery, timing, and quantity of feed. Managers should select feeding strategies which are compatible with their recirculation system, fish species, and budget. However, in high overhead situations such as recirculating aquaculture, the primary consideration is the how to maximize total yearly production through feeding strategies.

Traditionally, feed has been delivered to culture tanks by hand, demand or automatic feeders. Hand feeding is a good management tool to observe fish and maximize feed intake by feeding fish to satiation. Good managers can almost eliminate feed waste that may occur using other feed delivery systems. However, hand feeding is time consuming and probably only practical for small production systems with small quantities of feed. Demand or pendulum type feeders can reduce the amount of labor required for feeding while achieving near maximal feed consumption. Feed waste is reduced by proper calibration of the pendulum.

Feed delivery in large scale recirculation systems is best accomplished through automatic systems. Automatic systems reduce the labor associated with feed handling, but require more time in tracking growth and biomass of individual tanks of fish. The feeding of a ration, expressed as % body weight per day, must be accurately calculated to ensure that no feed is wasted. Satiation feeding or maximum feed intake is difficult to attain by automatic feeders feeding a predetermined amount of feed.

Feed back mechanisms developed for use on aquaculture tanks have improved automatic feeding systems to reduce feed waste while increasing feed intake. Ultrasonic waste feed controllers (Summerfelt et al 1995) can detect uneaten feed exiting the tank and deactivate the feeder for a period of time to prevent feed waste. Hankins et al (1995) found that ultrasonic feed controllers improved fish growth over that of pendulum demand feeders or ration feeding. In that study, satiation hand feeding resulted in the highest growth rates with ultrasonic feed controllers were second.

Feeding frequency can influence the water quality of the recirculation system. Dissolved oxygen (DO) and total ammonia nitrogen (TAN) concentrations are of primary importance in recirculating systems. By increasing the number of feedings per day and the day length over which the feed is offered, peak TAN and low DO concentrations can be decreased, reducing stress. Phillips et al (1998) found that increased feeding frequency increased the mean daily DO concentration and reduced the mean daily TAN concentration. This reduction in TAN variability could benefit the biofilter microbes by supplying a more constant source of nutrients, thereby improving biofilter efficiency. The increased DO could reduce the oxygen input to the system, reducing production costs.

Conclusion

Fish production in recirculating systems can be improved by management of feeds and feeding strategies. Feeds should be selected based on nutritional criteria such as high protein digestibility and optimal protein to energy ratios to reduce excess ammonia production in the system. Physically, the feed should be durable to withstand handling by each particular feed system. Feeding systems and frequency can be modified to reduce waste feed, improve water quality, and increase productivity. By optimizing both feed and feeding strategies, total system productivity can be increased, increasing the profitability of recycle systems.

Currently feeds and feeding systems should be specifically designed for each culture system. However, in the future, recycle systems will be designed only after the criteria for feed and feeding systems have been clearly specified.

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Effluent Management: Overview of the European Experience

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Abstract

The specific effluent loading from European salmonid culture has been reduced by 50 - 70 % since 1980, mainly due to: improved feed quality and feeding strategy; better farm management; and improved culture system design. Danish authorities require that freshwater farms use high quality feed and strict feeding management regimes with a maximum FCR of 1.0.

Local discharges to receiving waters, especially at freshwater sites, have also been greatly reduced as a result of environmental legislation requiring the use of effluent treatment, or refusal to grant consents for new facilities to discharge to freshwater. A wide range of regulations and standards relating to fish farming, and subsequent effluents, exists throughout the EU and in other non-EU European countries. Typically, discharge consents in land-based farms are based on water discharge volumes, or on nutrient quantities or concentrations.

Effluent treatment systems, such as microsieves and swirl separators, normally remove about 50 % or more of the suspended solids and phosphorus emanating from flow-through farms. Recent research shows that reduced water consumption, or pre-concentration of the waste solids, for example using within-tank particle concentrators and separate sludge outlets, can greatly increase treatment efficiency. Several studies indicate that traditional effluent settling ponds are inefficient or useless as primary separators. They are though more suited to secondary de-watering. In large land-based marine farms, multi-stage treatment systems combining a retention pond, foam fractionation and micro-algae/bivalve filtration, have demonstrated promising solids and dissolved nutrient removal efficiencies. The running costs of a recently developed system combining effluent micro-sieving and sludge processing, at large salmon hatcheries, was estimated as about US $ 0.2 - 0.5 per kg of smolts, i.e. 2 - 7 % of the production costs.

Fish-farm discharges, water abstraction and feed usage are taxed in some countries. These can amount to a significant proportion of the production costs.

Regulations controlling Wastes

General

There are a wide range of regulations and standards throughout Europe controlling the discharge of effluents from fish-farms. These were reviewed in 1992, at the 'Fish farm Effluents and their Control in EC Countries' Workshop (Rosenthal, 1994). Regulations from 19 EU and non-EU countries were presented.

Most of the legislation still conforms to that described by Rosenthal (1994), especially with respect to effluents from land-based farms. Some concepts and models used to regulate the local impacts of cage-based farms have though been initiated. In this brief description, only regulations from a few European countries can be described.

Land-based Farms

Freshwater recipients

Inland, land-based farms necessarily utilise rivers, or lakes as primary recipients. The impacts of salmonid farm discharges on freshwater resources are well documented (NCC, 1990; Oberdorff and Porcher, 1994), providing clear evidence that strict regulations are required.

On the Jutland peninsula in Denmark for example, it is common for several trout farms to be situated along the same river. Negative impacts on the recipient, such as oxygen depletion, elevated nutrient concentrations and reduced biotic diversity, have been reported in the 1960s and 70s (Markmann, 1977). In the early 1970s stricter environmental legislation was enacted, and since then few new farms have been granted a license (Stellwagen, 1993). The main regulations governing the operation of river-based trout farms are as follows (Stellwagen, 1993; Jokomsen, pers. comm.):

- the maximum allowable quantity of feed used is mainly based on the median minimum flow rate of the river;
- the feed conversion rate (FCR) should not exceed 1.0 (kg feed/kg weight gain);
- the feed used should meet the following quality standards, i.e. minimum 5.7 Mcal/kg dry matter (DM), metabolic energy minimum 74 % of gross energy, maximum 9 % total nitrogen (TN) and 1 % total phosphorus (TP) of DM, maximum 1 % dust;
- the allowed limits of increased concentrations from passage through the farm (outlet conc. - inlet conc.) are, BOD 1 mg/L, SS 3 mg/L, TP 0.05 mg/L, TN 0.6 mg/L (NH_4-N 0.4 mg/L), dissolved oxygen (DO) outlet minimum 60 % of saturation;
- there are no charges for effluents from fish farms.

The introduction of these water quality limits has resulted in the need for effluent treatment using technology, such as sedimentation ponds and microsieves. Both often combined with biofilters (Heerefordt, 1991). Effluent monitoring is conducted by the environmental authorities and by the farmers themselves (Dansk Dambrugerforening, 1993). As a result of this range of management and technology intervention, the nutrient loading from Danish trout farms was greatly reduced during the period 1980 - 1991 (Warrer-Hansen, 1993), in terms of the mass flow of nutrients (kg) per tonne of production: from 600 to 247 for BOD (59 % reduction); from 180 to 49 for TN (73 %); and from 30 to 6 for TP (80 %).

Discharge consents for fish-farms in England and Wales typically specify the volumes of discharge water parameters, i.e. outlet - inlet BOD, SS and NH_4 concentrations and DO saturation in the outlet (Lloyd, 1993). The application of treatment technology is not a statutory discharge licence requirement. The associated costs of monitoring, licence approval, and administration by the National Rivers Authority and the abstraction of water are borne by the fish-farmers. In Scotland, freshwater fish-farm licensing requirements are based on local water quality objectives (Kelly, pers. comm.).

In Wallonia, southern Belgium fish-farmers are taxed in direct proportion to the quantity of feed supplied (Peng *et al.*, 1997). Taxation does not though take into account the quality of the feed which can strongly affect the waste production.

Marine recipients

The expansion of fish-farming in Norway is not permitted at sites with freshwater recipients (Leffertstra, 1993), so the majority of hatcheries/smolt farms are situated on the coast with an outlet to the sea. In most cases, the recipient capacity is, with high water exchange and favourable topography, sufficient to accept these discharges. Some farms are however loading sites with a limited organic waste acceptance capacity, and hence they are liable to oxygen deficits and particle sedimentation (e.g. fjords with sills).

In Norway, licenses to discharge are administered by the county environmental authorities. In order to avoid negative impacts from fish-farm effluents in vulnerable recipients, the authorities require a biological study of the seabed at the outlet point. If the local seabed is significantly affected by organic waste, the fish-farmer is advised to assess methods to reduce the effluent discharge, e.g. effluent treatment. Usually, the authorities require a study of the recipient conditions as part of an application for farm expansion (Maroni, pers. comm.). This is to be funded by the farmer.

Cage Farms

Freshwater sites

Freshwater cage culture of rainbow trout is commonly practised in Finland, Sweden, Scotland and in NE Germany. In Scotland, some salmon smolt production is conducted in lake cages.

Scottish cage culture discharge consents are, in some regions, based on specific water column TP standards which must not be exceeded, thus ensuring that the oligotrophic nature of the lakes (lochs) is maintained (Burbridge *et al*., 1993). Limits can be placed on production via three, usually separate, methods (Kelly, pers. comm.):

♦feed usage and TP content of the feed;

♦total permissible fish biomass;

♦TP concentration in the ambient water.

In Sweden, the licensing system is based on maximum limits of cage volume, feed consumption, fish production and N and P annual loads (Enell, 1993). The feed quality standards (N, P, metabolic energy) are similar to Danish standards. Some requirements must be met prior to the establishment of a fish-farm:

♦the most appropriate location must be selected;

♦the best available environmental protection technology which is environmentally justifiable and economically realistic, must be used;

♦there must be no substantial detriment effects on the ecosystem.

Regulations and administration relating to aquaculture in Sweden are so restrictive that the industry has been effectively stifled in recent years.

Marine sites

In order to identify coastal areas suitable for aquaculture, the so-called LENKA system was introduced in Norway (Kryvi *et al*., 1991). A more comprehensive management system called MOM (Modelling Ongrowing fish-farms Monitoring), that integrated the elements of environmental assessment, monitoring of impacts and environmental quality standards into one system, has recently been developed (Ervik *et al*., 1997). The MOM system is considered a valuable regulatory tool in planning fish farms (modelling) and for the determination of the degree of exploitation of operational fish-farm sites (monitoring).

Waste Management Techniques

Feed and Feeding Management

The feed derived waste production in salmonid farms has been significantly reduced, due to an increased energy density (increased fat : protein ratio) with a lower content and an improved bioavailability of protein and phosphorus (Bergheim and Åsgård, 1996). A recent report (Peng *et al*., 1997) however, demonstrated a wide range of feed quality was still available on the European market (10 commercial diets): from 16.8 to 26.9 g DP/ MJ DE (DP: digestible protein, DE: digestible energy) and from 0.85 to 1.42 % P. In terms of kg weight gain, using these diets in rainbow trout fingerling production, the waste production was 36 - 105 g N/kg, 6.2 - 15.3 g P/kg and 563 - 1111 g organic matter.

Land-based Farms

Flow management

Oxygen is commonly added to the salmon tank or farm inlet water in quantities of up to 160 - 200 % saturation. This is primarily to increase productivity, but also assists effluent management. The specific water consumption of Atlantic salmon can be reduced from 1 - 2 l/kg/min, down to about 0.2 l/kg/min. The outlet waste concentration in the farm effluent will then be a factor of 2 - 5 times greater than a non-oxygenated site, assuming the same food conversion ratio. This will influence effluent management in two main ways. Firstly, higher fish density in oxygenated fish tanks can improve self-cleaning, reducing the need for manual cleaning and flushing of tanks and improve the culture environment. Secondly, the more concentrated waste stream will more suitable for the application of separation technology.

Waste pre-treatment

Several recent studies, such as those by Cripps (1995), have shown that there are significant advantages to be gained by pre-concentration of wastes, prior to the main effluent treatment processes. Solid wastes can be partially separated from the main carrying flow either temporally or by location. Temporal concentration is achieved by allowing wastes to build up within the tank, either in the culture area or a separate downstream sedimentation zone. These solids are then flushed to waste intermittently, as described above. This traditional method is probably the most common method of pre-treatment, at sites where, deliberately or otherwise, pre-concentration is conducted.

A newer method that appears to function well is the use of within-tank separation technology, such as that produced by AquaOptima (I. Schei, pers. comm.). Here, the bottom flow dynamics of the culture tank are manipulated to increase the settlement of the solids that would otherwise have been carried out of the tank in an uncontrolled manner in the primary effluent stream. These settled solids are diverted to a separate solids outlet with a flow rate that is often well below 3 % of the primary flow. The sludge flow at the majority of sites using this technology is further concentrated using small hydrocyclones at each tank outlet.

The advantage of pre-concentration is that the hydraulic loading on the solids separators, such as microscreens, is substantially reduced, allowing treatment effort to be targetted where it is most required. This also reduces sludge volumes requiring dewatering, because backwashing rates are reduced. A further advantage of pre-concentration is the formation of a filter mat on the microscreens, that enhances particle separation and removal (Cripps, 1995).

Treatment technology

Various designs of sedimentation basins are common throughout the European fish-farm industry. They range in design from simple ponds dug downstream of the farm, up to compact second stage cones, or advanced basins incorporating automatic sludge removal and flow manipulation. Simple designs are often adapted from spare ponds or tanks. Despite their widespread use, they are, in any form, rarely suitable for the treatment of the primary effluent because of inadequate flow dynamics and sludge removal problems. Sedimentation is appropriate for the localised (i.e. within tank) pre-concentration of wastes, and for second stage de-watering of separated sludge within a multi-stage treatment system. This latter use is though rare within Europe.

