FEASIBILITY ASSESSMENT OF FRESHWATER ARCTIC CHAR & RAINBOW TROUT GROW-OUT IN NEW BRUNSWICK

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EXECUTIVE SUMMARY

Freshwater aquaculture is a highly productive and sustainable use of the aquatic resources with considerable potential for growth throughout all regions of Canada. Many rural communities across the country have the bio-physical resources and socio-economic interests to participate in freshwater aquaculture development. Considering Canada's freshwater resource base and other strategic advantages, the current level of output is not commensurate with the opportunity and potential that exists.

Approximately 8,400 tonnes of freshwater fishes are farm-raised in Canada with an annual farm-gate value of ~$44 million. Salmonid species account for more than 91% of this production tonnage and 89% of the sector value. Ontario (46.8%), Quebec (17.5%) and Saskatchewan (14.6%) are the dominant producers of farmed freshwater fish in Canada. In spite of its leading status in marine aquaculture, New Brunswick, which produces approximately 50 tonnes of trout annually, is a minor player in the freshwater aquaculture sector.

In the November 25, 2008, Speech from the Throne, the government of New Brunswick noted that "*Freshwater finfish are very successful species in other provinces – New Brunswick should emulate this potential by providing adequate funding programs and infrastructure*." In response, the New Brunswick Department of Agriculture & Aquaculture (NB-DAA) has solicited proposals to conduct a Feasibility Assessment of Freshwater Arctic Char and Rainbow Trout Grow-Out in New Brunswick.

The general purpose of this project was to provide an updated assessment on the potential for raising Arctic Char (*Salvelinus alpinus*) and Rainbow Trout (*Oncorhynchus mykiss*) in freshwater land-based facilities at a commercial scale in New Brunswick.

The study was based on primary research (interviews with researchers, producers and regulatory authorities) and secondary research (literature search, accessing previously published reports, etc) and describes a business model based on current technology available with the following specific objectives targeted:

- An overview of freshwater salmonid aquaculture identifying trends, challenges, opportunities and future outlook.

- An assessment of the available production technologies and systems and a description of a conceptual facility design for the effective and efficient production of freshwater salmonid fishes in New Brunswick.

- An evaluation of the scale and economic viability of the conceptual design.

1.0 INTRODUCTION AND BACKGROUND

Globally, European nations are the major producers of trout and char in freshwater systems; particularly France, Italy, Turkey, Spain and Denmark. Combined, these five countries produce more than 170,000 tonnes of trout per year in freshwater systems. Canada ranks a distant 13th in total trout and char output, behind countries such as Columbia, Iran and Japan (Figure 1)[1,2].

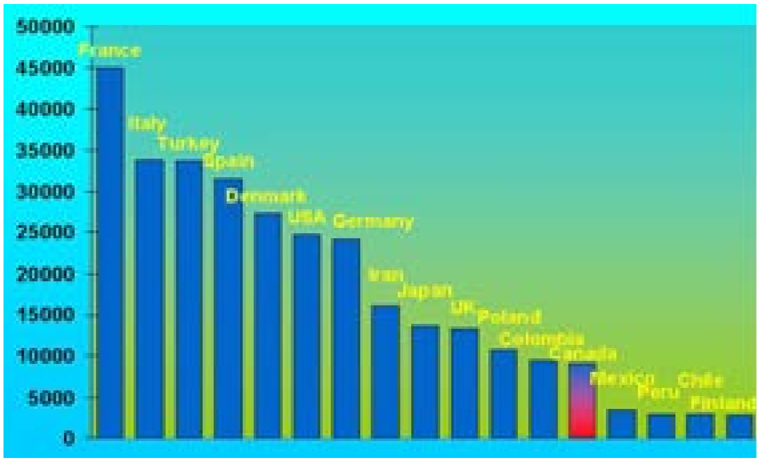

Figure 1: Trout and Char production by Country[2]

The number and output of freshwater aquaculture operations in Canada is approximately 8,300 tonnes with a farm-gate value of $44 million (2006). Salmonid species account for more than 91% of the production tonnage and 89% of the sector value. Ontario (46.8%), Quebec (17.5%) and Saskatchewan (14.6%) are the dominant producers of farmed freshwater fish in Canada. It is estimated that more than 1,000 jobs are created by freshwater aquaculture throughout Canada[3].

In spite of its leading status in marine aquaculture, New Brunswick is a relatively minor player in freshwater aquaculture. Moreover, New Brunswick's output is not commensurate with the inherent potential of the province, given the competitive advantage presented by a plentiful resource base, proximity to the U.S. market which is increasingly dependent on imported seafood, and existing aquaculture (marine) infrastructure. Growth of a sustainable industry that generates employment and prosperity throughout rural New Brunswick is constrained by the absence of a strategic vision for the sector. As a direct result, freshwater aquaculture ventures are losing domestic and international market share; principally to suppliers in South America (Chile, Argentina). Successful and sustainable freshwater aquaculture development in New Brunswick is dependent upon development and implementation of a strategic approach to generate the knowledge, technologies and practices necessary to resolve these challenges.

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[1] Vandenberg, Grant, W., Stechey, Daniel, Gilbert, Eric (2007). An innovative approach to sustainable freshwater aquaculture development in Canada: The Inter-Provincial Partnership. Aquaculture Canada 2007. Aquaculture Canada 2007 - Proceedings of Contributed Papers, AAC Special Publ. No. 13 (in press).

[2] Gilbert, E. (2004). Freshwater Aquaculture in Canada: Status, Potential and Developmental Challenges. Proceedings of the Canadian Freshwater Aquaculture Symposium, Quebec City, QC. AAC Special Publ. No. 11-14:20.

[3] Stechey, D, Albright, L, Foss, D, Gilbert, E, Lareau, S, Maheu, J, McNaughton, M, Meeker, M, Robertson, W.D. (2007). Status and Outlook for Freshwater Aquaculture in Canada: Regional Perspectives. Aquaculture Canada 2007 - Proceedings of Contributed Papers, AAC Special Publ. No. 13 (in press).

Freshwater aquaculture is a highly productive and sustainable use of aquatic resources with considerable potential for growth throughout all regions of Canada. Many rural communities across the country have the bio-physical resources and socio-economic interests to participate in freshwater aquaculture development[2]. Considering Canada's freshwater resource base and other strategic advantages, the current level of output is not commensurate with the opportunity and potential that exists. Furthermore, Canada's freshwater aquaculture sector is well-positioned to benefit from the following competitive advantages:

- Plentiful resource base (i.e. water supplies, etc.);
- Industry experience, expertise and desire to support sustainable development;
- Substantial export potential with proximity to the U.S. market which is increasingly dependent on imported seafood;
- Increasing global demand for fish and seafood due to population growth, increased affluence and the recognized health benefits of the products; and
- A considerable potential and need for agricultural diversification and latent infrastructure to support development.

Throughout Canada, however, the freshwater aquaculture sector is not capitalizing on these inherent advantages and opportunities. In fact, growth in the sector has been forestalled for several years, largely encumbered by the difficulty to attract investment, stagnant farm-gate pricing, and challenges to product development and industry clustering due to the small scale and geographic dispersion of producers[4].

At the same time, political leaders at all levels are increasingly challenged to resolve the developmental and economic problems within Canada's agricultural sector. Diversification of agricultural enterprises has been identified as a means to stabilize agricultural income and bring increased prosperity to family farms. Canada has considerable under-developed potential for rural economic development in the form of experienced farmers with a desire and willingness to engage in new ventures, a rural infrastructure and labour pool, as well as biophysical, economic and market assets to exploit. Aquaculture is one potential means to fulfil this potential[5]; particularly land-based production of freshwater salmonid species.

In the November 25, 2008, Speech from the Throne, the government of New Brunswick noted that "*The aquaculture industry is an excellent example of government and industry working together to foster sustainable economic development*." The government also recognized that "*Freshwater finfish are very successful species in other provinces – New Brunswick should emulate this potential by providing adequate funding programs and infrastructure*."[6] In response, the New Brunswick Department of Agriculture & Aquaculture (NB-DAA) has commissioned this study to conduct a Feasibility Assessment of Freshwater Arctic Char and Rainbow Trout Grow-Out in New Brunswick.

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[4] Nabi, R. (2008). Canadian Trout Industry: Competitive Advantage and Strategic Options. Aquaculture Canada 2008 - Proceedings of Contributed Papers. AAC Special Publ. No. 14-49:51.

[5] Stechey , D. and E. Gilbert (2004). Aquaculture as an Agricultural Diversification Strategy. Proceedings of the Canadian Freshwater Aquaculture Symposium, Quebec City, QC. AAC Special Publ. No. 11-159-168.

[6] AMEC Earth & Environmental (2009). New Brunswick Aquaculture Summit - Final Report. TE91030. 16 p. + Appendices.

2.0 PURPOSE & OBJECTIVES

Purpose

The general purpose of the project was to provide an updated assessment on the potential for raising Arctic Char (*Salvelinus alpinus*) and Rainbow Trout (*Oncorhynchus mykiss*) in freshwater land-based facilities at a commercial scale in New Brunswick. The study also focussed on establishing a business model based on current best technology that is available. The information provided is intended to serve as the background for developing a strategic direction and policy to enhance the growth and competitiveness of the freshwater aquaculture sector in New Brunswick[7].

Objectives

The intent of this study is to summarize the biological, marketing, technological and financial parameters pertinent to development of a viable freshwater rainbow trout (*O. mykiss*), arctic char (*S. alpinus*) and hybrid char (*S. alpinus* x *S. fontinalis*)[8] aquaculture sector in New Brunswick.

Using a combination of primary research (interviews with researchers, producers and regulatory authorities) and secondary research (literature search, accessing previously published reports, etc), this project addresses the following specific objectives:

- To provide an overview of freshwater salmonid aquaculture with emphasis on Canada, and identifying trends, challenges, opportunities and future outlook.
- An assessment of the available production technologies and systems and a description of a conceptual facility design for the effective and efficient production of freshwater salmonid fishes in New Brunswick.
- An evaluation of the scale and economic viability of the conceptual design.

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[7] NB Dept Agriculture & Aquaculture, Tender No. 7060005. Request for Proposal for Feasibility Assessment of Freshwater Arctic Char and Rainbow Trout Grow-Out in New Brunswick. 17 p.

[8] Based on practical experience in Québec, Denmark and Germany where hybrid charr have been raised successfully, we elected to include hybrids as part of this study.

3.0 MARKET & INDUSTRY OUTLOOK[9]

Objective: *To present an overview of the current status of freshwater salmonid aquaculture to markets, identifying trends, challenges, and future outlook.*

3.1 Global Situation & Outlook

Total harvests from once-abundant global fisheries have continued to decline while the overall demand for fish and seafood products from an expanding and more affluent international marketplace has been growing. Looking into the foreseeable future, these trends in the global fish and seafood sector are expected to continue and the role of aquaculture as a leading supplier of fish and seafood will increase substantially.

Total global fish and shellfish supply rose in 2005 with aquaculture production up (+2.3 million tonnes) and wild fisheries harvests down (-1.1 million tonnes). According to the Food and Agriculture Organization of the United Nations (FAO), global aquaculture output has grown to almost 52 million tonnes in 2006, which translated into a growth rate in excess of 9% per annum. Aquaculture output is now expected to surpass global beef production by the end of 2010. Aquaculture is the fastest growing food sector on the planet and currently provides 45 percent of the global supply of fish and seafood for human consumption. Over the course of a few decades, the sector has evolved from a small-scale, artisanal activity into a large-scale science and technology based sector due to innovation and ingenuity in feeds and feeding, systems design, husbandry and management (Halweil 2008).

In its 2002 review of global aquaculture practices, the FAO noted that "*development has been of the win-win type, as both producers and consumers have gained when prices for cultured species have fallen as a result of increased production.*" The FAO also concluded that "*public management of aquaculture is not dissimilar to public management of agriculture and, in developed economies, management and enforcement costs as a share of the value of the produce are lower for aquaculture than for capture fisheries*." Not surprisingly, the FAO predicts that "*public policy support for aquaculture is likely to grow worldwide*" as nations, communities and individuals increasingly pursue business opportunities in aquaculture. As a result, the world over, governments are evaluating policy and regulatory approaches respecting aquaculture to identify prudent mechanisms that will enable this sector to grow and prosper.

3.1.1 Consumer Perceptions

In the developed world, a variety of factors influence consumer perceptions and consumption of food (including fish and seafood), including:

- **safety**: information pertaining to food safety is important to many consumers and quality assurances are increasingly expected;

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[9] This section of the report is comprised largely of previously published information and other materials sourced from the literature, trade publications, government reports and commissioned studies, the internet, etc. In many cases, portions of previously published material have been reproduced herein, however, each case has not been specifically cited. A list of articles and reports used as reference material for this report appears at the end of the document.

- **science**: adherence to standards in food production and processing has become more important while new technologies are stirring debate and concern (e.g. bioethics, genetically modified organisms, environmental sustainability);
- **communications**: non-governmental organizations (NGOs) are better organized and more influential, ranging from legitimate consumer groups, single-topic groups and environmental groups to groups whose activities classify them as 'eco-terrorists';
- **media**: the digital age has given the media new powers of influence which have, at times, prompted food scares while the internet enables faster and wider dissemination of 'news'; and
- **Marketing**: marketing efforts are fundamental to influencing consumer behaviour and generating demand.

The safety and wholesomeness of seafood has been the target of media attention for several years, particularly in North America. In 1992, Consumer Reports magazine published an article entitled "*Is Our Fish Fit to Eat?*" A subsequent article, entitled "*America's Fish: Fair or Foul?*" was published in 2001. In response to the 1992 article, the Alaska Seafood Marketing Institute sought professional advice to counter this negative publicity. In view of the fact that "consumers have short memories when it comes to negative publicity regarding seafood safety," the Marketing Institute was counselled to invest into promotion of their products, not into counter-campaigns.