Several authors have described the available types of particle separators, including Wheaton (1977) and Cripps and Kelly (1996). Within about the previous 5 years, microscreen sieves for the separation of particles in the effluent have become more widespread. Triangle, rotary drum (Hydrotech) and rotary disc (Unik) screens are in common use. More advanced models incorporate automatic particle load switches for intermittent operation, thus reducing sludge volumes produced by screen backwashing. The solid removal potential of microsieves has been clearly demonstrated in recent studies at Scottish hatcheries (Kelly *et al*., 1996; Kelly *et al*.,1997). A wide range of screen mesh sizes is used, ranging from 200 - 60 µm (30 um for microscreens at the farm inlet). Cripps (1993) and Kelly *et al.* (1996) indicated that 60 µm seemed to be a reasonable compromise between hydraulic capacity restrictions and particle removal potential.

In a Norwegian test of the Unik Filter (Ulgenes 1992a), removal efficiencies, using a combination of 250 and 120 µm pore screens, were suspended solids (SS) 16 - 94 %, total phosphorus (TP) 18 - 65 % and total nitrogen (TN) 1 - 49 %. Efficiency was generally improved using a smaller pore size, of 60 µm, on the downstream screen: SS (67 - 73 %), TP (43 - 74 %) and TN (38 - 67 %). Ulgenes (1992b) also tested the treatment efficiency of a drum filter commonly used in Europe (Hydrotech), fitted with a 60 µm pore size screen. Treatment efficiency varied considerably within the ranges SS (67 - 97 %), TP (21 - 86 %) and TN (4 - 89 %). Efficiency was found to vary proportionally with the waste effluent concentration, again indicating the advantages of particulate pre-concentration. A similar test using a drum filter (mesh size 70 µm) for the treatment of the effluent at a German trout farm was reported by Eichholz and Rösch (1997). The average treatment efficiencies found were lower than reported in the Norwegian tests (Ulgenes, 1996a,b).

As the number of farms employing primary effluent treatment increases, the quantity of sludge resulting from these separation activities, will increase. This sludge requires thickening and stabilisation. The waste production from all Norwegian farms during 1990 was estimated as 8,320 t N and 1,440 t P (Ibrekk 1989). The actual proportion of the total number of farms employing sludge treatment techniques is small. Currently, sludge treatment and disposal options available include: transfer to domestic wastewater treatment facilities, landfill dumping, infiltration through soil filters and use as a crop fertiliser (Cripps and Kelly, 1996). If the farm is located near a mains sewage system, linked to a treatment works of adequate size to cope with the loadings and fluctuations in loading that will be produced by a farm, then sludge can be discharged directly to the sewer. This is the situation, for example, for wastewater from Danish eel recirculating systems. More often the farm is located in a rural community with little or no intensive sewage treatment, or with no communal sewer system. In this case, the sludge will have to be transported, in the same way as septic tank liquor, by vehicle to a treatment works. This will incur a transport cost, in addition to treatment charges levied by the operators of the treatment works.

Sedimentation, as a first step for de-watering of sludge water, is efficient at producing a settled sludge. The settling velocity of particles after microsieving is fairly high (Warrer-Hansen, 1993), and a settling removal of 85 - 90 % in a thickening tank at an overflow rate of 1 m h^{-1} has been achieved (Bergheim *et al*., 1993). After a settling period of less than 24 hrs, the DM content is in the range 5 - 10 %. This sludge has to be further processed (Bergheim *et al*., 1993). Stabilisation by adding lime appears a suitable method for the further treatment of settled sludge from fish farms (Mäkinen, 1984; Liltved *et al*., 1991). A multi-stage system for sludge treatment, developed in Europe, was described by Bergheim *et al.* (1997).

For the reduction of both solids and dissolved nutrients in effluents from large marine land-based farms, Hussenot *et al.* (1997) described a multi-stage treatment system. The recommended system combines particle settling in a retention lagoon, foam fractionation and micro-algae/bivalve filtration. Experimental tests indicate a potentially high solids (SS, POM) and dissolved components (TAN, PO_4, SiO_2) removal efficiency.

Cage farms

Waste collection

Waste collection or removal from cages is difficult, and so only a few methods have been tested in Europe, with varying success. These include: collectors, closed cages, water column and sediment pumps. Bergheim *et al.* (1991) described a cage sludge collection system with a horizontal area of 50 m^2, corresponding to 40 % of the cage area. It was reported to have collected 75 - 80 % of the settleable particles during a 4 month period. The collected material, with a dry matter content of 5 - 15 %, was pumped daily from a sump at the bottom of the trap. The collection efficiency of a similar German system was found to be highly dependant on the action of wild fish eating and disturbing the collected material (Wedekind, 1997).

The *Lift Up* system (Lift Up A/S) for the collection and subsequent removal of waste particles and dead fish has been described as operating efficiently (Braaten, 1991). The system comprises a coarse mesh net around the outside of the cage. The lower part of the net forms a finer mesh net funnel. Waste material is pumped intermittently to a coarse screen located above the water level on the cage collar. Independent test results estimated that almost 100 % of waste pellets larger than 6 mm were collected within minutes (Braaten, 1991).

Closed cages, in which the containing structure is made of a solid material, such as high density polyethylene rather than netting, have yet to make any commercial progress in Europe. During the past 5 years, economic constraints have limited the development of this system, but at present industrial and research interest is increasing again.

The use of fish-farm sludge for land application can sometimes be limited because of high levels of both zinc and cadmium, in excess of levels in cattle manure (Table 1). These metals must have originated in the fish feed.

TABLE 1. Trace metal content of fish farm sludge (Bergheim, 1997) and cattle manure (A. Fludal, pers. comm.) compared with recommended maximum concentrations for unrestricted land application (Norwegian Department of Agriculture, 1996).

Metal	**Fish farm sludge**	**Cattle manure**	**Recommended max. conc.**
Copper, mg/kg DM	14 - 68	75	150

Zinc,	“	478 - 608	220	400
Lead,	“	1.7 - 4.3	1.8	60
Cadmium,	“	0.60 - 0.86	0.20	0.80
Chrome,	“	1.0 - 2.3	2.4	60
Nickel,	“	10 - 19	1.7	30

Effluent Treatment Costs

A complete system for effluent treatment and sludge handling at land-based salmonid farms has been estimated to increase the total production costs by up to 7 % (Table 2). The treatment costs can however be reduced to about a third if these units are outside. The break-even level for economically sustainable effluent treatment is closely connected to the size of the farm (Muir, 1981), because the allowable additional capital costs for effluent treatment increases with the annual fish production.

Generally, the profit margin of trout producers is low (Peng *et al*., 1997), so the investment and operational costs therefore need to be correspondingly low. Under poor growth conditions, such as warm summer periods with reduced fish growth, the extra costs of sludge collection using cage funnels can represent a heavy burden to the farmer (Wedekind, pers. comm.).

Devices for collecting wastes can be useful tools to control feed losses in both land-based and cage-based farms. In Norway, the “Lift-Up” system for the collection of waste feed and dead fish in sea cages also functions in this respect to improve the feed utilisation (Johnsen *et al.*, 1993). The manufacturers claim a potential reduced production cost of 0.2 US $, due to the improved control of the feeding and the fish stock (Table 2).

Charges for discharges, abstraction of water or feed usage can amount to1 - 5 % of the production costs. In Great Britain, fish farmers are also charged for the licence application and advertising (“one off” costs) each at a cost of 1,000 - 1,700 US $ (Kelly, pers. comm.). Such charges are often in addition to effluent treatment costs.

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TABLE 2. Effluent treatment costs and charges in European salmonid production. Comparisons should not be made between different culture systems.

Type of production	**Effluent treatment facilities or effluent charge**	**Annual costs, US $**			**Costs per kg produced fish, US $**	**% of total production costs**	**Comments**
		Fixed	**Operating**	**Total**			
Hatchery producing 100 t Atl. Smolt/year (1 mill. Individuals/year). Norway (Bergheim, 1997; Knutsen, pers. comm.)	Screening (microsieves) - sludge thickening (gravitational tank) and stabilisation (adding lime)	10,500 -48,000	7,000 - 8,200	19,700 - 55,000	0.20 - 0.55	2 - 7	Treatment costs dependant on extra investments as building and fittings (Mundal, pers. comm.)
On-growing freshwater cage farms producing 100 t rainbow trout/year. Germany (Wedekind, 1997)	One PVC funnel per 10 fish cages (5 t prod./year), totally 20 funnels. Sludge pumping and thickening (gravitational tank)	11,500	9,100	20,600	0.20	9 - 10	Treatment costs under optimal conditions: 0.08 US$/kg (3 - 4 % of tot.). (Wedekind, pers. comm.)
On-growing sea water cage farm producing 300 t Atl. Salmon/year. Norway (Johnsen et al. 1993)	Collecting nets for excess feed and dead fish ("Lift-Up" system). Sieving system for feed pellets			< 19,600	- 0.20 - 0.07	< 4	The system is considered to reduce the total production costs (e.g. less feed loss)
Land-based trout farms in Wallonia, Belgium (Peng *et al.* 1997)	Charge based on annual feed used: 0.077 US $/kg				0.08	3 - 5	
Land-based trout farms in England & Wales (Kelly, pers. Comm.)	Charge based on abstraction and discharge of water (supply: 100 L/s)				0.03 - 0.09	1 - 5	Costs for licence application/advertising not included

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The Importance of Biosecurity in Intensive Culture

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Introduction

The explosive growth of worldwide aquaculture has resulted from culture intensification and from an increased number of species being cultured in an increased number of locations. As culture intensification has proceeded, catastrophic loss from infectious disease outbreaks has been repeatedly identified as a major cost to industry productivity. Major causes of disease-related financial loss are direct losses, market losses and costs resulting from lost opportunity. Direct losses include mortality, facility closure orders, restriction of movement orders, and the inability to replace stock. Market losses include reduced quality of survivors (e.g., from reduced growth rates and lower yields or reduced product quality), a restricted market for healthy stock because of damage to a facility's reputation, and missed markets. Examples of opportunity costs are diversion of management and labor and underutilization of the fish production facility (Paterson et al., 1991).

The purpose of this paper is to describe, 1) how increased intensification results in an increased risk of infectious disease outbreaks, 2) summarize the major risk factors for infectious disease outbreaks in finfish culture, and 3) describe ways to use the principles of biosecurity to decrease the risk that outbreaks of infectious disease will occur at facilities where intensive culture of finfish is an economic necessity.

Increased intensification results in an increased risk of infectious disease outbreaks

Crowding increases the vulnerability of a population of animals to disease and death from opportunistic and obligate pathogens. The theory behind why this increased vulnerability occurs has been well-established since the early 1900's. As described in the review by Anderson (1982), Hamer (1906) suggested that the course of an epidemic depends on the contact rate between susceptible and infectious individuals. This "mass action principle" states that the rate of disease spread is assumed to be proportional to the product of the density of susceptibles times the density of infectious individuals. In addition to Hamer's mass action principle, Kermack & McKendrick (1927) established the threshold theorem. According to the threshold theorem, the introduction of infectious individuals into a community of susceptibles will not lead to an epidemic outbreak unless the density of susceptibles is above a certain critical threshold density. Therefore, culture intensification creates ideal conditions because not only does the density of susceptible animals increase, but the introduction of even one infectious individual will result in proportionately more contacts with susceptible animals, thereby increasing the risk of an outbreak.

Many fish culturists reason that if they start a cohort with more fish, they will be able to “make up for” losses if an infectious disease outbreak does occur. Unfortunately, the disease dynamics are such that this strategy does not result in the ability to culture more fish. Results from infectious pancreatic necrosis (IPN) experiments (Fig. 1) where one infectious fish was added to each of 12 tanks of various densities of susceptible rainbow trout fry, demonstrate that at the end of 60 days there were no more fish remaining in the high density tanks than in the low density tanks (Bebak, 1996).

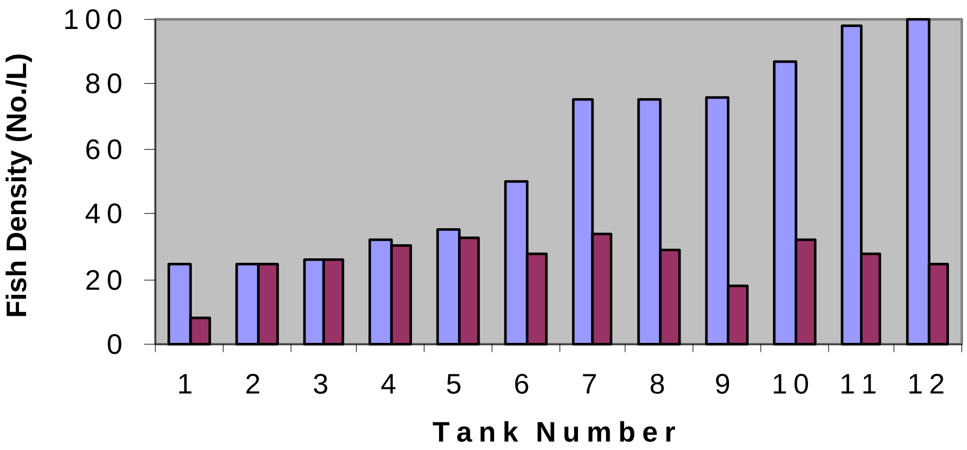

Figure 1. Rainbow trout fry densities at the beginning and end of epidemics of IPN

When fish culture density is not strongly influenced by economic factors, the fish culturist naturally, through experience, keeps cultured fish populations below their critical threshold density. An example of this tendency toward the threshold number of susceptibles can be seen in Piper et al. (1982), which recommends that a “rule of thumb that can be used to avoid undue crowding is to hold trout at densities in pounds per cubic foot no greater than 0.5 their length in inches”. In laboratory experiments on the effect of density on IPN epidemics in rainbow trout, Piper’s cutoff turned out to be the cutoff above which an IPN epidemic was more likely to occur (Bebak, 1996). An additional example of threshold densities can be seen in Wedemeyer and Wood (1974), who published a table of hatchery pond loading rates for chinook and coho salmon. Above these loading rates they found that infectious disease outbreaks were more likely to occur.

Facilities that culture fish for conservation purposes are more likely to have the freedom to culture fish below the population’s critical threshold density. Economics require that food fish production facilities must intensively culture finfish. Fortunately, the minimum threshold density of susceptible individuals for an infectious disease outbreak will change as the environmental conditions change. The principles of biosecurity can be used to increase that threshold density of susceptibles and decrease the risk that an infectious disease outbreak will occur.

Biosecurity

Intensive biosecurity practices have been more commonly employed in European and Japanese fish hatcheries than in North American fish hatcheries (Amend and Conte, 1982). Biosecurity, or “hazard reduction through environmental manipulation” (Plumb, 1992), is often defined as practices that reduce the number of pathogens that enter a facility. This paper will use an expanded definition for biosecurity, which consists of management practices and procedures that 1) reduce the risk that pathogens will be introduced to a facility, 2) reduce the risk that pathogens will spread throughout the facility and 3) reduce conditions that can enhance susceptibility to infection and disease. Often one would like to think that implementing biosecurity practices on the fish farm will prevent entry of even a single pathogen. Realistically, biosecurity for food fish production accomplishes pathogen reduction rather than pathogen elimination.

Reducing the risk that pathogens will be introduced to a facility

Entry of pathogens through the water supply (usually when fish are present) and through the introduction of fish to a facility have been identified by epidemiologic studies as major risk factors for outbreaks of infectious disease in cultured finfish (Thorburn, 1987; Jarp et al., 1993; Bebak et al., 1997). Any food fish production facility that plans to intensify culture in a given water supply, and 1) uses a water supply with a resident population of fish or 2) imports fish into the facility, can expect to experience infectious disease outbreaks if no changes in these two management practices are made.

Ideally, a farm would use a pathogen-free water supply that is protected from contamination and would purchase only certified eggs to restock the facility. Unfortunately, not all farms have access to a pathogen-free water supply, nor do all farms culture species that are readily available as eggs. If a pathogen-free water supply is at risk of contamination, or is unavailable, then incoming water should be disinfected. Ozonation and ultraviolet radiation are the most commonly used methods. If possible, the facility should only be restocked with fish hatched from certified eggs that have been disinfected upon arrival at the facility (Appendix 1). If fish must be imported into the facility, then strict quarantine procedures should be implemented (Appendix 2). In addition, fish should only be purchased from a reliable source with certified broodstock that has been kept in a pathogen-free and/or disinfected water supply. The risk of pathogen introduction can also be reduced by keeping the number of different suppliers to a minimum. Farms that culture species that are not available as certified eggs should actively support research on broodstock development and egg production.

As biosecurity practices are considered, begin with the areas where the population is most susceptible (e.g., egg and fry rearing areas). Management practices that may be implemented to further reduce the risk of introduction of pathogens include:

- Wash hands with anti-bacterial soap upon entering the facility.
- Disinfect footwear or change footwear to disposable, or disinfected non-disposable, boots before entering the facility.
- Access to egg incubation and fry facilities should be restricted to a minimum number of well-trained individuals.
- Reduce the number of visitors to a minimum and/or only people working on the farm should be allowed into the facility.
- Disinfect wheels of delivery vehicles when they come onto the facility and when they leave. Establish a visitor parking area on the periphery of the facility grounds.

Reducing the risk that pathogens will spread throughout the facility

Meticulous husbandry is an essential component of an effective biosecurity plan. Feces, uneaten feed, algae, aquatic plants and other decomposing debris provide a substrate for opportunistic pathogens to flourish. Tank surfaces should be kept free of uneaten feed, feces, algae and aquatic plants. Inflow and outflow pipes, aerators, spray bars and any other equipment inside the tanks should be cleaned frequently.

It is critically important that every part of the rearing system be constructed so that the system can be easily cleaned as necessary. All parts of recycle systems including the biofilters, low head oxygenators (LHOs) and CO_2 strippers should be accessible for cleaning. Clean-outs should be installed to access pipe interiors. Construction materials should be non-porous and easy to clean and disinfect. Avoid the use of wood. If wood is to be used, it should be considered disposable. Wood use should be limited to temporary structures and these structures should never be transferred to another site.

Culling dead and sick fish is a very important strategy that can reduce the spread of pathogens from fish to fish. How culling will be accomplished should be considered early on in facility design. Culling should be done at least once a day or, if possible, on a continuous basis. Culled live fish should be humanely killed and not allowed to die from suffocation.

Monitoring is an important part of early identification, isolation and treatment of a problem. How monitoring will be accomplished should be considered early on in facility development. Ideally, daily observation of the fish should be possible. Dim lighting and very large tanks with limiting viewing access limits the possibility of visual inspection of fish, one of the most valuable tools for detecting an incipient problem. Culled fish should be periodically assayed for pathogens. Records on growth and feed conversion ratios can be used to detect subclinical problems. Consider keeping a susceptible species as sentinel fish.

Other important management practices that will decrease the risk that pathogens will be spread around the facility include:

- Frequent hand-washing with anti-bacterial soap should be standard practice.
- Disinfectant and rinse areas should be readily accessible for disinfecting buckets, nets, dissolved oxygen meters, thermometers and other equipment.
- Tanks and equipment should be disinfected before using for a different group of fish.
- Even when tanks are on the same recycle loop, each tank should be regarded as a discrete rearing unit and the potential for cross-contamination should be minimized.
- Strategically schedule culture activities. Minimize the number of different personnel working with a particular group of fish. As soon as any suspicious mortality above baseline levels occurs, only one person should be allowed to work with affected fish. Alternatively, if personnel resources are limited, work should be done on the unaffected tanks first, leaving the affected tanks for last.
- Aerosol transmission of pathogens can occur. Consider placing barriers between tanks.
- Minimize transfer of fish between tanks.
- Whenever possible, employ the use of vaccination as a disease prevention management tool.

Reduce conditions that are stressful to the fish and that can enhance susceptibility to infection and disease

Stress associated with crowding, low water flow, poor nutrition, poor water quality and other husbandry related factors will render fish more susceptible to, and aggravate the consequences of, infection with opportunistic and obligate pathogens. There are many strategies that can be used to increase fish vigor and reduce stress. Some of these include:

- Use of gentle fish crowding and other methods of gentle fish handling
- Monitor water quality parameters to verify that they remain within recommended limits.
- Poorly nourished fish are more susceptible to disease. The fish feed schedule and feed characteristics should be such that the fish receive the best nutrition possible.
- Purchase eggs and fish only from optimum year class broodstock.

Summary

Intensive culture of finfish increases the risk of infectious disease outbreaks that can have catastrophic effects on a facility’s ability to meet production goals. Effective biosecurity can help decrease the risk that infectious disease outbreaks will occur. But, effective biosecurity if very difficult to implement after a problem begins. Biosecurity should be considered in the early stages of intensification of an existing facility and in the early design of a new facility. Biosecurity should not be considered to be a static, unchanging set of rules and procedures. Biosecurity is implemented in a dynamic biological system. Once they are in place, biosecurity plans and protocols should be constantly reevaluated and changed as necessary.

Appendix 1. Egg disinfection procedures

Very few disinfectants have properties that can be safely used around fish eggs and still have quick-acting, broad-spectrum activity. In addition, the disinfection of eggs for food fish falls under the regulatory jurisdiction of the FDA and only disinfectants that are included as FDA-Approved New Animal Drugs or Unapproved New Animal Drugs of Low Regulatory Priority (LRP) for FDA may be used (Federal Joint Subcommittee on Aquaculture, 1994). Iodophors (organic iodine complexes), are one commonly used option. Iodophors, which are LRP drugs, are generally used at 100 ppm for ten minutes after water hardening to disinfect fish eggs. One advantage of iodophors is the amber color which indicates the disinfectant is effective. Once the color turns yellow or colorless, it is no longer effective. With other disinfectants, it is more difficult to determine if the solution is effective (Amend and Conte, 1982).

Appendix 2. Quarantine

Quarantine is designed primarily to prevent introduction of pathogens into a facility from which eradication would be difficult or impossible. Isolation is the key to quarantine. Quarantine can be costly, and should be considered early in the facility design phase. There is no “recipe” quarantine protocol that covers all fish species cultured in all conditions. The following guidelines should be included when developing quarantine protocols for a facility. Many of these recommendations are included in (Harms, 1993).

- Quarantine protocol development should take into account the species, age and source of fish being quarantined.
- Length of quarantine should take into account information about incubation periods and development times for the pathogens that are known to present a risk. Although 30 days is often given as the “standard” quarantine period, it could be longer or shorter depending on pathogen life cycles and expression of clinical disease in warmwater vs. coldwater conditions.
- Quarantine should protect against foreign or exotic pathogens to avoid the introduction of a potentially serious, “new” problem.
- Do not use prophylactic antibiotics as part of a quarantine protocol. Prophylactic antibiotic use is illegal and can have serious consequences for the development of bacterial resistance to antibiotics.
- Quarantine must be closed. Any addition of fish to ongoing quarantine resets the quarantine clock to day zero.
- Fomites (e.g., nets, buckets and hands) and aerosols can breach even well-designed isolated quarantine systems. Minimize aerosols with tank covers

and by maintaining quarantine and exhibit tanks in separate rooms. Quarantine equipment should be used only in quarantine.

- Personnel should wash hands before going between areas and should save quarantine work for last.
- Consider keeping water temperatures at the upper end of the species optimum range to speed up pathogen life cycles.
- Introduce production system water before transfer so that fish can acclimate to it.
- Some authors recommend keeping fish densities as low as possible to minimize stress. Alternatively, consider exposing the fish to the same conditions they will encounter in the production system, so that a problem may be detected before the fish are moved out of quarantine.
- Consider transferring fish to a new tank within the quarantine system if dealing with the possibility of stages of organisms that can be left behind when the fish are moved from the tank.

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Culture Tank Designs to Increase Profitability

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Abstract

Tank-based, cold-water fish farms tend to use large inputs of high quality flowing water to maintain water quality during production. However, increasing the profitability of tank-based, cold-water aquaculture farms in today's regulatory environment requires strategies and technnologies to optimize the use of the water resouce, feed input, and stock management, as well as strategies that minimize the total waste discharged. Culture tank design has a dominating influence on all of these variables and ultimately on profitabilty.

The objective of this paper is to review several culture tank designs, with focus on increasing the profitability of tank-based, cold-water fish farms. This paper describes the design, use, and cost implications of fish production within circular culture tanks, raceway tanks, and hybrid raceway tanks that have been modified to create a series of mixed-cells within the same raceway. This paper also reviews how the cost of fish production is impacted by culture tank size, carrying capacity, stock management, and waste management.

Introduction

Larger systems and enhanced production management strategies have helped to reduce the cost of production in tank-based, cold-water fish farms. However, current production technologies are being challenged by lower farm gate prices and the implementation of new state and federal regulations that govern the total maximum daily load (TMDL) of wastes and/or the concentration of wastes discharged from fish farms.

The type of culture tanks used and their management have a significant influence on fish farm profitability. Culture tanks, their water distribution and collection components, support equipment (e.g., fish feeders, oxygen probes, flow or level switch, etc.), and floor space requirement add up to a large portion of fish farm capital. As well, the management of the culture tanks and the control of their waste discharge can constitute a large portion of farm operating costs. Therefore, a large financial incentive exists to select the best culture tank, scale, and operating strategy to optimize fish farm profitability.

This paper discusses the design rationale, use, and cost implications of circular culture tanks, raceway tanks, and a new mixed-cell rearing raceway-type tank. The advantages and disadvantages behind each culture tank design are summarized as they influence water use, hydraulic characteristics in the tank, feed input, stock management, solids degradation, solids flushing, and ultimately, overall effluent management. First, however, this paper reviews how issues of culture tank scale, carrying capacity, and stock management influence the cost of fish production, and how rapid solids removal from the culture tank can effect waste management.

This culture tank information can be generally applied to either flow-through designs or water recirculating systems.

Scale Issues

The capital costs per unit culture tank volume decrease significantly with increasing volume. For example, only about a 5-fold cost increase is required to achieve a 10-fold increase in culture tank volume. Also, the costs of miscellaneous equipment and labor decrease when a given culture volume can be achieved with a few larger culture tanks rather than with many smaller tanks. Use of fewer but larger tanks (1) requires the purchase and maintenance of fewer feeders, dissolved oxygen probes, level switches, flow meters/switches, flow control valves, and effluent stand-pipe structures; and (2) reduces the time required to analyze water quality, distribute feed, and perform cleaning chores (i.e., the times are about the same for a larger tank as for a smaller tank).

However, the advantages achieved through the use of larger tanks must be balanced against the risk of larger economic loss if a tank fails due to mechanical or biological reasons. There are also difficulties that could arise in larger culture tanks when removing mortalities, grading and harvesting fish, and controlling flow hydraulics, e.g., water velocities, tank mixing, dead-spaces, and settling zones.

Carrying Capacity Issues

Production efficiencies are being boosted by increasing the carrying capacity of culture tanks. The carrying capacity is influenced by feeding rate, spatial requirements, oxygen consumption, inlet and outlet dissolved oxygen concentrations, water exchange, water pH, and waste production and removal (Losordo and Westers, 1994). For example, doubling the hydraulic exchange through a tank will double the carrying capacity of the tank (i.e., production is doubled with only a small increase in capital, assuming that water is not limiting). However, super-saturating the dissolved oxygen in the water flowing into the tanks has also been popular, and often a more cost effective method to improve the profitability of cold-water fish farms. For example, if the oxygen concentration entering a culture tank was increased from 10 mg/L to 14 mg/L, the available oxygen in the supersaturated flow would double the carrying capacity of the system, assuming an outlet dissolved oxygen concentration of 6 mg/L. Supersaturating the flow with dissolved oxyen can be achieved cost effectively with many different oxygen transfer devices, even in low head applications (Boyd and Watten, 1989).