For several years, organized communications campaigns have targeted the environmental impact and safety of farmed salmon. In spite of the well-funded and well-organized "*Farmed and Dangerous*" campaign, farmed salmon consumption continues to expand, with notable exceptions in specific markets (e.g. Greater Vancouver). Consumers appear to be influenced more by the quality, convenience and value that the product offers. Nevertheless, increasingly seafood production must be recognized as being sustainable.

3.1.2 Emerging Regulatory & Non-Regulatory Measures

Demand for fish and seafood in domestic and international markets is driven largely by consumer perception of product quality, food safety and value. Assurances of environmentally sustainable production, socially acceptable resource use, adherence to stringent food safety protocols, and farm-to-market traceability for all products are increasingly sought by consumers and seafood buyers looking for independent verification of attributes beyond what would be certified by governments (DFO 2010). Moreover, driven largely by the persistent efforts of environmental groups which continue to pressure major seafood retailers to use only certified sources of supply, a number of international certification standards have emerged. To date, a clear leader has yet to be established amongst the leading initiatives (e.g. World Wildlife Fund, Global Gap, ISO, United Nations Food and Agriculture Aquaculture Certification Guidelines, etc.). Nevertheless, most initiatives have targeted the same issues; namely: farm-to-market product traceability, quality control, environmental sustainability, social sustainability, ethical production, etc. It is important to recognize that these programs are being driven by third parties and do not offer increased margins for producers; however, they will add cost. They are widely recognized as being essential to secure continued market access.

3.1.3 Profitability, Competitiveness & Investment

Profitability is a primary objective of this sector as it is for all farming sectors. In the absence of profit, a venture cannot provide sustainable economic returns to the country or provide a stable base of employment for its citizens. Profitability is also important to a firm's ability to access new markets, new species and/or new products, all of which require a significant financial investment. Poor profitability creates structural weakness and instability in any sector.

Sufficient operating profits must be generated to cover not only loan payments and a return to shareholders (or income for owner-operators) but to also enable sufficient re-investment into the venture for equipment upgrades, new technologies, product innovation, marketing and market development, and other strategic business investments to improve competitiveness. In the long run reduced profits further weaken competitiveness, which in turn leads to a further erosion of profitability.

When asked what factors affect competitiveness, the general response from existing producers is "anything that reduces costs." Value-addition is a means to enhance competitiveness through differentiation and is any factor that adds value in the mind of the buyer, such as just-in-time delivery, the supply fresh product year-'round, portion control, better packaging, etc.

Investment is essential to drive industry growth, development, diversification and sustainability. Industries that are profitable (or which show potential to generate substantial profits) can readily attract investment. Investment, however, does not flow to industries or sectors that are deemed marginally profitable, that have cumbersome regulatory and/or management environments or that have inherent instability or uncertainty. The inability to secure investment within a sector will inevitably lead to consolidation - the larger players will get larger and smaller players will be forced out of business. Yet, small business is the backbone of the economy.

3.1.4 Socio-Economic and Environmental Sustainability

It is understood that the social acceptance of production and processing operations must be consistent with the broadly held social and environmental values that are shared by all stakeholders. Due to the over-exploitation and collapse of many fisheries and the global controversy surrounding the impacts of some forms of aquaculture, environmental sustainability has become an essential requirement for success in the sector. Today, environmental groups (ENGOs) are successfully encouraging consumers to purchase seafood from only those sources that are recognized to be sustainable. This has a spill-over effect on seafood buyers who are increasingly demanding proof of environmental sustainability from their suppliers.

Environmental sustainability can and should become a differentiating benefit for aquaculture producers, who have the capacity to manage all aspects of their operations. The key challenge is establishing clear environmental standards and sustainability practices. Implementation of Codes of Practice, adherence to which is rewarded, is being increasingly adopted to uphold and demonstrate environmental sustainability in the aquaculture sector.

3.2 United States (US) Situation & Outlook

3.2.1 Market Overview

The US seafood market is one of the largest in the world due to the population base (350 million) and their respective purchasing power. Domestic supplies of seafood, however, are not sufficient to meet the demand. In 2006, US commercial landings of seafood and aquaculture production (primarily farmed catfish) actually decreased to 3.54 million tonnes. Seafood consumption, however, continued to increase, with imports filling the gap in supply. Total imports in 2006 were valued at US $13.4 billion. In 2007, the US trade deficit for fish and seafood was in excess of US $9.2 billion.

Imports now account for 81 percent of the seafood consumed in the United States (this calculation is on a round weight basis and adds U.S. landings and aquaculture production plus imports minus exports). With limited opportunity for expansion of capture fisheries and minimal growth potential in aquaculture, as well as growing exports of U.S.-produced seafood, the United States will continue to be reliant on imports to meet future seafood demand.

3.2.2 Consumer Behaviour

Over the past decade, US per capita consumption of fish and seafood has ranged between 7.26 and 7.48 kg. Fish and seafood consumption has increased by more than 1.8 kg per person since 1980, and evidence suggests that consumption will continue to grow at a modest pace for a number of reasons. The relative price of seafood compared to other proteins (e.g. poultry, beef, pork, etc.) remains as a significant barrier to increased sales. Additionally, the lack of an industry wide generic campaign to promote the benefits of seafood and educate consumers on how to enjoy it is also a factor.

Increasingly, U.S. seafood consumers are seeking high-quality, value-added products that are pre-cooked (shrimp) or skinless/boneless fillets (salmon, catfish, tilapia); quality products that offer value and are easy to prepare. The fear of failure associated with home preparation of fish and seafood is a major deterrent to increased household penetration. Therefore, low cost, convenience (ease of preparation) and consistency are fundamental drivers of sales in the U.S. Products such as boneless fillets and heat-and-serve items have gained considerable market share.

3.2.3 Nutritional Marketing

For more than a decade, North American consumers have been informed of the health benefits of good nutrition and “low-fat” diets have been encouraged. Today, however, obesity continues to be a major health risk. Furthermore, it appears that consumers are not necessarily making “healthy” food choices and, therefore, the “health” message may not be selling more fish.

3.2.4 Eco-Friendly Marketing

In recent years, environmental groups have been advocating that consumers purchase only sustainable or “eco-friendly” seafood. “*Dolphin-safe tuna*” and “*farmed and dangerous*” salmon campaigns are prime examples. Consumer research has indicated that only 1 in 3 consumers are aware of “eco-labelling” and say that it influences their purchase decisions.

3.2.5 Market Trends

The consumer market for fish and seafood can be segmented into three distinct outlets:

- Foodservice: The foodservice industry consists largely of hotels, restaurants and institutions (hence it is often referred to as the HRI market). The restaurant trade is the main user of fish within the foodservice industry where fish is commonly an entrée item; however it is increasingly being used in appetizer and salad dishes in combination with less costly produce. Standardized quality and flavour requirements are foremost for this market.

- Retail: This category represents all outlets from large grocery chains to specialty fish shops that sell directly to consumers.

- Club Stores (e.g. Costco, Sam's Club): Club stores carry fewer products with higher volume requirements. While the foodservice and retail sectors purchase their seafood supplies from brokers and wholesalers, club stores often go directly to the source to purchase seafood. It is anticipated that seafood will play a more important role in the future of club stores.

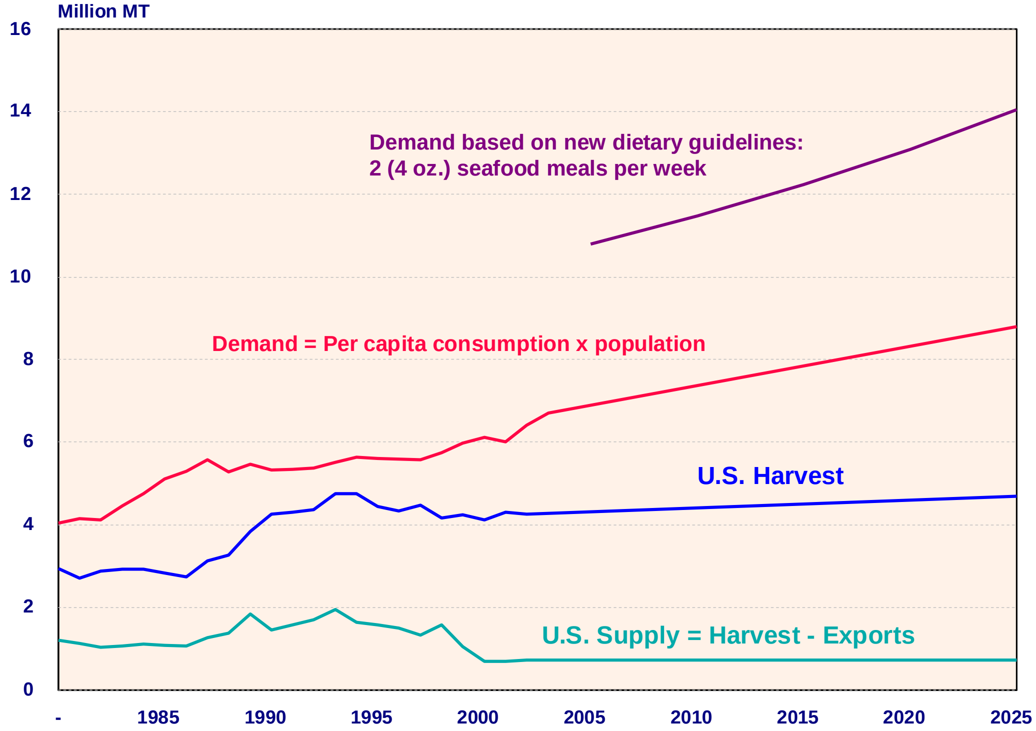
On a volume basis, seafood sales in the U.S. market are almost evenly split between retail and foodservice. However, on a marketed value basis, foodservice accounts for about two-thirds of U.S. seafood sales. The mark-up at foodservice is generally higher than at retail. Dual-income families, women in the workforce, higher household incomes and the frenetic pace of life continue to drive Americans to eat out.

During downturns in the U.S. economy, sales at many white tablecloth restaurants decline considerably. Since this segment serves a relatively high percentage of seafood, economic downturns can have a negative impact on the sale of more expensive seafood products. In contrast, seafood sales in the mid-scale dining operations can remain relatively strong as U.S. consumers opt for a moderate dining-out experience.

The most significant trend in retail sales of seafood in the U.S. has been the entrance of discount chains to the sector – e.g. Costco, Sam's Club and Wal-Mart's Supercenters. Wal-Mart is able to operate at much lower food margins than traditional supermarkets, which has put pressure on large supermarket chains to increase efficiencies. As a result, some large supermarkets have removed full service seafood counters. The variety of seafood sold at supermarket counters has also been reduced.

Demographic research also shows that people between 50 and 60 years old are the major purchasers of seafood. Given that the baby-boom was from 1947 to 1966, this points to increasing seafood consumption for at least the next 16 years. Due to population growth, the volume of seafood consumed in the United States continues to increase.(Figure 2).

Figure 2: US Seafood Supply and Demand – Past and Projected (round weight)



Source: NOAA National Marine Fisheries Service

3.2.6 US Trout Production

U.S. trout production has moved within a relatively narrow range over the past 15 years. Although trout is farmed commercially in more than a dozen states, sixty to seventy percent of total U.S. trout production comes from the state of Idaho, which enjoys a large natural advantage because of the Snake River aquifer, which produces a constant supply of fresh water at a year round temperature of 58ºF (14ºC). Most of the state's trout producers grow trout in raceways clustered along a 50-kilometer stretch of the Snake River known as "Magic Valley." A very small number of high-volume producers dominate the farmed trout industry.

In 2008, U.S. trout farmers sold just under 24,000 metric tonnes (live weight basis) of fish for human consumption with an average weight of 1.16 pounds (526 grams). The majority of this production was sold to processors. The state of Idaho accounted for almost three-quarters of all trout produced in the US. The Idaho industry continues to market un-pigmented fish in a different form (butterfly fillet) and smaller size than most Canadian producers.

Clear Springs Foods, a fully integrated operation with its own hatchery, production raceways, feed mill and processing plant, has at least a 60 percent share of the U.S. trout market. Approximately 70 percent of Clear Springs' sales are fresh. The company's product mix has changed over the years from head-off bone-in (boned) trout to boneless fillets, which the company sells under its trademarked Clear Cuts™ brand. According to the company president, more than half of the company sales are now boneless fillets. "There's not much market left for boned product," he says. "A few foodservice accounts still buy head-on boned trout, but it's dwindling away. That product form has served its life cycle. Boneless fillets are the gold standard."

The majority of Clear Springs sales are to the foodservice sector of the U.S. seafood market. The company grows trout to an average size of 22 ounces (624 grams). This size yields fillets that average 5-7 ounces (140-200 grams), an ideal size for foodservice operators, who require strict control over portion sizes.

Clear Springs estimates its cost of production on a round weight basis has jumped from about US $.60/lb. where it remained for many years, to about US $.80/lb. The company says that feed accounts for two thirds of its cost of production. Because of its large size and economies of scale, Clear Springs is confident it has the lowest cost of production in the North American trout industry.

Over the years, the trout industry in Idaho has consolidated considerably. In addition to Clear Springs, there are only two other trout processors of significant size: Idaho Trout Processors and Blue Lakes, both of whom sell some of their round fish to Clear Springs.

Besides Idaho, the two primary trout producing states are North Carolina and Pennsylvania. Farmers in these states use naturally flowing spring, pond or lake water which cascades through either small earthen ponds or raceways. As is the case in Idaho, the raceways and ponds use gravity to keep water constantly flowing.

While large Idaho trout farms produce millions of kilograms each year, trout farms outside Idaho typically grow less than 90,000 kilograms per year. Almost all of these farms are small, family-owned operations that provide modest incomes for their owners.

Unlike Clear Springs, many of the smaller trout farms outside Idaho use carotenoid pigments to produce red-coloured flesh. They sell their product to local markets and most of the farms that do produce fillets, fillet by hand because they lack the capital to invest in automated equipment. Their lack of size also prevents them from going after any large, national accounts, so almost all their production is sold regionally.

3.2.7 US Trout Production – Future Outlook

It is unlikely the U.S. trout production will increase substantially in the foreseeable future. Water availability is becoming a major issue within the United States with inter-state battles for water rights and farmers fighting with manufacturers for access to the same resource.