However, when a culture tank or a group of culture tanks operating under serial or parallel water reuse receives inadequate water exchange to flush the fish wastes, i.e., at excessive fish loading rates, the dissolved carbon dioxide and ammonia produced will accumulate in the culture tank and can limit fish production. Intensive farms can use the water flow without worry of ammonia and carbon dioxide limitations (assuming no biofiltration or air-stripping) up to a cumulative dissolved oxygen consumption of about 10 to 22 mg/L, depending upon pH, alkalinity, temperature, and the fish type and life stage (Colt et al., 1991). After reaching this cumulative oxygen demand, the water flow cannot be used again unless it is passed through a biofilter and air-stripping unit to reduce its ammonia and/or carbon dioxide accumulations.

Stock Management Issues

Total system production can be doubled through the use of a continuous production strategy, rather than a batch production strategy (Watten, 1992; Summerfelt et al., 1993; Hankins et al., 1995). The maximum economic productivity of the culture system (e.g., single culture tank, row of culture tanks, or entire fish farm) can be obtained with year round fish stocking and harvesting, because continuous production maintains the culture system at or just below its carrying capacity. Heinen et al. (1996a) showed that rainbow trout stocked every 8 weeks and harvested weekly acheived a steady-state annual production (kg/yr) to maximum system biomass (kg) ratio of 4.65/yr. Similar results on a commercial farm would have a large positive effect on production costs.

Continuous stocking and harvesting strategies require frequent fish handling. Harvesting and grading fish can add considerably to the labor cost, and a convenient mechanism that can be used to grade fish and harvest each culture tank must be incorporated into the culture tank design. Simply netting the fish out of the tank, or using a net to crowd the fish for harvest or grading is an obvious solution. Fish can also be lifted out of the tank with a pump or cage once crowded. Crowding and grading can also be achieved with crowder/grader gates that move down the length of a raceway or pivot around the center of a circular culture tank. Using automated equipment to save on labor and avoid hand grading is essential to reduce costs.

Waste Management Issues

The concentration of waste discharged from most tank-based, cold-water fish farms is relatively low under normal operating conditions. However, the large flowrates involved can make the cumulative waste load (i.e., total maximum daily load) discharged from cold-water farms significant. Consistently meeting strict discharge standards can also be difficult because pipe, channel, and tank cleaning routines can produce fluctuations in discharge flowrates and in the consistencies and concentrations of waste material. The distribution of the nutrients and organic matter between the dissolved, suspended, and settleable fractions affects the choice of method used and difficulty of effluent treatment. The filterable or settleable solids contain most of the phosphorus discharged from tanks (50-85%), but relatively little of the total effluent nitrogen (about 15%) (Braaten, 1991;

Heinen et al., 1996b). Most of the effluent nitrogen released (75-80%) is in the form of dissolved ammonia (or nitrate when nitrification is promoted). The variability in the nutrient and organic material fractionation between dissolved and particulate matter is largely dependent on the opportunity for particulate matter to break-apart, because the production of smaller particles increases the rate of nutrient and organic matter dissolution. Fecal matter, uneaten feed, and feed fines can be rapidly broken into much finer and more soluble particles by water turbulence, fish motion, scouring along a tank/pipe bottom, and pumping. It is much more difficult to remove dissolved and fine particulate matter than larger particles. Therefore, culture tank designs and operating strategies that remove solids rapidly and with the least turbulence, mechanical shear, or opportunity for micro-biological degradation are important to help the fish farm meet discharge limits.

Circular Culture Tanks

Circular tanks have been widely used in land-based salmon farms in Norway, Scotland, and Iceland (Karlsen, 1993), as well as in North America and other parts of the world. Circular tanks used for salmon and trout production are generally large, usually between 12 to 42 m in diameter tanks (although smaller tanks are used in hatcheries and smaller farms), and with diameter to depth ratios ranging from 3:1 to 10:1 (Karlsen, 1993).

Circular tanks have several advantages: they can provide a uniform culture environment; they can be operated under a wide range of rotational velocities (with relatively small waterflow compared to raceways) to optimize fish health and condition; they can be used to rapidly concentrate and remove settleable solids; they allow for good feed and fish distribution; and, they can permit designs that allow for visual or automated observation of waste feed to enable satiation feeding (Timmons and Summerfelt, 1997).

Relatively complete mixing of the water in circular culture tanks is necessary to prevent flow from short-circuiting along the tank bottom and to produce uniform water quality throughout the tank. The water exchange rate can then be set to provide the fish with good water quality throughout the entire culture tank, even when operating up to maximum carrying capacity.

The velocity of the water rotating in the culture tank must be swift enough to make the tank self-cleaning, but not faster than the desired fish swimming speed. The tank becomes self-cleaning at water rotational velocities > 15 to 30 cm/s, which are adequate to create a secondary radial flow strong enough to move settleable solids (e.g., fish feed and fecal matter) along the tank's bottom to its center drain (Burrows and Chenoweth, 1970; Mäkinen et al., 1988). To maintain fish health, muscle tone, and respiration, a review by Losordo and Westers (1994) indicated that water velocities should be 0.5-2.0 times fish body length per second. For salmonids, Timmons and Youngs (1991) provided the following equation to predict safe non-fatiguing water velocities: $V_{safe} < 5.25/(L)^{0.37}$. where L is the fish body length in cm and where V_{safe} is the maximum design velocity (about 50% of the critical swimming speed) in fish lengths per second. In circular tanks, water velocities are usually somewhat reduced in a torroid region about the tank center, which allows fish to select a variety of water velocities, as compared to raceway designs where velocities are uniform and much slower.

The self-cleaning attribute of the circular tank is also related to the overall rate of flow leaving the bottom-center drain and to the swimming motion of fish re-suspending the settled materials. However, only about 5 to 20% of the total flow through the tank is required to flush settleable solids from the tank's bottom-center drain, because the water rotational velocity and the swimming motion of the fish control the transport of settleable solids to the tank's bottom center drain (this is the principle behind the use of dual-drain tanks to concentrate settleable solids). Therefore, the flow through the culture tank does not have to be increased beyond that required to support a selected carrying capacity, assuming that the water inlet structure is designed properly.

The water inlet structure must be designed correctly to obtain uniform water quality, select specific water rotational velocities, and achieve rapid solids flushing. According to studies from the SINTEF Norwegian Hydrotechnical Laboratory (Skybakmoen, 1989; 1993), the tank rotational velocity is roughly proportional to the velocity through the openings in the water inlet structure. The impulse force created by injecting the flow into the tank controls the rotational velocity in the tank and can be regulated by adjusting either the inlet flow rate or the size and/or number of inlet openings (Tvinnereim and Skybakmoen, 1989).

Results from the SINTEF Laboratory indicate that injecting flow through an open-ended pipe creates poor mixing in the central-torroid zone (resulting in short circuiting of the flow), much higher velocity profiles along the tank wall than in the tank central-torroid region, resuspension of solids to all tank depths, and poor flushing of solids from the bottom. Additional SINTEF results indicate that distributing the inlet flow using a combination of both vertical and horizontal branches achieves uniform mixing in the culture tank, prevents short circuiting of flow along the bottom, produces more uniform velocities throughout the tank; and more effectively transports waste solids along the tank bottom to the center drain.

Because of their capability to concentrate settleable solids at their bottom and center, circular fish culture tanks can be managed as "swirl settlers." A portion of the flow (5-20% of the total) is withdrawn through the bottom-center drain with the bulk of settleable solids, while the majority of flow is withdrawn free from settleable solids at an elevated drain. Timmons and Summerfelt (1997) reviewed the application of dual-drains in circular culture tanks. Use of dual-drains has been reported used to help remove settleable solids from fish culture tanks since 1930. Patents covering specific dual-drain tank designs have been awarded to Lunde et al. (1997) (U.S. Patent No. 5,636,595) and Van Toever (1997) (U.S. Patent No. 5,593,574). A non-proprietary design, the "Cornell-type" dual-drain tank, is a circular culture tank with a center drain on the tank bottom and an elevated drain part-way up the tank sidewall (Timmons et al., in press). Separating the two drains so that one is part-way up the tank sidewall and the other is in the tank center makes the "Cornell-type" dual drain tank easy to install, even as a retrofit on existing circular culture tanks. Also, because the elevated drain in the "Cornell-type" design is part-way up the tank sidewall, it does not capture many of the solids that sometimes “plume” up in the center of circular culture tanks under strong radial flows.

Depending on the settling velocity of fish fecal matter, use of the dual-drain approach can greatly increase the concentration of solids being removed from the bottom center drain. Dense and intact fecal matter can settle well, at a rate of 2-5 cm/s (Warrer-Hansen, 1982). Lunde and Skybakmoen (1993) report that 91% of the fecal matter and 98% of uneaten feed has been concentrated into the bottom flow leaving dual-drain culture tanks. However, different aquaculture feeds produce biosolids with variable settling velocities; finer and/or less dense particles may only settle at 0.01 cm/s (IDEQ, 1998), which would not allow solids to concentrate effectively at the bottom center of dual-drain tanks. Under the correct circumstances, the dual-drain approach has large economic implications; it can reduce the capital cost, space requirement, and headloss requirement of the downstream solids removal units (Timmons and Summerfelt, 1997).

Whether an internal or external stand-pipe is installed, a velocity of 30 to 100 cm/s should be used to size the bottom drain pipe and the stand-pipe, which would allow the heaviest/largest solids to rapidly flush through the pipe. Juell (1991) reported settling velocities for five different salmon diets (5-12 mm pellet diameter) ranged between 15.2 to 17.9 cm/s. However, sinking fish feed settles at different rates, depending on how the feeds were produced.

A simple, fast, and reliable method that can be used to remove mortalities from the bottom center drain is necessary to decreases labor costs, as well as to reduce the spread of fish disease and to maintain water level in the culture tank. There are a variety of approaches to address this need (Timmons and Summerfelt, 1997). A method in use at the Freshwater Institute simplifies the removal of dead fish from large circular tanks by incorporating the center drain outlet screen into the inner pipe of a two-pipe center post system (Figure 1). To remove dead fish, the inner pipe is raised inside of the fixed center post while the external standpipe over the mortality drain is removed, producing a surge of flow down through the center drain that carries the dead fish out of the tank (Figure 1).

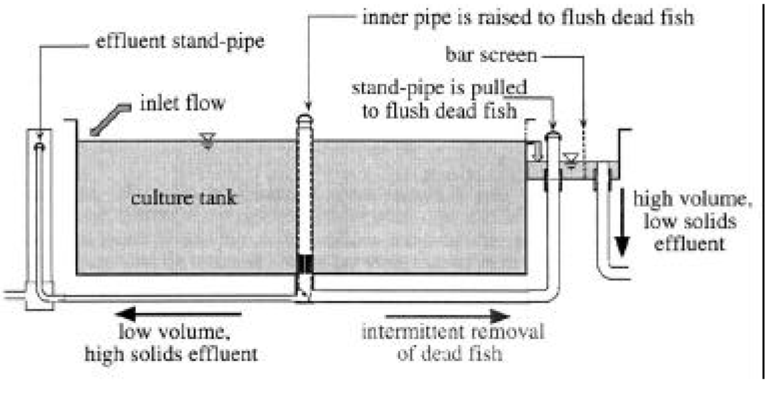

Figure 1. A concentric pipe system to flush solids and remove dead fish from the bottom center drain; also shown is an elevated side-wall drain for removing the high volume, low solids effluent, and a smaller bottom center drain pipe for removing concentrated settleable solids (Timmons and Summerfelt, 1997).

Raceway Tanks

Raceways are the most common rearing tank design prevailing in locations where aquaculture has tapped into huge groundwater resources. Such is the case with aquaculture in Idaho, which contains the largest producer of rainbow trout in the world (MacMillan, 1992). In Idaho, raceway dimensions are typically around 3-5.5 m wide, 24-46 m long, and 0.8-1.1 m deep (IDEQ, 1998). Raceways usually have a length to width ratio of 1:10 and a depth < 1.0 m, and require a high water exchange rate, e.g., one tank volume exchange every 10 to 15 minutes (Westers, 1991).

Water enters the raceway at one end and flows through the raceway in a plug-flow manner, with minimal back mixing. The plug-flow produces a concentration gradient along the axis in dissolved metabolites such as oxygen, ammonia, and carbon dioxide. The best water quality exists at the head of the tank, where the water enters, and then deteriorates along the axis of the raceway towards the outlet. As oxygen is often the limiting criteria, fish may congregate at the head of the raceways and cause an unequal distribution of fish density throughout the tank. It is also more difficult to distribute feed throughout raceways than it is within circular tanks.

The velocity of water through the raceway is generally 2-4 cm/s, so a substancial amount of solids settle in the rearing area. However, these solids are slowly moved downstream through the rearing area with the assistance of the swimming activity of larger fish (Westers, 1991; IDEQ Quality, 1998). A series of baffles spaced at intervals equaling the width of the raceway and placed perpendicular to the flow can be used to create high water velocities (20-30 cm/s) between the bottom of the raceway and the bottom edge of the baffle. The baffles allow solids to be continuously swept from the raceway (Westers, 1991). However, the Idaho Division of Environmental Quality (IDEQ, 1998) report that baffles can be troublesome, because they must be moved to work the fish and can provide a substrate for biosolids growth in the summer.

In practice, raceways are managed based on their oxygen design requirements, rather than for their cleaning requirements (Timmons and Young, 1991). The velocity required to flush solids from unbaffled raceways is much greater than the velocity required to supply the oxygen needs of the fish. However, the high water exchange rate supports high fish densities (Timmons and Young, 1991; Westers, 1991). Even so, raceways are incapable of producing the optimum water velocities recommended for fish health, muscle tone, and respiration.

Raceways are designed to minimize cross-sectional area and promote the maximum velocity, which is why many raceway systems are operated in series, with the discharge of the upstream raceway serving as the inflow water of the next one downstream. Some rearation is provided by hydraulic drops between raceways in series.

Because of their aspect ratios, raceways are very convenient culture tanks for managing fish when crowding or grading. Crowders or graders can be placed in the raceway at one end and slowly worked down the axis of the tank.

Raceways can be constructed side-by-side, with common walls, for maximizing the utilization of floor space and reducing construction costs. However, when constructed without common walls, because of their large aspect ratio (L:W), raceways require 1.5 to 2.0 times as much wall length as circular tanks (Westers, 1991). Circular tanks can also better structurally handle the weight of the confined water and can thus use thinner walls than rectangular tanks.

A quiescent zone devoid of fish is usually placed at the end of a raceway tank to collect the settleable solids that are swept out of the fish rearing area (Westers, 1991; IDEQ, 1998). These solids collection zones are the primary means for solids removal to meet discharge permitting at many large trout farms (IDEQ, 1998). The overflow rate recommended to capture solids in the quiescent zone is < 1 cm/s. Settled solids should be removed from these quiescent zones as frequently as possible; settling zones are cleaned occasionally as often as daily and at least twice per month (IDEQ, 1998). However, this prolonged storage allows for some nutrient leaching, solids degradation, and solids resuspension (due to fermentation of the organic matter). Suction through a vacumm pump is the most common method for removing solids from the quiescent zone (IDEQ, 1998) and sometimes from the fish rearing areas. Even with efficient vacuum systems, operating labor for solids removal has been reported to exceed 25% of the total farm labor (IDEQ, 1998).

Mixed-Cell Raceway Tanks

We have noted that circular tanks offer the advantages of elevated water velocities, uniform water quality, and good solids removal characteristics whereas linear raceways make better use of floor space and facilitate harvesting, grading, and flushing operations. The cross-flow tank is a recent hybrid design that incorporates the desirable characteristics of both circular tanks and linear raceways (Watten and Beck, 1987; Watten and Johnson, 1990). Water is distributed uniformly along one side of a cross-flow tank via a submerged manifold, and is collected in a submerged perforated drain line running the length of the opposite side. The influent is jetted perpendicular to the water surface with sufficient force to establish a rotary circulation about the longitudinal direction. Comparative production trials with hybrid stripped bass (Watten and Beck, 1987), tilapia (Watten and Johnson, 1990), rainbow trout (Ross et al., 1995), and lake trout (Ross and Watten, In Review) have been positive but application has been hampered by the need for the small diameter, fixed, and submerged inlet jets and drain ports, as well as costs associated with rounding the lower side areas to streamline flow. The rectangular mixed-cell tank avoids these problems while achieving the same overall objective: a hybrid tank design. Here, a standard raceway section is modified to create horizontal counter rotating mixed cells with cell length equal to vessel width (Figure 2). Cells receive water from vertical pipe sections extending to the tank floor and positioned in the corners of the cells. Vertical pipe sections incorporate jet ports that direct water into the cell tangentially to establish rotary circulation. The pipe sections can be swung up and out of the water during fish crowding or grading operations. Water exits each cell through a centrally located floor drain. Hydraulic characteristics of the tank have been established and indicate that tank performance approximates that of a circular tank (mixed-flow reactor), both with and without fish present. Water velocities averaged 15, 12, and 12 cm/s for tank surface, mid depth, and bottom regions and were sufficient to scour and purge fecal solids. Cell interaction was significant with cell to cell exchange rates representing about 3 to 4 times the tank inflow rate. This characteristic contributed to the observed uniform distribution of fish throughout the vessel. Further, the energy requirement of the design was kept low (just 1.32 m of water head) through use of a large number of low velocity inlet jets. Given that the tanks drain is similar to that of a circular tank, application of double-drain solids concentration is feasible and desirable.

Figure 2. Illustration of a mixed-cell raceway tank.

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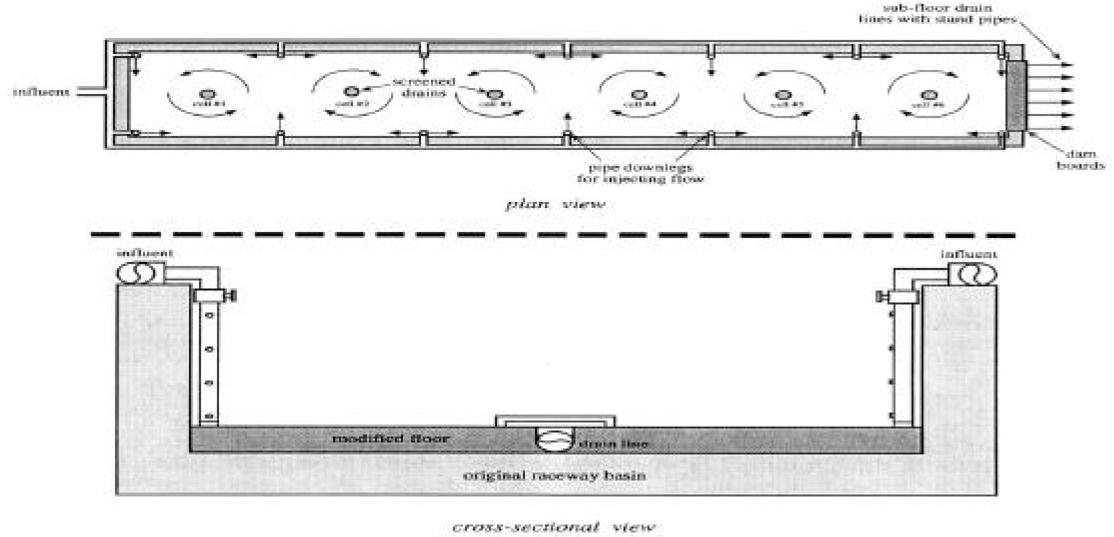

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Value-Added Market Opportunities For Small and Medium Scale Businesses

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Overview of the U.S. Seafood Market

In the late 1980's the National Fisheries Institute, the leading trade organization for the United States fish and shellfish industry, adopted a theme "20 by 2000" signaling their anticipation that U.S. per capita consumption of seafood would rise to 20 pounds by the end of the century. However, since that time, or more precisely, since 1987 when consumption set a record of 16.2 pounds, seafood consumption in the United States has been drifting lower and in 1996 reached just 14.8 pounds per capita.

With flat to declining consumption, the question becomes *Are there opportunities in the U.S. seafood market for small and medium scale companies?* While the short answer to this question is "yes," it is important to understand the underlying dynamics of the U.S. seafood market before looking at specific opportunities and strategies for growth within a "no growth" market.

U.S. Seafood Supply

The United States seafood supply is made up of domestic capture fisheries, aquaculture production and imports. While U.S. seafood production increased significantly in the 1990's, setting a record in 1993, domestic landings have peaked and will likely decline as the annual catch quotas for several leading species, such as Alaskan pollock and Pacific cod, have been lowered. Thus while domestic seafood landings (capture fisheries) totaled 3.9 billion pounds (round weight) in 1987 and 8.2 billion pounds in 1993, landings have been decreasing since. In 1996, the last year for which full data is available, domestic landings totaled 7.5 billion pounds. Aquaculture production, while increasing in the United States, added approximately 750 million pounds in 1996, primarily catfish, trout and salmon (also clams, oysters, tilapia, striped bass and other species).

Table 1. Status of Major U.S. Fisheries

Species	1996 Catch (Million Lbs)	10 Year Trend
Alaskan Pollock	2,623	Level to slight decrease
Pacific Salmon	877	Up
Cod	637	Pacific Cod up, Atlantic cod down
Flounders	460	Up (mostly Pacific species)
Crab	392	Decreasing
Herring	318	Increasing
Shrimp	317	Decreasing
Clams	123	Decreasing
Rockfishes	95	Decreasing
Mackerel	65	Decreasing

The United States is a net importer of seafood both in terms of volume and value. In 1996 the U.S. had a seafood trade deficit of $4.7 billion on imports of $6.7 billion and exports of $3.0 billion. Leading seafood imports include shrimp, tuna, lobster and salmon.

It is important to note that much of the growth in supply, both domestically and via imports is the result of aquaculture. As capture fisheries continue to decline, the role of aquaculture will become even more import. In the past decade aquaculture has gone from being a stepchild to the U.S. seafood industry to its future salvation. Aquaculture now commands respect from all segments of the U.S. seafood industry, importers, wholesalers and retail and foodservice buyers. The aquaculture industry has arrived.

U.S. Seafood Usage

While U.S. per capita consumption may be flat or declining, the mix of products that make up the leading seafoods consumed in this country is changing. Many of the seafoods experiencing growth in consumption are from aquaculture.

When it comes to examining seafood consumption in the United States it is better to look at the parts rather than the whole. For example, a major element of U.S. seafood consumption is canned tuna and recent declines in tuna consumption may significantly affect the overall per capita figure while having little or no impact on the industry as a whole. What is significant for aquaculture is that salmon, shrimp and catfish have recorded gains in consumption over the past decade. If we produce it, at reasonable value, the market will respond.

To understand U.S. seafood consumption it is important to understand the U.S. seafood consumer. Through this understanding can come strategies for small and medium scale companies to serve segments of the U.S. market and achieve success. Niche marketing.

Table 2. Top 10 U.S. Seafoods 1990-1996 **Source: National Fisheries Institute**

		Pounds Per Capita						% Change
	1996	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**	**1990 vs 1996**
Total	**14.8**	**15.0**	**15.2**	**15.0**	**14.8**	**14.9**	**15.0**	**-1.3%**
1. Canned Tuna	3.200	3.400	3.300	3.500	3.500	3.600	3.200	0%
2. Shrimp	2.500	2.500	2.600	2.500	2.500	2.400	2.200	+13.6%
3. Ak Pollock	1.620	1.520	1.520	1.200	1.230	0.990	1.270	+27.6%
4. Salmon	1.440	1.190	1.113	0.995	0.871	0.970	0.730	+97.3%
5. Cod[1]	0.918	0.983	0.928	1.030	1.076	1.120	1.380	-33.5%
6. Catfish	0.899	0.864	0.855	0.988	0.907	0.770	0.700	+28.4%
7. Clams	0.518	0.567	0.544	0.589	0.616	0.580	0.610	-37.0%
8. Flatfish[2]	0.384	0.302	0.361	0.623	0.507	0.380	0.570	-32.8%
9. Crabs	0.333	0.319	0.312	0.375	0.333	0.320	0.290	+14.8%
10. Scallops	0.269	0.244	0.292	0.257	0.272	0.250	0.300	-10.0%

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[1] Atlantic and Pacific cod combined.

[2] Sole, flounder, halibut.

One of the reasons U.S. seafood consumption, on a per capita basis, has not reached higher levels is likely due to the fact that many Americans are of English and central-European origin where seafood was not a primary part of the diet. As a result, for many Americans (Asians and Scandinavians excepted) seafood was an "acquired" taste. A recent survey of U.S. consumers found that 12 percent of the respondents indicate they do not eat seafood, 32 percent were classified as "light (1 to 4 times in past four months) seafood consumers," 29 percent as "medium" (5 to 10 times) seafood consumers and 21 percent as "heavy" (11 or more times) seafood consumers.

Reasons For Eating Seafood

Americans consume, or do not consume, seafood for a variety of reasons including ethnic background, personal preferences, age, income, education and geographic region. In a 1994 survey[3] heavy seafood users reported that taste (96%) was the primary reason for eating seafood followed by nutrition (79%), meat substitute (66%), variety in the diet (64%) and special occasions (27%). While health may be an underlying reason for eating seafood, it is secondary to taste.

Reasons For Not Eating Seafood

When non-seafood consumers were asked why they did not eat seafood, the responses varied including: taste, difficulty in preparation, cost, rejection by one or more family members and problems handling fresh fish[4].

Eating More Seafood

When all seafood consumer groups (heavy, medium, light and non-users) were asked what it would take to increase their seafood consumption, the three seafood usage groups all gave "lower prices" as their top responses. Forty-two percent of non-users responding stated that "nothing" would cause them to eat more seafood[5]. Seafood marketing strategists believe the responses by non-seafood users indicate it would be difficult to convert this segment to seafood consumption. A better strategy would be to target light and medium users and induce these consumers to eat more seafood. Retail price promotion has proven to be an effective tool in reaching these consumers. Since all responding groups cited the need for easier preparation as a purchase criterion, the trend toward value-added seafood products may also increase consumption. Seafood safety was not a primary concern to survey respondents even though considerable negative publicity has been generated regarding this issue.

U.S. Seafood Consumer Demographics

As consumer surveys indicate, the U.S. market is far from homogenous when it comes to seafood consumption. For example, heavy seafood users are generally older (55-64 years

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[3] Simply Seafood Magazine Consumer Survey

[4] Source: National Fish and Seafood Promotion Council

[5] California Seafood Council Consumer Survey

old), better educated and have higher incomes. Given the high price of many seafoods, such as shrimp, crab and lobster, these demographics are not surprising. However, according to the Bureau of Labor Statistics, African-Americans spend 26 percent more on seafood at home than the national average. Most likely African-Americans consume fresh catfish at rates higher than the national average. Asian consumers purchase far more whole fish (head on) than other groups. In reality, most U.S. seafood markets are niche markets with their own unique demographic characteristics.

Some U.S. Seafood Market Micro-Segments:

Asian	- Live fish, whole fish (high and low priced)
Hispanic	- Whole fish, low-priced species, dried fish
African-American	- Catfish

Size of the U.S. Seafood Market

For 1996, the U.S. seafood supply consisted of 13.7 billion pounds (round weight equivalent). This included 6.15 billion pounds of imports and 7.5 billion pounds of domestic landings. Aquaculture production, primarily catfish, trout, salmon, totaled less than 1 billion pounds. The U.S. seafood market had a wholesale value of $19.5 billion and a consumer value of $40.9 billion.