On the Snake River, where Idaho trout producers are located, for the past five years the trout industry has been involved in "heavy litigation" with land farmers who pump groundwater from the Snake River aquifer. The trout industry has had the upper hand in these negotiations as it has senior water rights. Even so, the aquifer is constantly being drawn down and spring flows have declined. According to Clear Springs, the industry's largest producer, a number of productivity improvements have enabled farms to compensate by using less water to grow the same amount of fish. Nevertheless, the company doubts it will be able to increase production more than 5 percent at best. Outside of Idaho, no other area of the United States has the water resources available to develop large-scale trout production.

3.3 Canadian Situation & Outlook

The Canadian seafood industry produces far more fish and seafood than its citizens can consume. The sector, therefore, is largely export-oriented. Over the past decade, there has been virtually no growth in total Canadian fish and seafood landings. Nevertheless, the value of total Canadian fish and seafood exports over the past ten years has increased from C$2.6 billion to C$3.6 billion registering a 3.4% average annual growth rate reflecting the increase in global fish and seafood prices.

Seafood consumption trends in Canada closely resemble those of the U.S. although per capita consumption in Canada is significantly higher. Canadians consume ~30% more seafood than Americans on a per capita basis. Canadian per capita fish and seafood consumption during 2007 increased fractionally (0.9%) to 9.47 kg from 9.39 kg a year earlier. Most of the increase was due to higher consumption of fresh and frozen finfish. (Figure 3).

Figure 3: Seafood consumption trends in Canada

Year	Seafish fresh & frozen	Seafish processed	Shellfish	Freshwater fish	Total all products
1998	4.03	2.38	2.11	0.32	8.84
1999	4.82	2.50	2.29	0.42	10.03
2000	4.51	2.19	2.35	0.46	9.51
2001	4.39	2.67	2.12	0.47	9.65
2002	4.01	2.96	2.17	0.43	9.55
2003	4.43	2.81	2.03	0.53	9.80
2004	3.94	2.74	1.93	0.51	9.12
2005	4.04	2.90	1.90	0.47	9.31
2006	4.16	2.89	1.84	0.50	9.39
2007	4.35	2.90	1.67	0.55	9.47

3.3.1 Canadian Consumer Trends

Consolidation within the grocery retail chains is leading to increased competition for the consumer's retail food dollars and lower prices. Mass merchandising of foods (including fresh and frozen fish and seafood) in club warehouse channels such as Costco, Sam's Club and Wal-Mart is increasing.

A strong visible minority population with South Asian and Chinese people's comprising ~48% of ethnic minorities has influenced food consumption trends via different, unique restaurant offerings. A similar influence is occurring at the retail level with regard to new product offerings.

Canadian consumers are aging and have increasingly more purchasing power. As a result, there is greater demand for fish and seafood as well as for innovative food items that appeal to the needs for convenience, health and status. Portability and convenience factors are playing an increasing role in consumer satisfaction of seafood. The majority of fish and seafood purchases (64%) are made at the foodservice level (i.e. restaurants). Comparatively, 28% of seafood is purchased at retail grocery stores and 8% is purchased from specialty stores and open markets.

3.3.2 Ontario Aquaculture Sector

Commercial production of fish for human consumption in Ontario was first permitted in 1962, following a long provincial history of fish production for public and private stocking purposes. Today, Ontario is largest producer of Rainbow trout and Arctic char in Canada. Rearing facilities encompass both open water (cage culture) and land based production.

In 2004, 149 operations produced fish in Ontario. These consisted of 104 land-based commercial ventures, 10 commercial cage culture ventures and 35 non-commercial operations (e.g. angling associations, rod and gun clubs, private pond stocking ventures). Since the previous inventory of fish farms was conducted, a number of ventures had terminated operations. The most common reasons provided for discontinuing operations included (i) high costs, particularly for electricity to pump water, (ii) on-going regulatory requirements and constraints, and (iii) retirement.

In total, 19 freshwater species are being reared in Ontario with production of salmonid species (particularly rainbow trout) accounting for ~92% of total output. In 2005, Ontario farms reportedly produced 4,075 tonnes of rainbow trout primarily for human consumption. Approximately 75% of total trout production is from cage culture operations in Lake Huron.

Most land based aquaculture operations are located in Central or Southern Ontario. A number of factors have resulted in the clustering of aquacultural operations in this part of the province including the availability of high quality water (ground and surface water supplies), suitable climate conditions, proximity to a large population/market base, and a well developed infrastructure for goods and services. The cage culture industry is mainly located in northern Lake Huron (with most operations centered in the North Channel area near Manitoulin Island and one operation near Parry Sound) while land based aquaculture operations are primarily located in Southern Ontario.

The scale of land-based ventures varies considerably from small hobby farms to large food fish producers (Figure 4). Cage culture ventures located in Georgian Bay, however, are of a much greater scale. In fact, the smallest cage culture venture is larger than the largest land-based operation.

Figure 4: Scale of commercial fish farms in Ontario

Statistic	Cage Culture (kg/yr)	Land-Based (kg/yr)
Average	417,369	18,034
Median	396,900	5,330
Minimum	175,090	136
Maximum	1,000,188	158,760

The total farm gate value associated with land-based and cage aquaculture production in 2005 was approximately $18 million. Rainbow trout production accounted for $15.5 million or 86% of the total farm gate values while the sales of Arctic char, bass and other fish species was estimated at about $1 million. Production associated with pond stocking facilities was conservatively estimated at an additional $1.5 million.

Ontario cage culture operators produced a total of 3,275 tonnes of rainbow trout in 2005 which had a total farm gate value of $12.5 million. The total employment associated with this production activity amounted to 50 full-time equivalent jobs. With respect to the indirect impacts, cage culture industry linkages with local and regional suppliers of goods and services generate significant economic benefits across a range of industry sectors including manufacturing, retail and wholesale trade, construction, transportation, and business services. It is estimated that these businesses generate $38.2 million in cage culture related sales and provide 179 full-time equivalent jobs. Collectively, cage culture operators and the businesses they deal with generate a total of almost $51 million in sales and support 229 full-time jobs. This includes a substantial number of jobs in the value added sector with two major processing facilities located in Ontario.

The economic multipliers associated with the Ontario cage culture industry are substantial. With an employment multiplier of 4.5, every job in cage culture production sustains an additional 3.5 jobs in the wider economy. The expenditure multiplier is 4.0, indicating that every dollar in farm gate sales generates an additional 3 dollars in the wider economy.

3.4 The Market for Rainbow Trout

3.4.1 Canadian Trout Markets

Virtually all rainbow trout marketed in North America are farm-raised. A cursory review of Canadian data for trout imports, exports and domestic production suggests that the Canadian market consumes approximately 9,236 tonnes (live weight) of rainbow trout annually. According to Statistics Canada, approximate production and trade quantities in 2008 were as follows.

Domestic Production	8,400 tonnes
Imports	1,975 tonnes
Exports	(1,139 tonnes)
Net Canadian Consumption	9,236 tonnes

Québec (39%) and Ontario (23%) represent the principal Canadian markets for trout while the remaining eight provinces and the three territories consume the balance (38%). With a population of approximately 33 million, however, Canadian per capita consumption of trout is only 280 grams – the equivalent of only one to two fillets per person per year.

Market growth can be attributed to increased emphasis on retail seafood counters, the emergence of Costco as a major retailer of fresh and frozen fish and the somewhat "hidden" volume of fish moved within the Hotel, Restaurant and Institutions sector. The market is price competitive and well-serviced by Ontario processors.

Montreal and the Metropolitan Toronto Region are the principal Canadian markets for trout. Trout consumption in Montreal is estimated to equal 8,000 - 9,000 kilograms (18-20,000 lbs) per week. The Metropolitan Toronto Region market for trout is estimated at 4,500 - 5,500 kilograms (10-12,000 lbs) per week. The market is price competitive and is serviced well by Ontario processors (many of the smaller producers service the market directly). The major retail accounts include Loblaw's, Metro, Fortino's, Barn, Zehrs, Sobey's and Costco. Trout is often promoted in these outlets as an in-store special, as frequently as once per month.

3.4.2 US Trout Market

Trout is widely recognized as a highly desirable fish by most American consumers. At the same time that seafood consumption has grown in the U.S., trout consumption has been flat due to lack of supplies, not lack of markets. In 2008, U.S. per capita trout consumption totalled 40 grams (0.09 pounds). To put that figure into perspective, the 10th leading seafood item consumed in the United States in 2008, clams, had consumption of 190 grams (0.42 pounds) edible weight - almost 5-times greater than trout consumption.

The vast majority of the trout consumed in the United States is rainbow trout (*Onchorhynchus mykiss*) although small quantities of brook, brown and golden trout are also grown. All of the trout sold commercially in the United States is farm-raised.

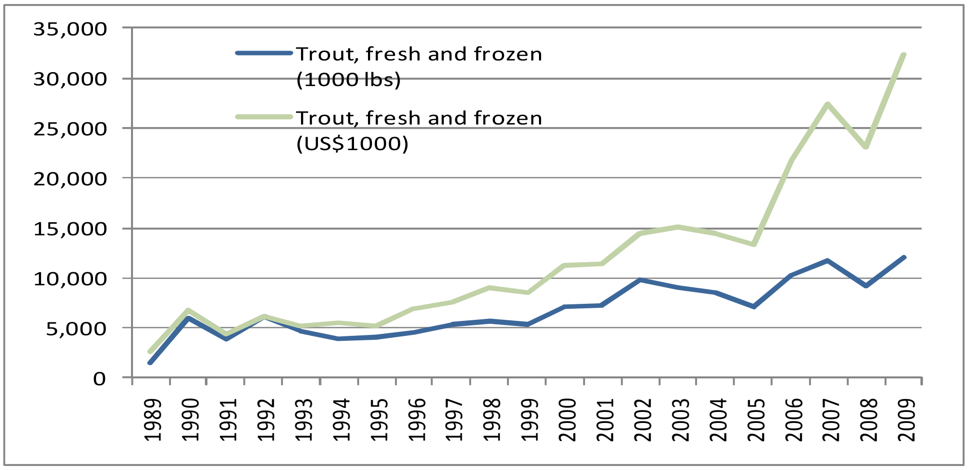
U.S. trout imports have increased sharply in recent years, but at about 5,450 metric tonnes they account for a very small percentage of U.S. seafood supply. Canada is the largest exporter of fresh trout to the U.S., however, Canadian fresh trout exports to the U.S. declined to less than 700 metric tons in 2007, due in part to the stronger Canadian currency. Canada accounts for about 60 percent of the U.S. imports of fresh trout.(Figure 5a, 5b)

Figure 5a: United States Imports, Exports and Re-Exports of Trout with Canada (2008)

Product	Imports	Exports	Re-Exports	Trade Balance
Total Trade	$6,783,780	$1,632,327	$273,734	-$4,877,719

Source: National Marine Fisheries Service (http://www.st.nmfs.noaa.gov)

Figure 5b: United States Trout Imports (tonnage and value) from 1989 to 2009



Source: http://www.ers.usda.gov/Browse/view.aspx?subject=TradeInternationalMarkets

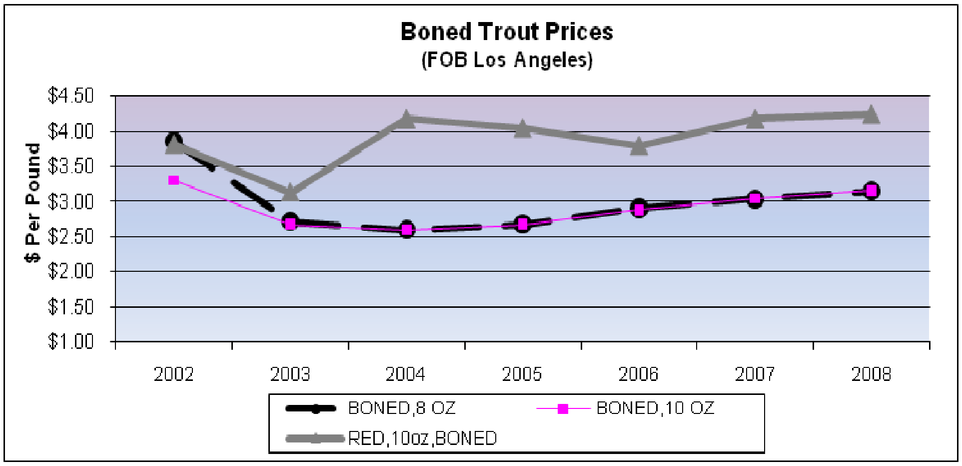
Frozen trout represents the largest product segment of U.S. trout imports; sales of frozen fillets have almost doubled over the past four years. In 2007, the United States imported 4,150 metric tons of frozen trout fillets with Chile supplying 1,635 metric tons and Argentina 1,354 metric tons. Together, those two countries provided almost 75 percent of the frozen trout fillets imported by the U.S. South American producers have low labour costs and they incur less of a transportation cost disadvantage when exporting frozen products.

Relatively little of the trout produced in Ontario is exported to the United States, in spite of the significant marketing opportunity south of the border and the fact that demand for trout is up in both the east and west coast. A large Saskatchewan producer, however, sells almost its entire production in New York City. U.S. mid-west and eastern seaboard lies within easy reach of Canadian producers. Moreover, these states have a combined population in excess of 100 million (1990 census) and most lie within one day's travel or less from the major trout producing areas of Canada. Opportunities for increasing market penetration are evident.

The US export market for fresh trout (whole and fillets) presents a good opportunity for Canadian producers. At current price levels of more than $5 a pound for fresh boneless trout fillets, producers in both Canada and Latin America appear to have adequate margins to increase exports to the U.S. Although Canadian producers have higher labour costs than Latin American trout producers they have much lower transportation costs.

Given the proximity of the U.S. market, Canadian producers are well-positioned to increase exports of fresh trout to the U.S. Producers in South America are expected to continue to focus on frozen exports. Moreover, in view of the production constraints being encountered by U.S. producers, it would seem that the only possible new significant supply of fresh trout for the U.S. would come from Canada. Therefore, if Canadian fish farmers are able to increase trout production, the growing U.S. seafood market represents an attractive market opportunity (Figure 6).