Growth Prospects for the U.S. Seafood Market

While the U.S. seafood market is not growing on a per capita basis, the market is increasing in overall volume. Per capita seafood consumption was 14.8 pounds in 1992 and 1996. However, population growth increased the overall market by 150 million pounds on an edible weight basis. This equals 450 million pounds on a round weight basis (equivalent to the current total output of the U.S. catfish industry). Using 1995 as the base year and 15.0 pounds per capita as base consumption, the U.S. market will require an additional 585 million pounds per year of seafood by the year 2010 based upon population growth alone.

This figure equals 1.6 billion pounds round weight; equivalent to the current size of the largest fishery in the United States, the North Pacific Alaskan pollock fishery. In reality most major U.S. fisheries are declining although two of the largest, Alaskan pollock and salmon re stable.

Role Of Value-Added In The U.S. Seafood Market

If the market is not growing, or the business is not profitable, one strategy for growth is through adding value to products currently produced. In the context of aquaculture products, there are several definitions of “value added” which may apply. They are:

Value-added to the Producer: Further processing of a product that provides revenue greater than the incremental cost of additional processing and/or further processing that increases sales volume without a decrease in profit margin.

Value-added to the Wholesale Seafood Buyer: Products which: reduce labor, decrease waste, provide easier stocking/storage/distribution, increase profit margins, increase sales volume, retain marketable life through distribution and come with market support.

Value-added to the Consumer: Products which have an increase "perceived value" (price/quality), provide greater convenience, are easier to prepare, taste good, are healthy, efficiently packaged and provide good storage life.

To see how value-added works, walk through a supermarket and locate all the products made from turkey. Start in the deli department and find smoked turkey breast, turkey pastrami and sliced turkey breast. Next move to the frozen food section and find the dinners and entrees made with turkey. Finally, move on to the meat department and check out the whole birds, parts, ground turkey and other items.

Creative Marketing Strategies For Value-Added Products

How to Develop Value-added Products

There is no "off the shelf" program involved in developing value-added products. However, there are some steps and strategies that individuals and companies can use to come up with product ideas that add value. For example:

- ✓ Talk to your customers. Find out what they need that they are not now getting.
- ✓ Talk to consumers. What do consumers want from products like yours?
- ✓ Know your own strengths and weaknesses.
- ✓ Brainstorm ideas.
- ✓ Be unique.
- ✓ Be flexible.
- ✓ Start small, learn from your mistakes.

Applying the Four "P's" of Marketing to Value-added Products

Product Strategies – *Differentiating*
- ✓ Make it unique (through processing and packaging)
- ✓ Size (make it bigger or smaller than normal)
- ✓ Appearance (red trout for example)
- ✓ Product form (butterfly fillets, skinless products, meat-only)
- ✓ Flavors (garlic sauces, marinades, spices, herbs)
- ✓ Convenience (easy to prepare, pre-cooked, portioned)
- ✓ Gift products (canned, retort pouched, boxed)
- ✓ Your product as an ingredient (stuffings)
- ✓ Make a niche product (snack, organic, natural ingredients)

Place Strategies – *Finding The Right Niche*
- ✓ On-site sales
- ✓ Local outlets (stores, gift shops, farmers markets, restaurants)

- ✓ Small independent and/or upscale retailers
- ✓ Ethnic markets
- ✓ Perishables-oriented stores
- ✓ Specialty seafood distributors
- ✓ Events (State Fairs, local celebrations)
- ✓ Caterers
- ✓ Tourist-based gift shops
- ✓ Direct mail (advertised on the Internet, magazines, catalogs)

Promotion Strategies – *Creating Image and Awareness*

- ✓ Develop a brand (that conveys an image)
- ✓ Create a logo (that supports the brand)
- ✓ Develop “signature” recipe concepts (for customers to use)
- ✓ Write your story (your business is unique)
- ✓ Your location makes you unique (take advantage of it)
- ✓ Find promotional tie-ins (with complimentary products)
- ✓ Use public relations (to get your message out)
- ✓ Advertise wisely

Price Strategies – *Developing Perceived Value*

- ✓ Identify premium price niches (uniqueness, limited supply)
- ✓ Make it easy to buy (small quantities, fast delivery, outstanding service)
- ✓ Understand buyer economics (visit stores/restaurants, study menus, ask questions)

Recommendations

Do Your Market Research First

Before launching major production, most aquaculture producers need to confirm whatever assumptions they have made regarding the marketability of their output.

- ✓ How big is the current market?
- ✓ Can the market absorb more supply without a major drop in prices?
- ✓ What price (farm gate) can the producer realistically expect for his products?
- ✓ Who is the competition? What are their production economics?
- ✓ What legal requirements exist for processing and packaging?

Start Small

Big mistakes are costly and sometimes fatal. Small mistakes can be learning experiences.

- ✓ Start with pilot scale production if possible.
- ✓ Limit initial orders of printed materials (promotional literature and packaging)
- ✓ Service a few customers well at the beginning.
- ✓ Seek objective evaluation regarding product quality.

Set Realistic Goals

If the market is $5.00 per pound, should you anticipate sales at $4.50, $5.00 or $5.50? When developing sales plans it is best to take a conservative approach on price. While the market price may be $5.00, this might be for suppliers that have developed long-term relationships with their customers and have a proven track record of delivery.

When it comes to production, don't over promise and under deliver. Buyers have long memories when it comes to being shorted on product they have purchased. Supply continuity is perhaps the most import element in the sales equation, even more important than price. Retailers with advertisements must be assured they will have product to meet their commitments. Restaurants with menu items based upon your product don't want to tell their customers they are out.

Sell it Yourself Initially

The best way to learn about your product and the marketplace is to sell it yourself. Make the sales calls; take the orders, delivery the goods. If you start your business using a broker to sell your product you will never learn what you need to know about the dynamics of the market. Once the business is in full production and sales are running smoothly you may want to consider sales agents. Brokers can provide a range of services, including invoicing, credit authorization and product delivery, but producers still need to have a thorough understanding of their market.

The Importance of Feed to the Economic Success of the System

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To date, the emphasis in Recirculating Aquaculture Systems (R.A.S.) has been on engineering, system design and monitoring. During the first conference in 1996, only two papers dealt specifically with feeds. It is this presenters opinion that too little attention is paid to feed/feed quality and its impact on the total system success, including profitability. The current situation can be summarized accordingly. (Table 1)

Table 1. Summary of Current Situation
• Diet is usually one of the highest production costs representing between 20 and 60% of total production cost.
• Most growers do not measure the differences in diet value and its effect on profitability
• Because of weak fish prices, more growers are wanting and selecting lower priced diets
• There are more manufacturers of aquaculture diets producing a wider range of products – more options
• Similar appearing diets may vary in value as much as 75%

It is well recognized that feed is a cost however seldom is feed viewed as an investment. Who gives consideration to the “engineering” of feed formulation and its profit potential?

In the planning phase where budgeting occurs, feed is given a line item cost where it is plugged into a model based on certain assumptions of performance. What happens though when the feed costs increase 5, 10, 20%? What happens when water quality deteriorates to the point where feed input is reduced or ceased until water quality recovers? The entire projections are blown out of the water. Growth is disrupted, days to market lengthened, cash flows are inadequate, ultimately profitability breaks down. Recently, at another aquaculture conference, an R.A.S. entrepreneur shared with me that he’s only able to feed “50% of what he’s supposed to be able to feed”. Whether it’s due to poor system design, poor feed quality, poor management or all of the above, he’s dead in the water! “Paper fish”, those that are grown in models don’t distinguish between mediocre and superior feeds. They don’t require good water quality and they never die. Unfortunately, there is no market for “paper fish”.

Clearly, the continuing objectives of aquaculturists are to reduce costs and be the low cost producer. Ultimately, the real objective is to increase the difference between the value received for the product produced and the input costs or profitability.

There are numerous companies offering a wide range of diets so how do you make the right selection, the one that's best for the profitability of your R.A.S.?

Diet Cost Per Pound is widely used to select feed, but bear in mind that you may get what you pay for with poor performance.

Diet Cost Per Pound of Gain goes a step further factoring in Diet Cost & Feed Conversion Rates, a performance measure.

Ultimately, the profitability of an R.A.S. should be the most business minded means of feed selection. Income Over Diet Cost measures the return on the feed invested.

In order to fairly collect the data needed to make these evaluation Protocols (Table 2) in field trials must be adhered to.

Table 2. Protocol - Field Trials

- Rainbow Trout was the targeted species
- Commercial farms – practical growing conditions – farmer managed – professionally assisted
- 2 diets – coded for confidentiality; all diets used were commercially available
- 2 reps per diet
- No. fish per rep 1500 ±
- No. of days 90±
- Demand feeders or hand fed to satiation
- Market value of fish $1.25 per lb.
- Objective: Focus on profits (Income Over Diet Cost)

Bear in mind that Diet A was from one supplier while Diet B was from four different suppliers. Clearly, based on Diet Cost alone, Diet B was the best choice. (Table 3.)

Table 3. Diet Cost Per Pound

Trial No.	Diet A	Diet B	Difference
1C	$0.194	$0.161	$0.033 (20.5%)
2C	$0.189	$0.178	$0.011 (6.2%)
3C	$0.220	$0.204	$0.016 (7.3%)
4E-BT	$0.250	$0.200	$0.050 (25.0%)

Using Diet Cost Per Pound of Gain, the results were mixed as to which was the best choice. (Table 4.)

Table 4. Diet Cost Per Pound of Gain

Trial No.	Diet A	Diet B	% Difference
1C	$0.316	$0.291	+ 8.6%
2C	$0.278	$0.290	- 4.2%
3C	$0.262	$0.275	- 4.7%
4E-BT	$0.545	$0.686	- 20.6%

Breaking it down still further, <u>Income Over Diet Cost</u> offers a measure of profitability. All trials were equalized to 100,000 pounds of gain. Clearly, Diet A in all cases generated greater return than Diet B. (Table 5.)

Table 5. Income Over Diet Cost
Equalized to 100,000 lb. of gain for the best feed.

Trial No.	Diet A	Diet B	Difference
1C	$93,378	$87,296	$6,0873 (6.5%)
2C	$92,250	$82,008	$10,242 (11.1%)
3C	$99,877	$83,436	$16,441 (19.7%)
4E-BT	$82,892	$51,131	$31,761 (62.1%)

Based on these results, it requires only a 2% increase in growth to completely pay for a 10% increase in feed cost. Additionally, a 1% increase in processing yield offsets that same 10% increase in feed cost.

How can such results exits? There are numerous Diet Related Factors which influence feed performance and profitability. (Table 6.)

Table 6. Diet Related Factors Associated with Performance – Profits

- Energy Content
- Nutrient Energy Ratio
- Ingredients/Digestibility
- Ingredient Stability
- Palatability
- Fines
- Fineness of Grind
- Method of Processing
    - Pelleting
    - Expanding
    - Extrusion
- Negative Factors
    - Pesticides
    - Mycotoxins
    - Anti-metabolites
- Changing Formulations
- Pellet Size, Uniformity & Stability

This dilemma of feed selection becomes increasingly difficult as the feed options available increase. What can be done to derail this diet dilemma?

- Understand and accept the potential for increased profits from the use of proper diets and make a personal commitment to do something!
- Make your supplier your success partner: Qualify, share information, communicate regularly, and set goals and work together to achieve them.
- Conduct diet trials on your farm: Dedicate 10-30% of production capacity, budget resources, confirm performance data on your farm, compare to the best, use professional help and proper test protocols and do computer modeling.
- **Focus on profits!**

Digestibility Issues of Feeds for Water Recirculating Systems

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Introduction

Feeding fish in their aqueous environment takes on dimensions beyond those considered in feeding land animals. As fish production systems become less dependent on natural food organisms and more dependent on prepared feeds, the need for nutritionally complete feeds becomes more critical. In highly modified environments such as water recirculating systems, nutritionally complete feeds are a necessity and the digestibility of these feeds can play a large role in the success or failure of the aquaculture production system.

The concept of nutrient availability has universal acceptance in the area of animal nutrition. The principle is attributable to the fact that nutrients in feedstuffs are recognized to be incompletely digested and metabolized by animals. The nutritional value of a feed or feedstuff is based not solely on its chemical composition but also on the amount of the nutrients or energy the fish can absorb and use.

This presentation will consider the importance of feed digestibility in water recirculating systems. Consideration will be given to factors that affect the digestibility of nutrients as well as methods of evaluating the digestibility of various feedstuffs. Utilization of available nutrient data in feed formulation will also be discussed

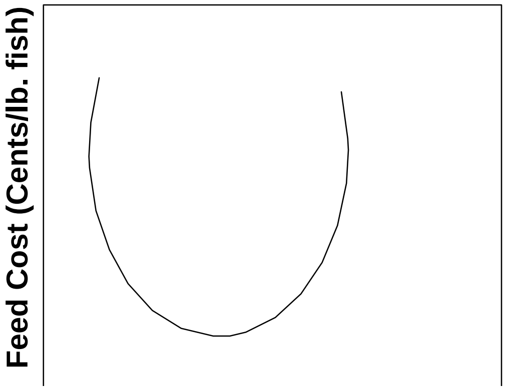
Importance of Feed Digestibility

The bioavailability of nutrients or energy in feedstuffs for fish can be defined mainly in terms of digestibility or, in the case of energy, metabolizability. Digestibility refers to the fraction of the nutrient or energy in the ingested feedstuff that is not excreted in the feces. Metabolizability describes the fraction of the digested energy that is not excreted in the urine or through the gills. Both digestible energy (DE) and metabolizable energy (ME) have been used to express feedstuff values for fish (National Research Council, 1981, 1983) but many researchers use and report only DE values because of difficulties in obtaining ME values for fish.

Feed digestibility impacts a number of production parameters and issues; not least of which is economics. Digestibility is one of the major factors that effects the efficiency of feed utilization. Economic efficiency (i.e., feed cost per pound of fish) is determined by multiplying feed conversion by the feed cost per ton of diet. In that digestibility impacts feed conversion, it also impacts the feed cost per pound of fish. The relationship between feed cost per ton of feed and feed cost per pound of fish produced is illustrated in Figure 1 below. The shape of the curve is a function of the efficiency of feed utilization.

Feed digestibility, by definition, has an impact on nutrient excretion to the environment. The excretion of waste nutrients to the environment is of particular concern in water recirculating systems; especially those with biological filter systems. If the waste nutrient load presented to the bacteria in the biological filter system is dramatically altered by significant shifts in the digestibility of the diet, water quality can suffer to the point where a system shutdown can occur. This can produce high mortality and markedly reduce profits.

An emerging issue for all animal production systems, including aquaculture, is their effect on the environment, and by far the main concern is the concentration of nutrients in manure. In the United States, legislation is being enacted to regulate and modify manure disposal methods. Several European and Asian countries have already imposed strict measures on farming activities as a means to limit pollution (Headon, 1992; Schwartz and Hoppe, 1992). Similar measures have been taken in some regions of the U.S. to deal with agricultural pollution (Brown, 1992). In addition to feeding for maximum performance and profitability, nutritionists must now consider feeding regimes that minimize excretion of critical nutrients.



Factors Affecting Digestibility of Feedstuffs

Digestibility of nutrients from various feedstuffs is affected by a great number of factors. Although it is beyond the scope of this presentation to address all of the factors that influence digestibility, several of the more prominent ones will be highlighted.

Probably the single greatest factor influencing the digestibility of a given feedstuff is the species of fish to which it is being fed. The differences in digestive physiology and biochemistry that exist among the various species of fish is quite remarkable when compared to the land dwelling species that are raised in commercial agriculture. With this variation in mind, the other factors discussed in this section should be viewed as generalities; realizing that they may not apply to all aquacultured species.

The apparent digestibility of a complete feed depends, to a large extent, on the digestibility of the protein, fat, carbohydrate and ash fractions of the selected dietary ingredients for the particular species being fed. Although not a complete data set, apparent digestibility factors for a number of ingredients and species can be found in the National Research Council=s Nutrient Requirements of Fish (1993). Diets composed of highly digestible ingredients generally exhibit a highly digestibility coefficient than diets containing less digestible ingredients.

Processing of ingredients and finished feeds can also have a significant impact on their digestibility. Proper handling and processing of fish meal is essential to prevent production of high levels of biogenic amines. These breakdown products of proteins can lead to impaired digestion and poor performance if they are at high levels. Stability of fish oil and residual oil found in fish meal is essential to prevent oxidative rancidity from occurring. Oxidized fats and oils are poorly digested and may also produce deficiencies of fat soluble vitamins.

Some ingredients, such as soybean meal, require heat processing to eliminate a trypsin inhibitor factor before they can be fed to fish or other monogastrics. The degree to which soymeal is toasted is a critical factor in determining its digestibility. The meal should be toasted enough to eliminate the trypsin inhibitor, however, if excessive toasting occurs the availability of a number of amino acids (especially lysine) is markedly reduced.

Processing of the finished feed itself can also play an important role in its digestibility. This topic is being covered in detail in another of the presentations and thus will not be discussed here other than to say that one should give consideration to this factor in any production system.

A number of management practices can also effect the digestibility of a feed, especially in a recirculating system. It has been found in a number of species that as meal size increases, digestive and absorptive efficiencies decrease (Solomon and Brafield, 1972; Elliot, 1976; Windell et al., 1978; Andrews, 1979). Thus, more frequent feedings of smaller meals will tend to increase the digestibility of a given diet.

Water quality and dissolved oxygen levels will also play a role in how well fish can digest and absorb their feed. Of course in recirculating systems, the digestibility of the diet can also impact a number of water quality factors. Sorting out which came first can be a difficult and frustrating task.

Any discussion of ingredient digestibility would not be complete without at least mentioning enzymes. A discussion of enzymes should be a topic in and of itself to do it justice, but a few generalizations will be noted here. Many of the differences observed between species, with respect to the digestibility of a given ingredient or nutrient, are a function of whether a given species possesses an endogenous source of a digestive enzyme. Advances in biological engineering are allowing for production of a number of enzymes on a commercial scale. These products can enhance the digestibility of a number of nutrients including: carbohydrates, proteins, lipids, and minerals. Key factors to consider as we go forward with enzymes in fish feeds will be the optimums of pH and temperature versus those of land-based homotherms.

Methods of Evaluating Digestibility

Methods for evaluating the digestibility of feeds and ingredients fall into the two general categories of biological and chemical analyses. Biological methods would include measuring production parameters such as growth, growth rate, and feed conversion ratio. Measuring the deposition of specific nutrients in the carcass is another way of evaluating the availability and balance of amino acids and the availability of some essential elements.

Digestibility coefficients can be determined for feeds and ingredients via indirect and direct methods. The indirect method involves the use of a nondigestible marker, such as chromic oxide (Cr_2O_3), which is included in the diet at a low concentration. It is assumed that the amount of the marker in the feed and feces remains constant throughout the experimental period and that all of the ingested marker will appear in the feces. The digestibility of the nutrient in question can be determined by assessing the difference between the feed and fecal concentrations of the marker and the nutrient or energy. The direct method involves measuring all the feed consumed by the fish and all of the resulting excreta. This method has only been used successfully with rainbow trout and is very difficult to employ.

A number of chemical tests can also be used to measure ingredient and diet quality. These tests address a number of issues previously described as they relate to ingredient digestibility. Several chemical tests for protein quality are used to measure the effects of processing of ingredients on protein quality. These tests include: pepsin digestibility, protein dispersibility index, potassium hydroxide solubility index, and urease index. Most of these tests were designed for soybean meal, but some are applicable to other protein sources including animal and marine by-products.

Lipid quality can be assessed by measuring hydrolytic and oxidative rancidity. Tests that aid in measuring oxidative rancidity include: peroxide value, thiobarbituric acid test (TBA), anisidine value, and 20 hour AOM test. Hydrolytic rancidity is generally measured as free fatty acid values.

Feed Formulation Considerations

Formulation of diets requires three major inputs. Firstly, one must know the nutrient requirements of the fish to which the diet will be fed and from this knowledge establish the nutrient specifications for the diet. Such nutrients will be provided by various ingredients and therefore knowledge of the content of these same nutrients within the ingredients is the second requirement. Because a least-cost situation is desirable, the final requirement is to know the current market price of the selected ingredients. With this information, numerous computer programs are able to generate least-cost diets.

In order to formulate the most cost effective diets, whose impact on the recirculating system and ultimately the environment can be predicted, one must formulate based on digestible or metabolizable values. Although values exist for a number of ingredients and a few species, the data set is far from complete. Obtaining good digestibility values for ingredients is difficult for fish due to their aqueous environment, however, it is precisely this data that will be required as we move forward to meet the challenges of feeding fish while at the same time giving consideration to the impact our diets have on the environment.

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Selection of Pelleted, Expanded, and Extruded Feeds

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Feed represent 50-60% of the production costs of farmed fish making it the single most significant costs to farmers. The first fish feeds were typically moist, semi-moist or steam pelleted with very low levels of fat concentration. These early diets tended to fall apart easily which fouled the water. Additionally they had limited shelf life. Fish feed sold in the United States for recirculating aquaculture systems is now far more sophisticated and is typically made via an extruder, an expander, or a steam pellet mill. Options include sinking, slow sinking, and floating. Each one of the three pelleting processes can be defined. The industry trend is evolving rapidly towards extruded or expanded products and away from steam pelleting.

Of primary concern to recirculation aquaculturists are feed cost, amount of fines, size, digestibility, buoyancy, vitamin and nutrient contents, shelf life, water stability, durability, palatability, and shape. All of these factors are affected by the manufacturing process which still remains as much an art as it is a science. Not only does each machine act differently, formulations and ingredients differ and individuals add their own interpretations concerning their opinion of an “ideal feed”.

Steam Pelleting

Steam pelleting of fish feeds has been employed since the 1950’s. The initial stage of production of any feed involves grinding the raw ingredients. After the ground mash is premixed, steam is added to condition and partly gelatinize the starches which assist in pellet binding. The mash is typically exposed to steam for short periods of time (less than 35 seconds), and exposed to processing temperatures of 100-180° F. Steam pellets are typically cylindrical in shape and are made 1.5 to 2 times longer than in diameter and marginally hard with a glassy exterior. A good example of what a pellet looks like would be to look at a rabbit feed. The conditioned mash is forced through a die and the resulting pellets are cut by a series of knives to a predetermined length. After the pellets are cut to their desired length, they are blown dry with a final moisture content of 9-10%. The final product has almost a glazed look to it and it is fairly dense and will sink. Advantages to pelleting include:

1) Less energy is required during manufacture.
2) Less heat means less destruction of heat sensitive nutrients, medications, and vitamins.
3) Initial cost is less.

Disadvantages of pelleting included:

1) Shorter cooking time and lower cooking temperatures and resultant pressure do not fully gelatinize the starch resulting in marginal pellet durability. Pellet binder which is “nutritionally blank” must be added to the formulation.
2) Product can only be made to sink because of its greater density
3) The sharp ends of the pellets combined with the softer nature cause breakup of the feed and a greater incidence of fines.
4) The smallest sized pellet that can be made is roughly 2.4 mm.
5) Feeding behavior is not easy to determine when the feed sinks.
6) Total fat content can not exceed 20%.

Extruded

Extruded feed has been catching on since the early 1990’s and may be the product of choice for the future. The premixed mash is introduced into an extruder barrel where significant amounts of moisture are added. This high moisture mash is then exposed to intense pressure, heat and friction which results in starch gelatinization two to three times that found in steam pelleting. In many extrusion lines, the mash is brought up in moisture and temperature in a preconditioner before it enters the extruder barrel. Preconditioning the mash can help improve palatability, digestibility, durability, and potentially allows feed to be made faster than without preconditioning. Processing temperatures during extrusion can reach up to 300°F. When this super heated mixture is then forced through a die, a rapid reduction in pressure occurs which causes the pellets to expand and potentially float. Upon exiting the die, the moisture level of extruded pellets is 10-15% higher than in steam pellets, so significantly more amounts of energy must be expended to dry the product to 10% moisture. Advantages of extruded feed include:

1) Fat levels higher than 20% are possible.
2) The expansion can be controlled to allow the product to sink, slow sink or float.
3) Floating feed can be an effective management tool for feed behavior observation.
4) Higher pressure, temperature and cooking time makes both the carbohydrates and proteins more available resulting in better feed conversion ratios (feed cost per pound of fish weight gain makes up for the slightly higher price)
5) Better digestibility means less waste for the system to handle.
6) Carbohydrates are used as binders so “nutritionally blank” ingredients are not required to bind the product. Better feed conversions and reduction in total fecal load is the result.
7) Structural integrity allows for smaller, more consistent sizes.
8) Pellets are durable, uniform and have few fines.
9) The reduction in fines, combined with lower solid and dissolved wastes contribute to improved water quality. Better water quality leads to improved fish health and better performance of the solid removing device and biofilters.

Disadvantages of extruded feed include:

1) Nutrient, medication and vitamin degradation is higher because of the additional heat used in the manufacturing process forcing these ingredients to be supplemented at higher levels.
2) The initial equipment costs, combined with nutrient degradation and a slower production rate force extruded feed to be slightly more expensive the steam pelleted feed (average cost of .01/pound higher).
3) Product is less dense and will fill up a bulk truck before the truck reaches it's maximum weight limit (typical bulk trucks might be able to hold 40,000 pounds of extruded feed and 42,000 pounds of pelleted feed).

Expanded

The expanded feed manufacturing process is similar to that of extruded feed except the expandite cooked mash must be sent through a pellet mill to form the pellets which typically results in sinking pellets (some units when combined with skilled operators can produce floating feed as well). Expansion does not require as much moisture as extrusion and the pellets can be dried without heat which reduces operating costs. Expanders produce denser pellets than extruders but not as dense as a steam pellet (the exterior glazing associated with steam pelleting does not appear). There are only a few expanders currently employed in the United States to produce fish feed.

Comparison of Feed Manufacturing Techniques

	COMPRESSED PELLETS	EXTRUDED	EXPANDED
Initial feed cost	lowest	highest	intermediate
Starch gelatinization %	<40	>80	60-80
Max. temp. (F)	180	300	300
Max. fat level %	20	40	30
Digestibility	good	best	better
Sinking available	yes	yes	yes
Floating available	no	yes	possibly
Slow sink available	no	yes	possibly
*Fines upon receipt %	1 to 6	<1	<1
Vitamin and nutrient degradation	lowest	highest	intermediate
Feed conversions	worst	best	intermediate
Uniformity of feed	variable	excellent	good
Availability	most mills	some mills	few mills

*Fines can result from poor handling practicing of finished feed or minimal grinding

The chart on the previous page is made assuming some generalizations. Actual performance is predicated upon ingredients, grinding, individual machines and operator choices.

Summary:

Advances in fish feed manufacturing technology have given the fish farmer several types of feed from which to choose. Extruded and expanded processing methods improve durability and digestibility. Additionally, extrusion adds the ability to produce a variety of feed buoyancy tailored to the needs of the system, farmer, and fish .Extruded feed typically produces feed with the best feed conversion numbers as well as producing product uniform in size/shape/quality. Expanded product typically is about as good as extruded product and at times is very difficult to tell apart from extruded. Steam pelleting is preferable when adding medication, but is not as desirable because of its limitations concerning buoyancy and feed conversion numbers. Size of ground pre-manufactured product together with species being raised, digestibility, and amount of fines all vary from manufacturer to manufacturer. System limitations might give the advantage to one feed over the other. Initial up front cost of a feed many times will not give you the true cost to raise your fish to market size. It is critical for the fish farmer to have a strong working relationship with, not only the feed representative, but also the nutritionists responsible for formulating their diets.

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Formulating Feed for Tilapia Reared in Recirculating Systems

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Introduction

Producing feed for Tilapia reared in recirculating systems presents several challenges. Not only do the fish have to grow rapidly under high density rearing conditions but the complete feed, has to have low environmental impact. Peleted feeds are not recommended for water reuse systems. Extruded feeds, including crumbles impart both greater digestibility and better water quality characteristics.