Figure 6: Boned Trout Pricing 2002-2008

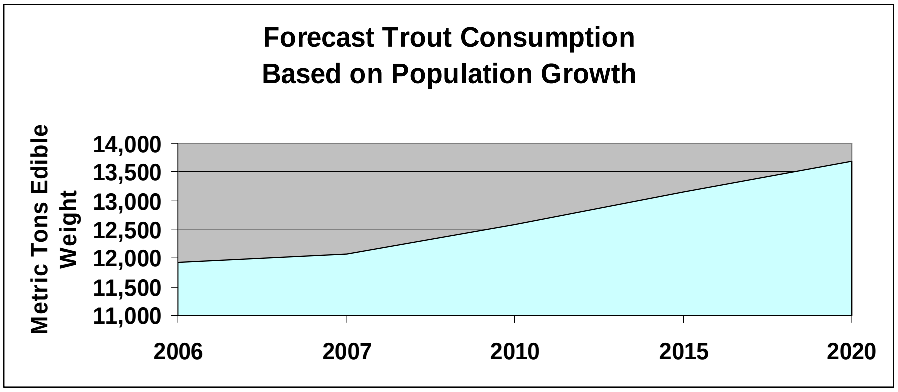


(Source: HM Johnson & Associates 2008)

Driven by population increases and favourable demographics, U.S. seafood consumption has been rising over the past decade. However, in the short term economic pressure may slow demand. In the long run, seafood demand is expected to increase. By 2020, there will be more than 70 million Americans over the age of 60. This age group is expected to eat greater amounts of seafood as health concerns and healthy aging become key considerations. Should adequate seafood supplies be available, it is possible per capita seafood consumption could top 20 pounds (9 kg) per capita edible weight. Accounting for population growth, the increase in demand would require an additional 1.4 million tonnes (live weight) of fish and seafood by 2020. If supplies are available, trout would be well positioned to take advantage of this strong demand.

At the current level of trout consumption in the U.S. (40 g per capita edible weight), population growth alone will generate an additional demand for almost 2,000 tonnes (edible weight) by 2020. This translates to approximately 6,000 tonnes live weight equivalent, a 10 percent increase over current supplies. Assuming U.S. production is constrained (by regulation and/or water availability) this increase would need to be met through imports. However, several scenarios could increase the demand for imported trout. Redmayne (Pers. Comm. 2008) estimates that the US market could reach 14,000 tonnes by 2020. (Figure 7)

Figure 7: Forecast Trout Consumption Based on Population Growth



(Source: HM Johnson & Associates 2008)

3.4.3 Product Characteristics

Long the mainstay of the trout industry, the pan-size whole dressed trout has been replaced in recent years by a single-side pin-boned fillet weighing 225 - 341 grams (8 - 12 oz). Boneless fillets have become the product of choice in most retail and foodservice markets. As a result, the major producers in the Canadian trout industry have re-defined their production strategies to produce larger fish (800 - 1400 grams) to yield two single-side fillets. Nevertheless, a number of the smaller farms continue to produce pan-size products for niche markets; the latter are often restricted from growing larger fish due to the design of their facility and/or a limited water supply.

In the U.S., 85% of trout is a white-flesh (un-pigmented) product whereas in Canada it is almost entirely a red-flesh (pigmented) product. Canadian trout exported to the U.S. is therefore often promoted as an alternative to salmon due to its red pigmentation. While this may appear to be cause for concern at times when off-shore countries “dump” salmon onto the North American market, it is usually at the retail level where the dumping occurs and not in the foodservice sector where a smaller fillet is required.

The white-flesh trout market is dominated by a hand-full of large ventures such as Clear Springs Trout Company, Ltd. (Clear Springs Foods) of Idaho. Conversely, relatively smaller players serve the red-flesh trout market and, presently, a category leader does not dominate the sector.

3.4.4 Product Pricing

In 2009, the wholesale price for fresh, pigmented, boneless farm-raised rainbow trout fillets from Canadian processors ranged between Cdn $11.02 and $12.96 per kilogram (Cdn $5.00 - 5.88/lb). Comparatively, whole dressed trout typically fetch a wholesale price of Cdn $7.05 - 7.80 per kilogram (Cdn $3.20 - 3.54/lb). Trout prices in the U.S. averaged US $5.00 per pound in 2008 (Cdn $11.60/kg). Canadian producers can currently expect to receive a farm-gate price of $3.75 - 3.97 Cdn. per kilogram ($1.70-1.80/lb) for whole trout. Most reports suggest that trout prices will continue to remain stable into the foreseeable future.

The data in Figure 8 provides an overview of the trends in Canadian wholesale trout prices since 1987. Since the data are not adjusted for inflation, the stability in these price structures suggests that the price of trout is declining in real terms.

Figure 8: Canadian Wholesale Trout Prices from 1987 - 2009

Product	Year	$/kg	$/lb
Boneless Fillets	1987	$9.92 - $10.47	$4.50 - $4.75
	1996	$8.82 - $9.48	$4.00 - $4.30
	1999	$8.93 - $10.47	$4.05 - $4.75
	2003	$9.81 - $10.47	$4.45 - $4.75
	2005	$7.94 - $8.93	$3.60 - $4.05
	2009	$11.02 - $12.96	$5.00 - $5.88
Dressed	1996	$5.29 - $6.39	$2.40 - $2.90
	1999	$5.62 - $6.17	$2.55 - $2.80
	2003	$5.84 - $6.61	$2.65 - $3.00
	2005	$6.17 - $6.61	$2.80 - $3.00
	2009	$7.05 - $7.80	$3.20 - $3.54
Whole (Farm-gate)	1996	$3.53 - $3.86	$1.60 - $1.75
	1999	$3.53 - $3.97	$1.60 - $1.80
	2003	$3.75 - $4.19	$1.70 - $1.90
	2005	$3.64 - $4.08	$1.65 - $1.85
	2009	$4.08 - $4.52	$1.85 - $2.05

3.5 The Market for Arctic Char

The flesh of Arctic char is similar to that of salmon, ranging in colour from rather pale to bright orange-red, depending on diet, and is regarded as a gourmet item. The flesh is also amenable to secondary processing such as marinating and smoking and can offer a full range of value added products.

Arctic char has a similar market as the more visible and better-known Atlantic salmon and trout and consequently the species has difficulty gaining market share. The development of niche markets may prove beneficial for Arctic char producers.

There appears to be very limited knowledge on the marketing of Arctic Char. What is known is that current markets for Arctic Char are predominantly in the Canadian, U.S. and European foodservice and retail sectors where fresh, frozen, dressed and smoked char are sold.

While it would appear that char might be differentiated in the marketplace from salmon and trout, thereby enabling the species to enjoy a premium price, efforts to do so on a consistent basis have been largely unsuccessful. Char is currently experiencing higher prices due to low volumes. The market price for char is very sensitive to volume. Currently, char sells for approximately $9.90 per kg for dressed fish. Other reports indicate that the prices have been as high as $19.78 to $24.18 per kg for fillets. Should aquaculture production of char increase without further market development efforts, there is a possibility that prices will decrease.

With less than 6,000 tonnes of char produced worldwide, one might expect customers to beat a path to the doors of producers to secure product. In reality, however, marketing of Arctic char has suffered largely because no one producer has been able to supply product consistently, 52 weeks per year. Rather, a number of small producers (many of whom are also trout farmers) began to “sell” char for little more than trout prices. This approach has not properly positioned Arctic char in the marketplace relative to its salmon and trout cousins. “The key to selling the fish” said one char producer cited in Seafood Leader Magazine, “is to differentiate it from salmon in the consumer’s eye.”

3.5.1 Product Characteristics

Unlike the trout industry, which has shifted largely to the production of 227 - 284 gram (8 - 10 oz.) boneless fillets, char is still sold predominantly in a dressed/gutted, head-on (DHON) form. Due to the presence of fine pin bones, conventional filleting practices for trout and salmon are not effective with Arctic char. Farm-raised product is marketed almost entirely as fresh product whereas wild harvest char is routinely frozen. While most markets are looking for nothing smaller than a 0.91 - 1.81 kg (2-4 lb) fish, there is increasing demand (and higher prices) for 1.81 - 2.72 kg (4-6 lb) fish in the foodservice (hotels / restaurants / institutions) sector. Farm-raised char is widely regarded as superior to wild harvest product. While the latter can be exceptionally good, product quality is known to vary considerably depending on the strain of char harvested and on post-harvest handling.

3.5.2 Product Pricing

Arctic char is currently differentiated from salmon and trout by price. Farm-raised Arctic char have been selling for no less than Cdn $7.00/kg ($3.18/lb), fob major market; and the latter tends to be for small fish (i.e. <0.9 kg). Urner Barry reports that Arctic char routinely sells at a premium of approximately US $0.20/lb (Cdn $0.28/lb or $0.62/kg) above Atlantic salmon. Some reports suggest that a price of US $3.30 / lb (Cdn $4.62/lb or $10.19/kg) can be attained with a consistent DHON product in excess of 3 lbs (1.36 kg) per fish. Prices for Arctic char obtained from several sources over the past few years are still reflective of current industry experience.

Since global output of farm-raised arctic char will remain far below mass market tonnage for the foreseeable future, it is likely that char prices will remain stable for some time. Therefore, a processed price of $9.00 to $10.00 per kilogram ($4.08 to $4.54 / lb) for one to two kilogram DHON fish can be considered realistic, ex-processing plant. (Figure 9)

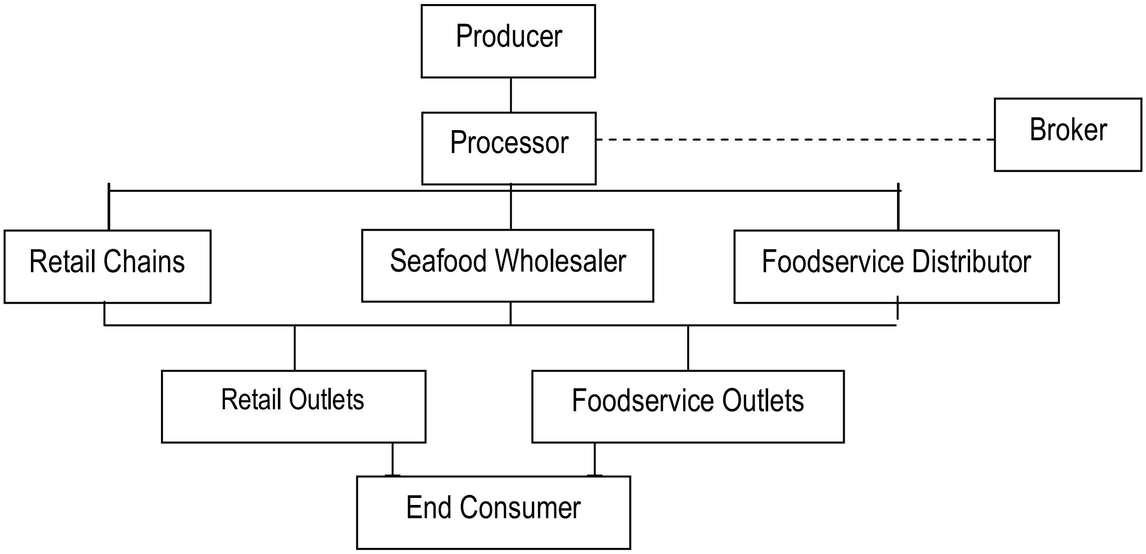
Figure 9: Recent prices for fresh, head-on dressed Arctic char larger than 0.9 kg (2 lb).

Source	fob	Value ($/kg)	Shipping ($/kg)	Ex-Plant ($/kg)	Yield (%)	Farm Gate ($/kg)
Québec	Toronto	$8.82	$0.55	$8.27	85%	$7.03
Manitoba	Winnipeg	$9.37	$0.33	$9.04	85%	$7.68
Ontario	Toronto	$9.37	$0.40	$8.97	85%	$7.62
Nova Scotia	Halifax	$8.50	$0.44	$8.06	85%	$6.85
PEI	Halifax	na	na	$9.37	85%	$7.96

[*] Price varies with size, quality & availability

3.6 Product Distribution

The ability to distribute fresh, quality products efficiently has enabled Canadian producers to compete effectively with less expensive trout products produced in the United States. Once the fish attain market size producers must sell the fish to a processor or, in some cases, they transfer the product to their own processing plant. Several alternative routes exist to get product from the processing plant to the market, as outlined in the following chart.



The services of brokers are generally used to facilitate volume sales. Brokers identify customers and arrange shipments in exchange for a commission on sales -- usually 3% to 5%. (The U.S. brokerage fees are between 3% and 6% with the average being 4.5%). Brokers are typically paid after the processor has received payment for the shipment. Some processors have established arrangements with more than one broker to diversify the risk associated with selling to only one or two major accounts. Each broker is usually given a territory in which he/she can sell the product.

Distributors handle a line of products (exclusively seafood or multiple food items) and generally mark-up the product by 5-20%. A direct arrangement with a distributor often nets the processor a higher price for the product; however, the processor must have sufficient quantities to meet the volume requirements of the distributor.

In some cases, processors deal directly with the retail or foodservice outlets. Generally, there are certain circumstances where this is feasible: accounts requiring very large volumes; very low or sporadic volumes; or specialty product niche markets. For high volume accounts, the processor must operate a large operation that is capable of guaranteeing product supply and consistency 52 weeks of the year. Smaller players in the industry generally service small volume and specialty accounts. The following chart illustrates the typical fish distribution channels.

3.7 Trade Issues

Since the passage of the North American Free Trade Act (NAFTA) in 1988, Canadian seafood products enter into the U.S. duty free. Nevertheless, U.S. trade policy is not as “free-trade” as it has been over the past decade and as a result it is likely that Canadian and other seafood producers will have to be prepared to fight skirmishes in the U.S. if the importation of their products has a negative effect on segments of the U.S. seafood industry. The U.S. trade environment is increasingly trade restrictive.

The U.S. Farm Bill

The 2002 U.S. Farm Bill includes a provision for country of origin labelling. This provision applies to certain commodities including farm-raised fish and wild fish. The section requires retailers in the United States to inform consumers at the point of purchase as to the country of origin of the product. A retailer may designate a commodity as having United States origin if, in the case of farm-raised fish, the fish is hatched, raised, harvested, and processed in the U.S. The notice of country of origin must also distinguish between wild and farm-raised fish. The information may be provided to consumers by means of a label, stamp, mark, placard, or other clear and visible sign on the commodity or on the package, display, holding unit, or bin containing the commodity at the point of sale. This provision, however, only targets retailers as it exempts foodservice establishments such as restaurants. This labelling requirement will likely create new marketing initiatives by both farmed and wild producers seeking to favourably position their products. Canadian producers would be astute to play-up favourable consumer perceptions regarding Canada as a source of clean waters and high quality products.

Food Safety

In the United States, a special section of the FDA’s HACCP guidelines apply specifically to aquaculture products. The focus of this section is on uses and abuses of chemicals and therapeutic agents in aquaculture that may pose a food safety threat. According to FDA, detailed preventive measures and procedures are established to control the use of aquaculture chemicals and therapeutic agents in aquaculture operations. This provision of the guidelines has been used as a non-tariff barrier to keep foreign product out of US markets in favour of domestic production, namely for Vietnamese catfish and southeast Asian shrimp.

4.0 SPECIES SITUATION & OUTLOOK

Objective: To present an overview of the current status of freshwater Rainbow trout and Arctic Char aquaculture production.

4.1 Rainbow Trout (*Oncorhynchus mykiss*)

4.1.1 Status of Culture Technology

Native to the west coast of North America, rainbow trout have now been introduced to every continent and are farmed in many countries with a temperate climate. Trout farming tends to be a relatively small-scale industry producing fish mainly for domestic consumption.

The technology for trout culture is well developed and is based on more than 100 years of culture experience by resource management agencies. Commercial production of trout began in Canada in the late1950s – mainly for stocking private ponds. In the 1970s, producers began farming trout to market size for restaurant and foodservice markets. Rainbow trout are produced in all provinces using both land-based and cage culture technologies. Increasingly, more of the food-fish production is being converted to cage culture operations to attain a lower cost of production. Approximately one-half of all trout production is Canada occurs in Ontario.

Land-based facilities are built on sources of high quality water available in ample quantities. Modern farms use a variety of sizes of fiberglass, steel or concrete tanks for the incubation of eggs and the rearing of fish from the juvenile stage to market size. Land-based facilities are normally flow-through, although recirculation systems are used where access to water is limited. In recent years, the majority of food-fish production has been from grow-out operations utilizing lake-based cage culture technology.

Rainbow trout grow rapidly to market size at high densities with efficient food conversion. They are resistant to disease and can be marketed before sexual maturity causes deterioration of the flesh quality. Domesticated brood stocks with many generations of selection for rapid growth are available. Production problems are usually disease related and caused by poor water quality, poor facility design and/or inexperience in husbandry practices. Depending on the water supply and temperature regime, trout are reared to a weight of about one kilogram in12 to 18 months. Cages systems in lakes take advantage of warm surface waters during the summer for more rapid growth and the production of larger fish (1 to 2 kg) for the fillet trade.

The trout farming industry enjoys access to an established support infrastructure. The nutritional requirements of rainbow trout are well known, and feed formulation is well developed. Several companies manufacture high-quality feeds. Disease diagnostic services are readily available, and disease control strategies are well developed. Specialized equipment for feeding, inventory control, and handling fish, although expensive, is readily available from a number of companies world-wide.

4.1.2 Seed Stock Supply

Rainbow trout have been domesticated to a large extent. Many hatcheries specialize in maintaining brood stocks and produce eggs and fingerlings for sale to grow-out operations.

Additionally, the industry imports a large percentage of its ova from certified US producers (e.g. TroutLodge).

Rainbow trout have been selectively bred for generations to improve traits desirable to commercial culture ventures; namely rapid growth, good feed conversion, high fillet yield, and late maturity. The timing of reproduction has been extended through selective breeding, photoperiod and temperature control and use of hormones to produce eggs all year round. Technology is also available for the production of all-female stocks to overcome the problem of sexual maturity in the larger fish required for filleting. Triploid (sterile) stocks can also be produced if there is concern that escaped farm fish will compete or breed with wild fish populations.

Currently, the Interprovincial Partnership for Sustainable Freshwater Aquaculture Development in Canada is launching a national broodstock program to develop enhanced performance in rainbow trout, specifically targeting improved fillet yield, enhanced growth rate and greater tolerance to warm-water conditions. Additional rainbow trout strains will be sought from local and/or imported stocks to enhance the genetics of existing Canadian strains, taking into consideration the genetic characteristics (performance) of the target strains and their disease profile.

Spawning techniques for rainbow trout are well known. Dry fertilization techniques are used when mixing the eggs and milt. Each female is capable of producing 1,100 to 1,400 eggs per kilogram of body weight.

4.1.3 Early Rearing Requirements

Hatchery production techniques have evolved to a routine that achieves high and consistent survival. Hatcheries require large volumes of high quality water. Ground water from springs or wells (artesian or pumped) is usually the best source, although surface water from lakes and rivers can be used.

Eggs can be incubated in a variety of systems, including “bell jars”, hatching boxes or trays suspended in troughs, and specialized tray incubation systems (Heath stacks). Hatchery procedures involve the maintenance of flow rates required to supply dissolved oxygen to the developing eggs and the control of fungal infection. The latter is usually accomplished with the administration of formalin.

Hatched fry are held in small circular or rectangular fiberglass tanks supplied with high quality water at an exchange rate of 1.0 to 1.5 tank volumes per hour. The optimum water temperature for feeding and growth of fry is 10 to 16^{o}C. Dissolved oxygen concentrations must be maintained above 6 mg/l. Formulated starter diets are used to initiate the fry to feeding, once the yolk sac is absorbed. This is a critical stage in the development of the fry and careful and frequent presentation of the feed is essential. Most hatcheries use automatic feeders to frequently dispense small amounts of feed 24 hours per day. As the fish grow, feeding becomes less frequent, and the fish are moved to larger tanks as required until they are large enough to meet the requirements of the grow-out facility.

4.1.4 Grow out Requirements

Grow-out in land-based facilities takes place in large tanks. Throughout the industry, the use of circular tanks and raceways is common. Circular tanks offer specific advantages in fish culture, including near-ideal hydraulic management to better control the quality and consistency of the rearing environment, thus enabling fish to distribute throughout the tank. They also offer the capacity to adjust rotational velocity (i.e. current and swimming speed) to improve the physical environment for the fish. Raceways offer the potential to make effective use of available space for rearing units and offer efficiencies in fish handling and labour requirements. With adequate flows (exchange rates), they can also offer a quality environment for the fish. In general, sufficient water is required to exchange the tank volume every 30 to 45 minutes. Rainbow trout are typically reared at densities of 50 to 70 kg/m^3 provided that dissolved oxygen concentrations can be maintained above 6 mg/l.

4.1.5 Fish Health

A wide variety of viral, bacterial and parasitic disease agents are known to infect rainbow trout, however, the disease agents are well known and diagnostic techniques have been developed. Rainbow trout are generally resistant to diseases provided that they are not stressed by poor water quality or husbandry practices. Vaccines and therapeutic agents can be used to control the most prevalent diseases, and veterinary services are readily available.

<u>Key Characteristics: Rainbow Trout Aquaculture</u>

Water Temperature	Do well at 10 to 16°C
Dissolved Gases levels to be achieved	
- Oxygen	+ 5 ppm and 75% of original saturation
- Carbon Dioxide	< 15 ppm (influenced by pH)
- Nitrogen	At or less than 100% saturation
Other Water Quality Parameters to maintain[10]	
- Alkalinity	20 ppm (min)
- Ammonia (NH_3)	< 0.05 ppm (influenced by pH)
- Hydrogen sulfide	< 0.003 ppm
- Nitrate	< 1.0 ppm
- Nitrite	< 1.0 ppm
- Total Dissolved Solids	< 400 ppm
- Total Suspended Solids	< 80 ppm
Other	
- Rearing densities	Up to 80 kg/m^3
- Consistent Growth Rates	
- Good quality genetic material available	

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[10] Adapted from two sources: Piper, R., et al. 1982. Fish Hatchery Management. US Dept of the Interior, Fish and Wildlife Service. A Guide to Integrated Fish Health Management in the Great Lakes Basin. 1983. Section 5: Selection of Water Supplies. Pg 37-48.

4.2 Arctic char (*Salvelinus alpinus*)

4.2.1 Status of Culture Technology

Arctic char occur naturally in many Arctic and sub-Arctic lakes and rivers and have a circumpolar distribution. Arctic char exhibit a wide variety of ecological and morphological diversity throughout their range (Scott and Crossman, 1973 cited in Lundrigan et al. 2005) including anadromous and land-locked, dwarf and normal forms occupying different ecological niches with different feeding habits and spawning times often occurring in the same geographic areas (Gross et al. 2004).

Three major lineages or genetic groupings of Arctic char exist in North America: the Arctic lineage with the most northerly distributed populations; the Labrador lineage consisting of both landlocked and anadromous populations in Labrador and Newfoundland; and the Laurentian lineage of landlocked populations in New Brunswick and Maine (Glebe, 2006).

Farming of Arctic char is a relatively recent addition to the aquaculture industry with serious farming efforts beginning in the mid-1980. Arctic char are farmed mainly the Nordic countries and Canada. Reliable statistics on Arctic char production are difficult to find. However, the Nordic countries produced approximately 5000 metric tonnes in 2007 (Siikavuopio et al. 2009) with Iceland's contribution at 2,200 metric tonnes (FAO Aquaculture Statistics). Recent figures for production of Arctic char in Canada are not available. However, Canadian production was estimated at 960 tonnes in 2001 (Rogers and Davidson 2001) and production has probably not increased and may have declined since this time. Other countries including the USA, Austria, Ireland and the United Kingdom produce small amounts (<100 tonnes) of Arctic char (FAO Aquaculture Statistics). Total world production of Arctic char in 2007 was in the range of 6000 tonnes (estimated from FAO statistics plus Nordic countries (5000 – Iceland production) plus Canada at 900 tonnes). To put this into perspective, total world production of salmonids was 2.3 million tonnes in 2007 of which Atlantic salmon and rainbow trout represented 1.4 million and 600,000 tonnes respectively (FAO Aquaculture Statistics).

Arctic char has been the subject of considerable interest for the aquaculture industry in Canada because it displays good growth at low temperatures (Rogers and Davidson 2001) typical in the Canadian environment, can be reared at high densities (Rogers and Davidson 2001) and has a high market value.

Arctic char are farmed using essentially the same techniques and facilities as are used for rainbow trout and Atlantic salmon. Development of the industry, however, has been constrained by lack of domesticated brood stocks, stunting of a significant portion of production lots, and undeveloped markets. Attempts to culture Arctic char under commercial production conditions have been inconsistent, which may be due to a failure to recognize that Arctic char have biological and environmental requirements that differ from those of other salmonids in subtle, but significant, ways. To be successful, the Arctic char farmer must apply a high level of scientific understanding of the unique characteristics of Arctic char which have allowed it to adapt to the Arctic environment and apply a high degree of management expertise in recording and analyzing production data in order to optimize the culture environment.

The fledgling Arctic char industry enjoys access to the same infrastructure that supports the Atlantic salmon and rainbow trout industries. Feeds formulated for other salmonids are suitable for Arctic char at all life stages, disease diagnostic services and vaccines and therapeutic agents are all relevant to Arctic char, and the equipment available for feeding, inventory control, and fish handling are standard.

Following the initial availability of Arctic char eggs and fingerlings in the mid 1980s, interest in producing Arctic char began to grow throughout Canada. However, over the following 10 to 20 years, as the majority of the early char ventures failed or switched to other species, interest in the species waned. At least four farms tried to rear Arctic char in Newfoundland, including a seawater trial, but none were operating as of 2006 (Glebe, 2006). Likewise, three farms in Prince Edward Island and three farms in Cape Breton, which grew Arctic char in the period from 1987 to 1993, have ceased to operate. One producer, Icy Waters Ltd, Yukon, is the largest Arctic char producer having been involved in the industry for over 20 years and currently produces over 120 metric tonnes per year; however, their principal objective is selling Arctic char eggs to domestic and international markets (McGowan et al. 2009).

4.2.2 Seed Stock Supply

Three strains of Arctic char have been used to develop brood stocks in Canada; the Fraser River strain from Labrador, the Nauyuk Lake strain from Nunavut, and the Tree River strain also from Nunavut. All three strains were developed from wild gamete collections conducted by the Department of Fisheries and Oceans with the fish reared and distributed from the Rockwood Aquaculture Research Centre in Manitoba (Lundrigan et al. 2005). All three strains were developed from small founding populations. The Fraser River strain, commonly called the Labrador strain, was developed from gametes collected from 19 females and 10 males in 1980, 40 fish in 1981 and 4 females and 4 males in 1984 (Lundrigan et al. 2005). The Nauyuk strain was developed from gametes of 3 anadromous females, 2 non-anadromous females, 1 anadromous male and 3 non-anadromous males collected in 1978 (Lundrigan et al. 2005). The Tree River strain was developed from gametes collected from 15 females and 19 males collected in 1988 (Lundrigan et al. 2005). The Tree River strain may be a combination of Arctic char and Dolly Varden (*S. malma*) based on morphological and genetic analysis (Lundrigan et al. 2005). A fourth strain, Bristol Bay, from Lake Alkenagik, Alaska was developed from 1986 to 1988 from 381 females and 128 males (Lundrigan et al. 2005), but this strain does not appear to be used in the aquaculture industry.

In addition to using small numbers of founding parents of unequal sex representation, eggs were commonly fertilized with milt from more than one male and pooled. This resulted in an increased degree of relatedness amongst the progeny, introduced inbreeding with the first year class, and prevented establishment of pedigrees for the management of future brood stock development strategies (Lundrigan et al. 2005). Distribution of eggs to other research institutions and to aquaculture facilities often involved provision of eggs from only a few families further compounding the problem (Rogers and Davidson 2001).