Nutrient requirements normally applied to practical feed formulations are not adequate in high density rearing situations. Nutritional contributions of vitamins, minerals, key lipids, protein and energy from the environment can not be counted on to contribute to growth. In addition to completely meeting nutritional requirements, the quality of ingredients and economic constraints play major roles in commercial feed formulation.

Many feed ingredients can be used to meet nutritional requirements but not all ingredients should be major components of complete feeds. Many are not sufficiently digestible, and some contribute to the production of excessive body fat or fillet pigmentation.

Ingredient Quality

Quality feeds can only be made with quality ingredients. Quality assurance begins at the feed mill with ingredient reception. Before grains are received, several tests for mycotoxins are performed as standard operating procedure. Corn is rejected if Aflatoxin levels exceed 20 ppb or Fumonisin is found at levels above 1 ppm. Wheat is screened for D.O.N. and is rejected if levels exceed 5 ppm. Fishmeal is accepted or rejected based on histamine levels.

Ingredient Analysis

After acceptance, periodic samples of ingredients are taken, and analysis for protein, fat, fiber, ash and moisture are carried out. These data, along with amino acid, and fatty acid profiles are used to update the nutrient specification matrix. The use of the nutrient matrix in feed formulation programs will be discussed at a later point. However, it is important to periodically update the matrix, as seasonal nutrient variability within key ingredients can impact extrusion characteristics, and final feed quality.

Quality Assurance

During extrusion bulk density of the product is measured, and extrusion parameters are adjusted to meet final characteristics. The completeness of float or sink and the amount of fines produced, are periodically monitored and adjustments in extrusion conditions (amounts of water , steam, oil and feed mash input rate) are made to produce a feed that meets customer specifications.

This loss in moisture as well as the amount of fines generated, and the loss of product upon start-up of the extruder are collectively termed shrink. The ingredient moisture level at reception, can range from 10 to 14 % and the moisture level in the finished product after drying of 6 - 8%. A shrink rate or percentage of the total feed mash, of 5% or below can depending on the extrusion situation be an acceptable cost, but increasing levels of shrink impact the final cost of the feed and ultimately profitability. In situations where shrinkage is high or variable, formulation, extrusion operation and ingredient quality or all three must be reexamined.

Fish Oil Specifications

While Tilapia can effectively utilize soy oil, fish oil is still the major oil component in most Tilapia feeds. However, its use requires special standards. In the commercial arena a key is to purchase cold processed fish oil. Upon arrival additional antioxidants are added. The addition 250 - 500 ppm BHA & BHT can be added by the supplier or by the manufacturer at ingredient reception. Fish oils acceptable for use in fish feeds should contain less than 3% free fatty acids, less than 1% moisture, less than 1% nitrogen and less than 20% Totox defined as (2 X (peroxide value) + (Anisidine Value). Fish oil should not be stored in heated tanks as increased storage temperature can contribute to increased oxidation.

Fish meal is used to maintain palatability as well as meet essential amino acid requirements. Fish meals are sold by protein levels, ash levels, and the temperature of processing. Principal indicators of fish meal quality are Salmonella SP negative, less than 500 ppm Histamine and stabilized with atleast 250 ppm Santoquin.

Finished Product Analysis

Finished feeds are periodically tested to assure that tag specifications in accordance with national regulations are being met. In the United States quality control procedures are in place to verify national standards established for both feed ingredients and finished feeds. In this way feed tags provide some guarantee for purchases of the freshness and quality of feeds. Additionally, feeds should be periodically monitored for non-nutrient components. Mycotoxins, Thiobarbateric Acid, histamine, as well as levels of feed protectants, Ethoxiquine, Vitamin E, and Vitamin C should also be periodically monitored. Samples should be taken from every 5th. bag of 50 to 60 bags and pooling the samples. Quantitative testing should only be performed by an approved laboratory for testing.

Finished Product Storage

Finished products are stored at ambient temperature of six months after manufacture. Ambient temperature rather than frozen storage is utilized so that should a concern be raised that a feed is not performing as expected, the comparison can be made with feed of the same "age" but stored cool and dry. Complete records should be kept for each batch of feed delivered to farmers. These data should include details of date of delivery, batch number, and quantity delivered. Many of the issues brought to the feed manufactures attention are the result of improper storage conditions.

Feedstuff Digestibility

Even though both Catfish and Tilapia are omnivores, digestibility of feedstuffs is different between the species. While it is not universally accepted, it is not appropriate to use a diet formulated to rear Catfish in ponds for Tilapia in recirculating systems. Wilson and Poe, 1985 have shown that extrusion as compared to peleted processing increased the digestibility of energy but had no effect on the digestibility of protein. Popma, 1982 described the difference in digestible energy between Catfish and Tilapia fed the same feedstuffs. Differences in digestible energy of key ingredients used in both Catfish and Tilapia commercial feeds are summarized in the following table.

Common Feedstuff Digestibility Differences

Ingredient Digestible Energy (Mcal / g)		
Ingredient	Catfish	Tilapia
Alfalfa, 17% Protein	0.67	1.01
Corn Grain		
Raw	1.10	2.46
Processed	2.53	3.02
Menhaden Fish Meal	3.90	4.04
Molasses	3.47	2.94
Soybean Meal, 48% Protein	2.58	3.34
Wheat Flour	2.55	2.89

Ingredients selected for use in Tilapia feeds can significantly impact the digestibility of the finished feed. Growth, feed conversion and pollution generated are directly related to the degree of digestibility of the finished feed and the amount and type of feces produced.

Feedstuff Selection

Feedstuff selection for recirculating systems is not only limited by unit costs for energy, protein, amino acid composition and ingredient digestibility but the level of phosphorus is also a consideration. The phosphorus / nitrogen of many ingredients such as animal by-product meals, with the exception of fish meals, have a high P / N ratio. Generally plant protein ingredients such as soybean and corn gluten meals have lower P / N ratio, which is a desirable characteristic for inclusion in low environmental impact diet formulations.

An example of a derivative criteria the phosphate / nitrogen ratio of several ingredients provided by Cho et al 1994 can be added to the nutrient specification matrix. The nutrient matrix will be discussed at a later point but it is important to know that actual nutrient levels as well as derivatives such as the P / N ratio can be used to assist in formulating low impact aquafeeds.

Feed Stuff Selection
Phosphorus/Nitrogen Ratio

Ingredient	Protein	Nitrogen	Phosphorus	P / N
Herring Meal	**72**	**11.52**	**1.00**	**0.087**
Feather Meal	**85**	**13.60**	**0.70**	**0.051**
Corn Gluten	**60**	**9.60**	**0.70**	**0.073**
Peanut Meal	**47**	**7.52**	**0.60**	**0.080**
Soybean Meal	**48**	**7.68**	**0.65**	**0.085**
Wheat, Soft	**11**	**1.73**	**0.30**	**0.174**
Yellow Wheat	**9**	**1.42**	**0.25**	**0.176**
Poultry Meal	**58**	**9.28**	**2.40**	**0.259**
Menhaden Meal	**62**	**9.92**	**3.00**	**0.302**
Wheat Midds	**17**	**2.72**	**0.91**	**0.335**
Meat /Bone Meal	**50**	**8.00**	**4.70**	**0.588**

U.S. discharge standards do not at present dictate low phosphorus standards. Coincidentally, many recirculating systems in turn discharge 1% or less of the rearing capacity on a daily basis. However, discharge standards of that small amount of water that is discharged will increasingly come under more restrictive regulations. Additionally, the Aquaculture produced fish can and have commanded increased values in the open market, due in part to the clean and wholesome image espoused by some marketing efforts.

Vitamin Requirements And Stability

Vitamin requirements for Tilapia have been determined for only vitamin C, Stickeny et al. 1984, Soliman et al. 1986; vitamin E, Satoh et al. 1987; Riboflavin and Pantothenic acid, N.R.C. 1993. Eventhough the complete vitamin requirements for Tilapia not been established, high density rearing conditions, make it necessary for the commercial feed manufacturer to provide a complete vitamin package. The commercial feed manufacturer in addition must provide a guarantee for 3 months after production of stated tag claims.

Extrusion manufacture increases digestibility of fish feeds over peleted feeds. At the same time vitamin stability during ingredient mixing, grinding and extrusion is a major challenge for the commercial feed manufacturer. The relative stability varies with the vitamin Coelho, 1991.

	Very High	**High**	**Moderate**	**Low**	**Very Low**
Vitamin:	Choline Chloride	Riboflavin	Thiamin Mononitrate	Thiamin HCl	Menadione
		Niacin	Folic Acid		Ascorbic Acid
	Ascorbic Polyphosphate	Pantothenic Acid	Pyridoxine		
	Sulfate				
	Monophosphate	Vit. E	Vit. D3		
		Biotin	Vit. A		
		B 12			

Recent advances in the stabilization of vitamin C made by Hoffman LaRoche, Pfizer and BASF, have resulted in chemically stabilized forms, Ascorbic 2-Polyphosphate, Ascorbic 2-Sulfate and Ascorbic 2-Monophosphate. These chemically stabilized forms of vitamin C are highly stable during extrusion manufacture. Earlier efforts to stabilize vitamin C using lipid encapsulation did not result in a products able to with stand the temperatures and moisture levels of extrusion manufacture. Commercial manufacture of aquafeeds seldom if at all uses an unstabilized form of vitamin C.

Vitamins are generally supplemented in excess of requirements to allow for losses during manufacture, shipping and storage prior to feeding. While new forms of vitamin C have greatly improved the cost effectiveness of vitamin C fortification, over formulation of other vitamins for extruded aquafeeds is still commonly practiced today.

Vitamin Addition Before Extrusion

Vitamin	**Percent Overage**
A - Acetate	**150**
D 3 – Cholecalciferol	**130**
E	**110**
Thiamin	**250**
B 12	**130**
Biotin	**110**
Folic Acid	**110**
Riboflavin	**110**
Niacin & Choline	**110**

Hurdle Strategy Of Feed Manufacture

After a feed is made the interaction between cationic minerals, vitamins and unsaturated fatty acids is seemingly in a race toward oxidation The wholesomeness of a finished feed is often dictated by how well it is stabilized. A well made feed contains several additives and ingredients that serve as hurdles to slow the oxidation of essential nutrients in a finished feed. Traditional feed formulation may include one or two of these feed protectants but the production of compete feeds should incorporate a more complete approach.

Hurdle Strategy For Wholesome Feed Manufacture

- BHA, BHT in Fish Meal and Oil
- Ingredient Arrival Testing
- Vitamin E Supplementation
- Stabilized Vitamin C Supplementation
- Extrusion Pasteurization
- Mold Inhibitors
- Feed Quality Assurance Testing

Practical Feed Formulation

Practical formulations commonly use no more than six to eight feedstuffs. The nutrient data matrix is utilized to meet minimum and maximum restrictions. The minimum and maximum restrictions along with the nutrient data base and ingredient costs are used in linear programs to optimumize the mixture of ingredients that best meet the nutrients considered.

The level of dietary energy is adjusted to provide the optimum protein: energy ration for the size of Tilapia being fed. The amino acid profile of the protein is balanced for essential amino acids. In this example Methionine is the first limiting essential amino acid. Even though the Methionine level in the commercial feed profile does not meet the standard reference level of 0.85 % of the diet, the sulfhydro amino acid requirement is met with a combination of cystine and Methionine levels. Based on the ingredient amino acid profiles, once the minimum levels lysine, methionine and threonine are met the rest of the amino acids will be available in excess.

Whether a feed completely floats, sinks, or partially sinks is dictated by the level of starch in the formula as well as the degree of striation of the starches. The float as well as the degree of pellet durability can be adjusted by the selection of feed stuffs. The amount of water and oil added internally to the feed can either enhance or inhibit the striation of starches.

Least Cost Formulation Restrictions for Tilapia Feed

Nutrient	**Restriction** **Minimum**	**(Percent)** **Maximum**
Protein	**32.5**	
Fat	**4**	**6**
D.E. (Kcal / Kg)		
Fiber		**4**
Lysine	**1.95**	
Methionine	**0.77**	
Met. & Cystine	**1.10**	
Threonine	**1.05**	
Arginine	**1.90**	
Starch	**22.5**	
Ash		**7.25**
Available Phosphorus	**0.6**	**0.9**
Calcium	**0.7**	
Phos. / Ratio		**0.17**

Nutrient Composition Of Typical Tilapia Feeds

	Nutrient Composition of Typical Tilapia Feeds			
Fish Weight **Nutrient**	**< 2.0 Gms.**	**2 to 10 Gms.**	**10 to 50 Gms.**	**50 to 545 Gms.**
D.E. - Min.	**4.0 Kcal / g**	**3.8 Kcal / g**	**3.5 Kcal / g**	**2.9 Kcal / g**
Protein - Min.	**48**	**45**	**40**	**36 or 32**
Lipid - Min.	**10**	**10**	**10**	**10 to 5**
Fiber - Max.	**4**	**4**	**5**	**5**
Ash - Max.	**7**	**7**	**9**	**9**
Starch - Min.	**12**	**14**	**20**	**24**
Ca. - Max	**1**	**1**	**1**	**1.5**
Avail. P04 - Min.	**0.6**	**0.6**	**0.6**	**0.6**
Lysine - Min.	**2**	**2**	**1.9**	**1.7**
Methionine - Min.	**0.9**	**0.85**	**0.85**	**0.7**
Threonine - Min.	**1.2**	**1.2**	**1.2**	**1**

Next Steps

There is a continual need to provide more efficient, cost effective diets for Tilapia reared in recirculating systems. New ingredients and strategies to enhance nutritional value of finished feeds need to be continually evaluated. The ultimate goal of this process is to expand the range of cost effective raw ingredients. In the immediate future maximizing quality by furthering the understanding of the interaction among supplemental enzymes and the major dietary ingredients.

Acknowledgments

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