The three strains have different characteristics of interest to aquaculture as would be expected given the wide variability in Arctic char populations. The Tree River strain is one of the fastest growing strains of Arctic char in the world (McGowan et al. 2009). The Nauyuk strain has lower fecundity, higher early growth rate, later age of maturity and later spawning date than the Fraser River char (Somorjai 2001). The Nauyuk strain matured at 5 to 6 years of age while the Fraser River strain matured at 3 years of age in a common hatchery environment (Tao and Boulding, 2003).

Moreover, the three strains were not selectively bred to enhance characteristics desirable for aquaculture (Lundrigan et al. 2005) until fairly recently. However, the genetic impacts of the early practices described above are apparent in the stocks. Comparison of the aquaculture strains to their wild sources revealed that all aquaculture strains had significantly less genetic diversity than their wild source populations, and stocks originating from the same wild collections but subsequently reared at different facilities are genetically distinct in some cases (Lundrigan et al. 2005). The strains derived from the fewest numbers of founding parents had the lowest genetic diversity (Lundrigan et al. 2005). The low number of founding parents constrained the genetic diversity initially and additional genetic variation was likely lost through hatchery practices such as non-random selection of parent stock and pooling of gametes for fertilization, leading to increased levels of inbreeding (Lundrigan et al. 2005). All strains now exhibit low fertilization and viability (Somorjai, 2001).

In 2001, Icy Waters Ltd. began collaboration with Simon Fraser University to incorporate improved genetic management into their brood stock strategy (McGowan et al. 2009). The program involves using molecular genetics to resolve the genetic relationships within the Nauyuk and Tree River strains, resolve pedigree questions, avoid further inbreeding and identify genetic markers associated with growth, disease and stress resistance for use in future brood stock development (McGowan et al. 2009).

Ironically, given that the ability to grow at low temperatures is an often cited advantage of Arctic char for aquaculture, Icy Waters is selecting brood stocks for tolerance of warmer water temperatures to broaden the potential for Arctic char to be reared in warmer regions where the temperature may exceed 15 ^{o}C (McGowan et al. 2009).

Icy Waters Ltd. has become the dominant supplier of Arctic char eggs to the aquaculture industry. Use of photoperiod control allows two spawning periods (spring and fall) (McGowan et al. 2009) to increase the availability of eggs. Icy Waters provides all-female stocks and triploid hybrids of the Nauyuk and Tree River strains to alleviate the problem of early maturity in male Arctic char (McGowan et al. 2009). The Nauyuk-Tree River hybrid strain represents 80% of Arctic char grown in North America (McGowan et al. 2009), and was found to be faster growing than the Nauyuk strain in trials in a recirculation aquaculture system at 13 to 15 ^{o}C (Summerfelt et al. 2004b).

4.2.3 Early Rearing Requirements

Egg incubation and fry rearing techniques are essentially the same as for other salmonids. Eggs are incubated at lower water temperatures, usually around 4^{o}C or lower to the eyed egg stage to ensure good egg survival (Scarratt 1996). Following eye-up eggs can be incubated at higher temperatures up to 12^{o}C with good survival (90% or more) (Bebak et al. 2000). Char eggs may be more sensitive than other salmonid eggs to vibration and other disturbances (Scarratt 1996). Arctic char fry are small compared to trout and salmon and are more difficult to introduce to manufactured feeds (Eriksson et al. 1993; Scarratt 1996). However, lower mortality and higher growth can be achieved by maintaining Arctic char fry under continuous light and presenting feed over 24 hours (Burke et al. 2005).

4.2.4 Grow-out Requirements

Arctic char can be grown-out to market size in the same tanks as other salmonids; however, they tend to tolerate higher stocking densities (up to 90 to 130 kg/m^3). For these reasons, and their ability to grow at low temperatures, Arctic char appeal to aquaculturists. The optimum temperature for growth of Arctic char is reported to be in the range of 10 to 15^{o}C (Scarratt 1996; Bebak et al. 2000), and Arctic char will survive in water temperatures as low as -1 ^{o}C (Rogers and Davidson 2001). At temperatures above 15^{o}C, growth rate and survival decline rapidly (Eriksson et al. 1993; Scarratt 1996).

Growth of Arctic char is highly variable and tends to slow with increasing age. Stunting has been a major problem for the development of an economically sound Arctic char industry. Within a single lot, up to 40% of the fish may never grow to harvest size (Rogers and Davidson 2001) and need to be culled. A common problem on (unsuccessful) Arctic char farms is that lots of different ages are mixed as fish are sorted for size and harvested for market resulting in the portion of the fish that do not grow remaining on the farm, sometimes for years, utilizing resources (space, oxygen, feed) that would be better given to production fish. It is imperative on Arctic char farms that lots (cohorts) of fish of different ages never be mixed and that the farmer has the discipline to cull non-performing fish.

Growth in wild Arctic char, especially anadromous forms, is cyclical with concentrated bouts of heavy feeding followed by long periods of fasting as the seasons, and photoperiod, change (Johnston, 2002). Growth rate of individuals, even within families, reared under controlled conditions is highly variable suggesting a complex genetic and environmental control of body size and growth (Somorjai, 2001). Arctic char reared in a recirculation aquaculture system exhibited seasonal depression in growth despite appearing to thrive based on their appetite, and also had lower feed conversion, and interestingly much higher total ammonia nitrogen (TAN) excretion rates per kilogram of feed consumed (Skybakmoen et al. 2009).

Arctic char have pronounced diurnal and annual patterns in appetite, feed slowly and if feed delivery is too concentrated will feed off the bottom of the tank (Eriksson et al. 1993). Arctic char do not consume as much feed per unit body weight as rainbow trout and tend to be not as efficient in converting feed (Summerfelt et al. 2004b).

Although standard trout or salmon diets can be used to grow Arctic char, char may require higher levels of essential fatty acids than other salmonids and higher quality protein sources than rainbow trout (Noble et al. 2005).

4.2.5 Fish Health

Although Arctic char are generally regarded as a relatively hardy species, they are susceptible to the same viral, bacterial and parasitic disease agents that infect other salmonids. Char have been found to be sensitive to diseases such as furunculosis, vibriosis and bacterial kidney disease and to fungal infection (Eriksson et al. 1993). Arctic char were also found to be more susceptible than rainbow trout to a respiratory disease associated with gram-negative intracellular bacteria with characteristics of chlamydia and/or rikettsial species when reared in a recirculation system (Summerfelt et al. 2004b). Good husbandry practices and excellent water quality are keys to controlling disease outbreaks.

<u>Key Characteristics: Arctic Char Aquaculture</u>

Water Temperature	Do well at below 15^{o}C
Dissolved Gases levels to be achieved	
- Oxygen	+ 5ppm and 75% of original saturation
- Carbon Dioxide	< 15 ppm
- Nitrogen	At or less than 100% saturation
Other Water Quality Parameters	Same as for rainbow trout
Other	
- Rearing densities	Up to 120 kg/m^3
- Inconsistent Growth Rates	
- Limited genetic material available	

4.3 Hybrid Char (*Salvelinus alpinus* x *S. fontinalis*)

Hybrids of Arctic char and brook trout have been tested in aquaculture settings on occasion. Hybrids are known to occur naturally (Bernatchez et al. 1995; Gross et al. 2004) and hybrids created through artificial fertilization between these species were first produced in the Alsace region of Germany around 1890 and named Elsasser saibling or Alscian char (Gross et al. 2004). More recently these hybrids have been called spartic char or spartic trout (Jansson, 2008).

Fertilization success and early survival are considered satisfactory for aquaculture purposes (Dumas et al., 1996) although lower than would be expected in the pure parental species. Survival to eyed egg and swim-up ranges from 72 to 93% and 44 to 89% respectively (The Char Network). Survival and growth are intermediate to those of the parental species but only slightly higher than brook trout prior to sexual maturity (Dumas et al., 1995a; 1996). The hybrids matured later than brook trout but earlier than Arctic char (Dumas et al., 1996).

Commercial production of hybrids is logical only when the hybrid exhibits a trait superior to that of either of the parental species. Hybrid salmonids usually have traits that are intermediate to, or comparable with, those of the parental species. This is the case with the hybrid between Arctic char and brook trout.

In trials of all-female brook trout (female) x Arctic char (male) crosses compared to Nauyuk x Tree River strain Arctic char, the Arctic char-brook trout hybrid had slightly slower growth, and poorer feed conversion than the Arctic char (Summerfelt et al. 2004a; 2004b). The hybrids also showed some gonad development in approximately 20% of the population prior to reaching the harvest size of 1.3 kg as compared to a few precocious males in the Arctic char. The hybrids were more resistant to a respiratory disease than the pure Arctic char. Overall there was no production advantage attributed to the hybrid. A commercial farm also found that Nauyuk x Tree River Arctic char gave superior performance than a Tree River strain x brook trout hybrid (Rimmer, 2003).

5.0 REVIEW OF INTENSIVE PRODUCTION TECHNOLOGIES

Objective: *To review available production technologies and systems for the effective and efficient production of freshwater salmonid fishes in New Brunswick.*

5.1 Overview of Aquaculture Systems[11]

One of the main factors influencing the complexity of an aquaculture facility is the water use strategy. Traditionally, facilities were designed as Flow-through Aquaculture Systems using a single-pass water use strategy. Water recycle systems, involving water treatment processes, provide an alternative to traditional systems. Recycle systems are usually classified as either Partial Reuse Aquaculture Systems or Recirculating Aquaculture Systems which primarily differ in the magnitude of the portion of the water that is recycled, and the complexity of the water treatment processes used.

5.1.1 Flow-through Aquaculture Systems

In traditional Flow-through Aquaculture Systems, water is passed through the culture system only once and is then discharged back to the aquatic environment. The flow of water through the culture system supplies oxygen to the fish and carries dissolved and suspended wastes out of the system. Water quality within the culture system is maintained by flushing of contaminants and by replacing all system water before dissolved oxygen concentrations drop below minimum acceptable limits or contaminate concentrations (i.e. ammonia, solids, and carbon dioxide) can accumulate to above maximum acceptable limits.

Although flow-through systems are predominantly constructed with raceway culture vessels, more and more facilities are being converted to use circular culture tanks which provide for more efficient use of water, superior mixing, superior removal of solid wastes, and the potential for increased fish densities.

Because flow through systems count on the exchange of water to flush contaminants from the system, high influent flow rates are required and equivalent high effluent flow rates are generated. Influent treatment and effluent treatment are often required to ensure that water quality is suitable and safe for fish culture or for discharge back to the environment. Because of the high flow rates, extensive treatments are often cost prohibitive and minimal environmental control is possible within the culture system. Temperature control is minimal and is often only possible through the use of systems that recover heat from the effluent flow.

Flow-through systems became a popular and cost effective approach for aquaculture when water sources were plentiful and competing uses for the water resource were low. However, sustainability principles, increasing competition for limited supplies of high quality water, and the need for improved control of culture conditions are generally causing aquaculture facilities to consider partial reuse or recirculation technologies as alternatives to traditional methods.

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[11] Sub-sections 5.1.1 through 5.1.3 have been sourced from http://www.praqua.com/culturesystems.html

Flow-through Facts

- Well known culture method that is widely practiced
- Site placement is limited by water availability
- Culture systems are relatively simplistic and easy to operate
- Typically lower capital investment compared to more advanced culture systems
- Requires high flow rates of high quality water of the appropriate temperature
- Temperature is fully dependant on intake water conditions
- Control of temperature and water quality is difficult and usually cost prohibitive
- Facilities are susceptible to disease ingress with intake water and disinfection of intake water is very costly
- Produces high volumes of dilute effluent which may be difficult and costly to treat
- Therapeutic treatments are difficult and inefficient

5.1.2 Partial Reuse Aquaculture Systems (PRAS)

Partial Reuse Aquaculture Systems (PRAS) use water treatment processes to allow a portion of the culture discharge water to be recycled and supplied back into the culture tanks. For aquaculture facilities faced with limited water resources, sustainability issues, or a requirement for improved control over culture conditions, reuse technology is the next step in the technological evolution of modern aquaculture systems.

When compared to flow-through aquaculture systems, PRAS offer significant reductions in water consumption, effluent discharge volumes, and potentially energy consumption. Reuse technology allows for location of new facilities where there are limited water resources, and allows existing facilities to increase production despite limited water resources. With reduced water use, influent treatment and effluent treatment become more economical. As such, disinfection of influent water for biosecurity protection becomes possible and impact of the facility on the environment may be better mitigated. In addition to these benefits, water quality and temperature become easier to control which may have production benefits.

Partial Reuse Systems focus on the use of a few, simple treatment technologies to provide significant reductions in water use. These technologies typically include gas balancing and oxygenation, may also include solids removal and disinfection, but do not normally include ammonia removal through biofiltration. Those water quality parameters for which treatment is not provided are maintained within acceptable limits by flushing and replacement of a portion of the system water. Water temperature is dependent on influent water temperature which may be more economically altered than in flow-through system due to the reduced flow.

Because flushing and water replacement is used to control the concentrations of some contaminants, the reuse rate is limited by the accumulation of untreated contaminants such as ammonia. The maximum reuse rate that may be achievable without the addition of more advanced treatment processes will depend on the biomass and feed load on the system, and on the specific water quality requirements of the fish cultured. Partial reuse rates from 50% to 90% of the total flow have been employed, depending primarily on fish sensitivity to unionized ammonia concentrations, although reuse rates between 50% and 75% are most common.

Partial Reuse Facts

- Significantly reduced water consumption and effluent volumes (50%-75% typical)
- Allows for significant production expansion without increasing water use
- Reductions in energy consumption are possible when influent pumping costs are high
- Typically lower capital investment compared to recirculation systems but higher than flow-through systems
- Site placement is less dependent on water availability
- More economical influent treatment and temperature control
- Disinfection of influent water for biosecurity protection is more economically
- Much less mechanical and operational complexity than recirculation systems but higher than flow-through systems
- Control of culture conditions is improved
- Reduced volumes result in more economical effluent treatment
- Therapeutic treatments are efficient and economical

5.1.3 Recirculating Aquaculture Systems (RAS)

Recirculating Aquaculture Systems (RAS) incorporate additional treatment technologies beyond those used in Partial Reuse Aquaculture Systems (PRAS), allowing for significantly greater quantities of water to be reused. Recirculation systems afford a level of control well beyond any other technology application in aquaculture and provide significant production and economic benefits.

Recirculation systems are usually used where new water supplies are limited or expensive to achieve (i.e. high pumping costs), the risk of introducing pathogens or contaminants into the system with influent water is high, effluent disposal capacity is limited, or where operators want to practice strict control over the water quality and temperature within the fish culture system. Such systems are characterized by increased technical complexity, capital costs, and in some applications, operating costs. However, because RAS allow optimum culture conditions to be maintained year round, independent of fluctuations in water supply quality and ambient temperatures, fish growth rates may be accelerated allowing more fish or larger fish to be produced in the same amount of time. In a well-designed system, the production benefits will outweigh the additional costs resulting in a net lower cost of production.

Recirculating Aquaculture Systems maximize water re-use by employing a comprehensive water treatment system. Water treatment processes typically include solids removal, biofiltration, gas balancing, oxygenation, and disinfection. By addressing each of the key water quality concerns through treatment, rather than flushing as is used in flow-through and partial reuse systems, ultimate control over culture conditions and water quality is provided.

Water quality in recirculation systems is highly dependent on the complexity and cost of the water treatment system used. Better water quality may be provided and higher recirculation rates may be achieved through the addition of additional treatment processes or with greater intensity of treatment. A typical recirculation system will provide a maximum recirculation rate of 95% - 99% of the system flow rate while maintaining optimal water quality for the fish. However, with the addition of denitrification technologies, and by capturing water extracted from sludge thickening processes, some systems may become effectively “closed” with very little to no exchange of water. A balance must be achieved in design between water quality objectives and treatment system complexity and cost.

Recycling has become an economic imperative in many industries and aquaculture is no exception. Recirculation technology has allowed aquaculture facilities to evolve to meet the growing need for economic and environmental sustainability.

Recirculation Facts

- Significantly reduced water consumption and effluent volumes (95%-99.9%).
- Minimal influent water consumption allows for cost effective treatments to improve water quality and prevent the ingress of disease.
- Minimal effluent volumes result in the ability to treat both effluent water and sludge to meet sustainability objectives.
- Full control of culture temperature is possible, allowing for year-round production independent of fluctuating environmental or influent water conditions.
- A high degree of control over culture conditions enables operators to optimize fish growth and feed conversion, increased production, and improve product quality.
- Generally more mechanically and operationally complex than other types of culture systems.
- Initial capital investment is typically higher but cost of production is typically lower than in other culture systems.
- Therapeutic treatments are efficient and economical as dosage is maintained in the system due to minimal water exchange.
- Facilities can be located almost anywhere; site selection is not tied to access to large volumes of water.
- System and technology performance have been proven by successful facilities in a wide range of aquaculture applications.

Recirculating systems are not truly “closed” systems because some new water must always be added to replace evaporative and other system losses. Nevertheless, they can operate efficiently with the addition of relatively small amounts of water on a daily basis.

Recirculating Aquaculture Systems (RAS) have been in inexistence in one form or another since the 1950’s (Helfrich and Libey, Date Virginia Tech). Water quality reconditioning technologies, instrumentation and computerized system design programs have been incorporated over the years and have revolutionized our ability to intensively grow fish in tanks. RAS can be defined as a fish culture system that incorporates the treatment and reuse of water with less than 10% of the total volume being replaced per day (Hutchinson et al, 2004). This is the key advantage of RAS and the main distinguishing feature from other water reuse systems. This is also the greatest risk factor as deterioration of water quality will occur quickly if the system is not designed and monitored properly (Molleda et al, 2007).

RAS are particularly useful in areas where land and water are expensive and/or not readily available. They are most suitable in northern climates where cold temperatures can slow fish growth and prevent year-round production. RAS can be designed to afford growers the opportunity to manage production to meet market demand throughout the year and to harvest the inventory at the most profitable times.

Commercial RAS should be supported by a credible design process that includes selecting the appropriate rearing units (quantity and size) and providing the analysis that quantifies all inputs and outputs that occur within the culture operation.

5.2 Rearing Unit Design

Historically, tanks for rearing fish have been designed to meet the needs of the fish as well as the needs of the people who work with the fish. Well-designed operations aid in optimizing growth and feed conversion and ease the husbandry and harvesting of fish while simultaneously ensuring the health and quality of the stock. Increasingly, however, environmental impact considerations are being reflected in systems design. In land-based operations, circular tanks and raceways are the two most common tank designs used in intensive production of salmonids and other species (Figure 10). Each has advantages and disadvantages and people often prefer one over the other for a variety of reasons. Listed below are the principal criteria important in tank design and the inherent advantages and disadvantages of circular tanks and raceways.

1. *The tank should be self-cleaning; waste solids are efficiently flushed from the tank without manual vacuuming, brushing or flushing.*

Circular Tanks: Properly designed, circular tanks are continuously self-cleaning.

Raceways: Raceways approach self-cleaning only when fish are reared at very high densities. Attempts to make raceways self-cleaning through the installation of baffles and other devices have been developed but have not been widely implemented.

2. *Waste management; solids removed from the tanks should be easily handled and stored for disposal.*

Circular Tanks: Modern circular tanks are designed with double drain systems which greatly reduce the volume of water that must be treated and increases the concentration of solids entering a treatment facility. Treatment facilities are much smaller as a result. Also, the continuous removal of solids means that less nutrients leech out of the faeces and enter a soluble phase. This is probably the most significant advantage of circular tanks over raceways.

Raceways: Faeces and waste feed tend to remain distributed along the length of the raceway floor. Fish activity will re-suspend the waste solids and gradually move them down the raceway, however, particulate matter is generally broken up into finer particles and nutrients leech out as this occurs. Labour-intensive daily cleaning routines are usually required to remove the solids either by vacuuming or brushing. Unless the solids are vacuumed or otherwise separated, the entire flow from raceways must enter a waste treatment facility for solids removal. This is probably the most significant disadvantage of raceways over circular tanks.

3. *Water velocities in the tank should be sufficient to exercise the fish but should not exceed their swimming capabilities or cause unnecessary fatigue or stress.*

Circular Tanks: Water velocities can be managed by controlling the direction and velocity of water entering the tank. A range of velocities can be made available to the fish. Water velocity is generally higher in tanks than in raceways.

Raceways: Water velocities in raceways are generally low with significant turbulence. Most salmonid species prefer the higher velocities of circular tanks. One exception is lake trout which perform better in the low velocities of raceways.

4. *Water quality should be uniform to discourage competitive territorial behaviour and to encourage even distribution of the fish.*

Circular Tanks: Water quality is consistent throughout the tank, if properly designed, and the fish tend to be more uniformly distributed.

Raceways: Water quality forms a gradient with the best water quality at the inlet end and the worst at the outlet end. The stronger, more aggressive fish tend to crowd into the inlet end of the raceway, while the weaker individuals are displaced toward the outlet and into the water of poorest quality.

5. *Feeding should be easily accomplished.*

Circular Tanks: The shape of the water surface makes it easy to broadcast feed over the surface so that all fish have an opportunity to access feed with a minimum of aggression. The current in circular tanks helps to keep feed particles suspended in the water column for longer periods of time, thereby reducing unconsumed (wasted) feed.

Raceways: It is more difficult to distribute feed equitably to the fish in raceways because the fish are not distributed evenly.

6. *Grading and harvesting of fish should be easily accomplished.*

Circular Tanks: Grading and harvesting is more difficult in circular tanks than in raceways. Installation of dividing screens is awkward and seining the fish is difficult given the shape of the tank. This is probably the most significant disadvantage of circular tanks.

Raceways: Grading and harvesting is easy in raceways. Fish can be readily crowded with seines or crowding screens and dividers can be easily installed to segregate populations. This is the most significant advantage of raceways.

7. *Footprint; the tanks should maximize production in a small area of land.*

Circular Tanks: The areal efficiency of circular tanks is less than that of square or rectangular tanks; however, circular tanks can economically be made deeper than raceways, which may compensate for their less-efficient shape. Moreover, fish usually perform better in deeper tanks.
Raceways: The rectangular shape makes more efficient use of area; however, the strength required in the long wall to support the weight of the water limits the depth to which they can be built, or increases significantly the capital cost of the raceways.

8. *Construction Materials and Portability*

Circular Tanks: Because the round shape provides more inherent strength, large circular tanks can be built from relatively light material such as fibreglass, steel or aluminum panels. They can also be built to virtually any depth. Additionally, circular tanks can usually be dismantled and moved if necessary, a feature that makes them more attractive to investors.

Raceways: The strength required in the long wall of raceways to support the weight of the water means that raceways are usually constructed with concrete. Raceways built of fibreglass or other materials are limited to sizes generally impractical for commercial production of fish. The inability to remove concrete tanks, and their limited use for other practical purposes, introduces a component of financial risk to a venture.

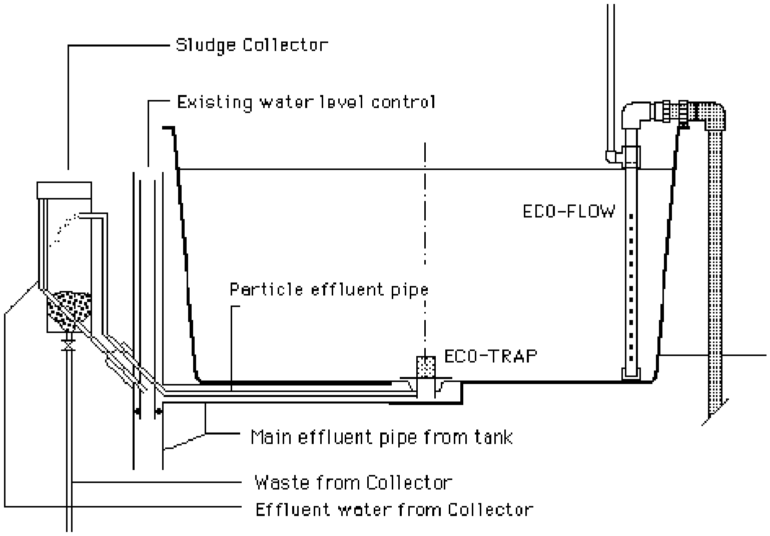
Figure 10: Examples of circular tanks and raceways used in intensive aquaculture.

Self-Cleaning Tanks

Any waste solids that accumulate in a rearing tank will negatively impact fish performance. Faecal wastes and uneaten feed will add to the oxygen demand, increase the risk of disease outbreaks and increase the concentration of dissolved waste in the water making effluent treatment more difficult and expensive. If solid wastes accumulate and become anaerobic (sometimes only a few centimetres thick), highly toxic hydrogen sulphide can be produced. Therefore, well designed fish culture tanks are self-cleaning. Furthermore, to reduce labour requirements, it is important that tanks do not rely on manual cleaning.

Double drain systems have revolutionized water management in aquaculture by enabling a tank to become self-cleaning and reducing the total volume of effluent to be treated. In circular or near-circular (i.e. octagonal) tanks, settled solid materials migrate to a central drain where they can be effectively removed using a small underflow – typically about 5% to 20% of total tank flow within minutes of settling to the floor of the tank (Figure 11). The remainder of the water, which is relatively clear of particulate wastes, exits from a separate drain near the surface of the tank either at the tank centre (axial outlet design) or through the side wall (Cornell-style lateral outlet design).

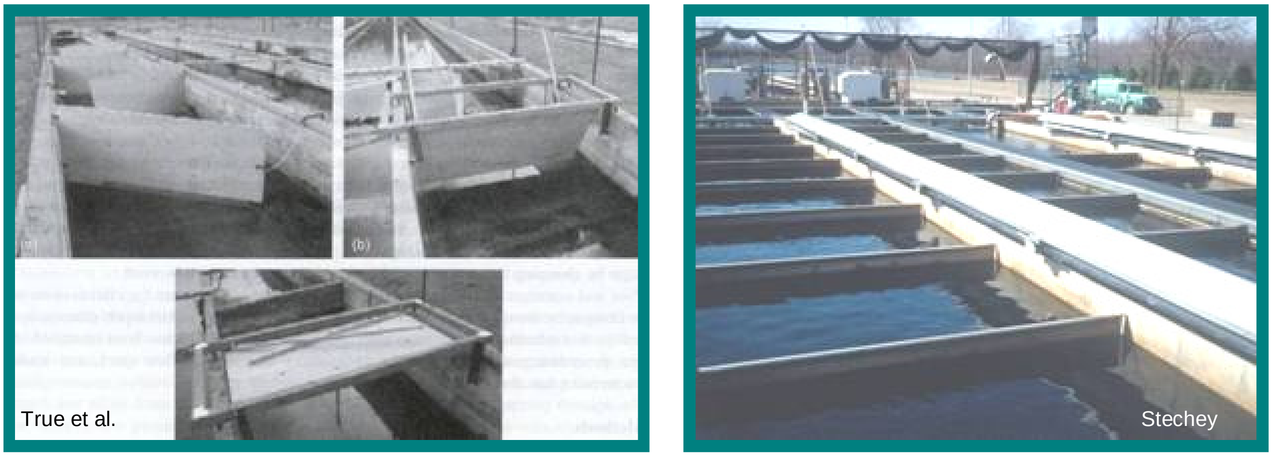
Figure 11: A typical double-drain system with an external sludge collector.
(Source: www.aquaoptima.com)



In settling basins, scouring velocities of 4-5 cm/sec are required to re-suspend settled aquaculture wastes from the floor of the basin. Boersen and Westers (1985) determined that the minimum velocity required to prevent solid wastes from settling in raceways and to carry them to the end of the raceway is approximately 0.24 - 0.3 m/s. Typical flow rates in raceways, however, are less than this critical velocity and, therefore, solid wastes tend to accumulate on the floor along the entire length of the unit. To overcome this limitation, Boersen and Westers (1985) and True et al. (2004) installed baffles in raceways to increase the velocity of water flow along the bottom of the raceway to encourage transport of solid wastes to settling chambers at the end of the units (Figure 3). Aluminum or wooden baffles were inserted at intervals equal to the raceway width and elevated off of the bottom sufficiently to create an under-baffle velocity of about 0.3 to 0.4 m/s. Although baffles are effective in facilitating the transportation of solid wastes to the settling areas, fish management in such systems is encumbered.

True et al (2004) describe removable baffles which somewhat alleviate these challenges by swinging the baffles aside or up to enable fish movement. In the photo below left, picture (b) depicts a baffle that is moved along the length of the raceway by the flowing force of water, maintaining a high-velocity, scouring flow immediately beneath it. Once or twice per day, the baffle can be raised from the water, rolled along the raceway wall to the head end of the tank, and re-engaged to scour settled solids along the length of the unit.

Figure 12: Baffles installed in raceways operated by the Michigan Department of Natural Resources (R) and in Idaho raceways (L).

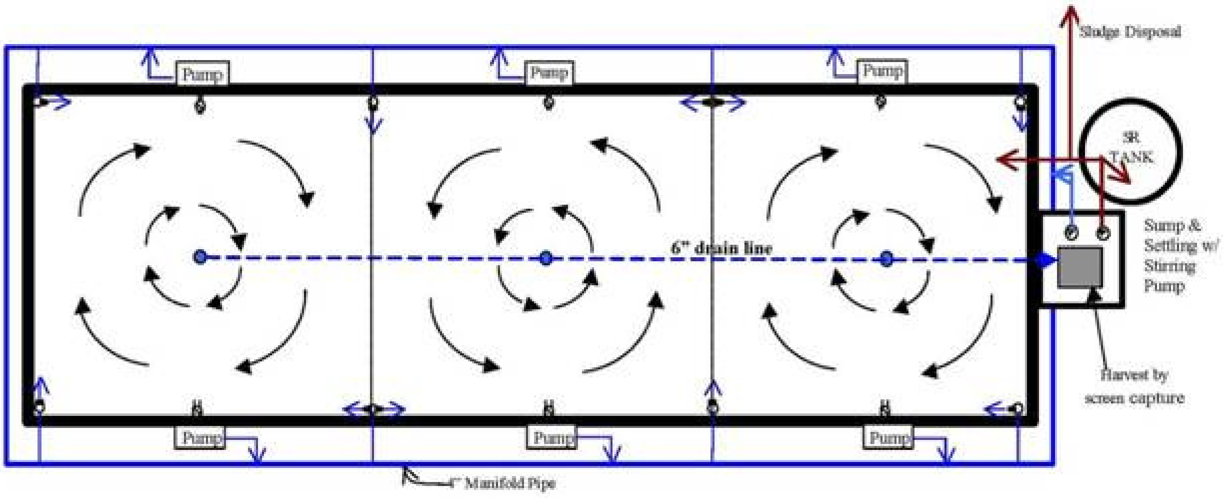


True et al.

Stechey

The mixed-cell raceway (Figure 13) was designed by Watten and Honeyfield (1995, 2000) to integrate the beneficial characteristics of raceways (e.g. grading, harvesting, efficient use of space) with those of circular tanks (e.g. self-cleaning design, elimination of metabolite concentration gradients, more homogenous hydraulics) by hydraulically segregating a conventional raceway into a series of counter-rotating mixed cells (Ebling et al. 2004; Labatut et al. 2004). Mixed-cell raceways offer the added advantage of being able to be operated as either partial re-use or intensive recirculation systems.

Figure 13: Mixed-cell raceway layout and flow pattern (Source: Ebling et al. 2004)

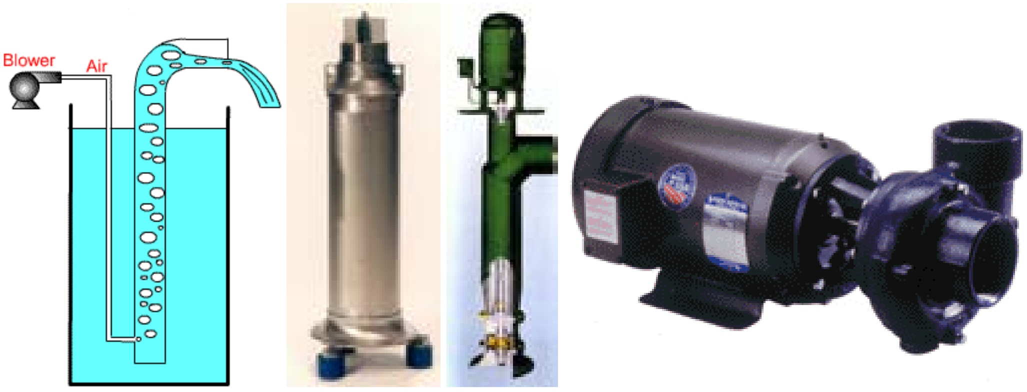


5.3 Hydraulics

The costs associated with moving water through an aquaculture system can be significant. It is important, therefore, that pumping efficiencies be factored into the design. Three pump types are typical: centrifugal impeller pumps, axial flow propeller (submersible) pumps and airlift pumps (Figure 14). Characteristics of each are provided in the following chart. All three types can be designed to operate efficiently in accordance with the needs of the system.

Pump	Operating Head	Solids Tolerance
Centrifugal	Medium ←→ High	Low
Axial	Low ←→ Medium	High
Airlift	Very Low	High

Figure 14: Basic pump configurations.
A. Airlift (www.geyserpump.com) B. Axial Flow–Submersible (www.carrymfg.com)
C. Axial Flow–Propeller (www.water-technology.net) D. Centrifugal (www.service-filtration.com)



A. B. C. D.

5.4 Suspended Solids Control

5.4.1 Sedimentation

Sedimentation occurs as a result of gravity forcing particles heavier than water to “settle” to the floor of a tank. Since the wet density of solid wastes from trout farming operations ranges from 0.93 to 1.26 g/cm^3 and averages 1.07 g/cm^3 (Johnson et al. 2002), settling chambers must provide for quiescent conditions for effective sedimentation. In turbulent flow conditions, such light solids will be easily re-suspended in the water column and removal efficiency will be compromised.

Installing settling zones at the end of raceways is relatively inexpensive in terms of direct costs for screens, vacuuming equipment for solids removal, etc. The loss of production space, however, can be significant.

Advantages and Disadvantages of Settling Basins for Clarification of Aquaculture Effluents

Advantages

- Simple
- No mechanical components
- Very low head loss
- Effective for end-of-raceway applications
- ~60% to 80% efficient
- Vacuumed wastes at ~5% solid matter

Disadvantages

- Large surface area required
- Difficult & labour-intensive to remove settled wastes
- Solubilisation of nutrients from sediment
- Only remove solids >100 µm

Sludge cones were invented in response to the need to enhance environmental performance in Danish raceway systems. After testing several design concepts, a 1 metre square by 1 metre deep pyramidal cone was selected as the design that offered the best combination of performance and practicality (Figure 15). Since considerable shear forces are required to flush fish manure, it is essential that the cones have a steep slope to facilitate the movement of the sludge to the base of the cone (Rasmussen et al. 2004). By periodically lifting a standpipe installed in the base of the cone, the settled solids can be intermittently flushed from the cones to a waste treatment / containment facility (Figure 15).

Sludge cones are positioned in raceways behind a screen intended to keep fish from swimming over the settling area. Although the settling area is relatively short (2 metres), Danish data demonstrate that sludge cones are effective for removing a considerable proportion of solid waste.

Figure 15: (L.) Sludge cones being installed in a raceway.
(R.) Standpipes extending from sludge cones in a Danish raceway

Michaelsen (2003)

Stechey

Advantages and Disadvantages of Sludge Cones
for Clarification of Aquaculture Effluents

Advantages

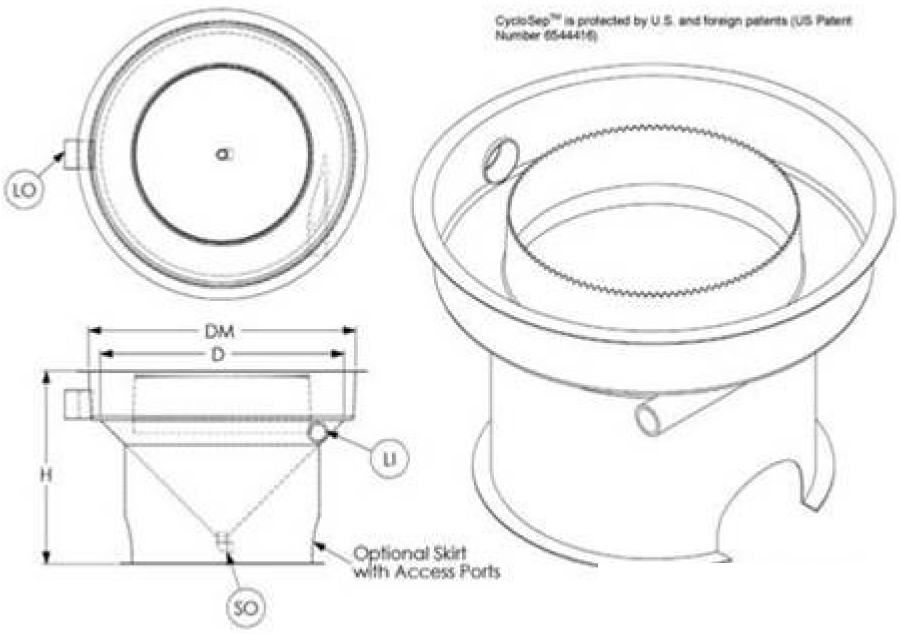
- Simple
- No mechanical components
- No head loss
- Effective for in-raceway application
- Solid wastes effectively concentrated and removed with little water
- May be retrofitted into existing operations

Disadvantages

- Only remove largest solids; > 100 µm
- Relatively expensive @ ~$500 each times 3 to 6 units per raceway

Swirl separators are commonly employed to pre-concentrate wastes from fish culture operations prior to further treatment and have been particularly effective for pre-concentration of wastes from double drain systems (Figure 16). Their most practical application is in reducing the total volume of water to be treated. Veerapen et al. (2003) confirmed that swirl separators operate by gravity (not by centrifugal action) and found that removal efficiency was proportional to overflow rate; that is the volumetric flow rate per unit surface area of the separator.

Figure 16: Swirl separator schematic (Source: PRAqua Technologies Inc.)



Advantages and Disadvantages of Swirl Separators
for Clarification of Aquaculture Effluents

Advantages

- Small footprint
- Reduces subsequent treatment needs
- Rapid sludge removal at ~2-5% solid matter
- No mechanical components
- Low pressure drop (hydraulic head)

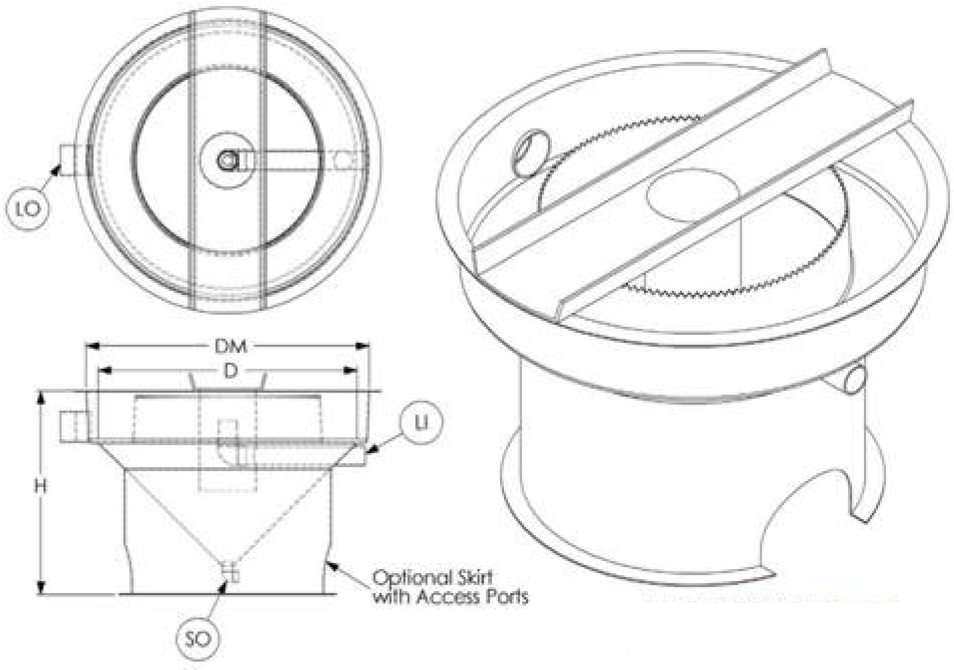
Disadvantages

- Turbulence breaks up solids into smaller particles
- Treated effluent may still contain substantial solids concentration
- Only effective for large particles (typically > 100 µm)

Radial-flow clarifiers are conceptually similar in design to swirl separators (Figure 17), however the hydraulics of the two technologies are markedly different. Water enters a radial-flow clarifier inside a central cylinder designed to dampen turbulence and flows radially toward an overflow weir located around the perimeter of the unit. Thus, the operational hydraulics of a radial-flow clarifier is more analogous to a settling basin whereas swirl separators utilize centrifugal hydraulics. Both units have a 60° cone-shaped bottom to concentrate the wastes and facilitate flushing.

Under similar operational conditions, Davidson and Summerfelt (2004) found that radial-flow clarifiers removed 72% to 80% of solid wastes compared to only 39% to 48% removal using swirl separators. Johnson and Chen (2004) observed that the efficiency of solids removal in radial flow clarifiers was similar to that of microscreen drum filters at equivalent TSS concentrations.

Figure 17: Radial-flow clarifier schematic (Source: Marine Biotech Inc. 2004)



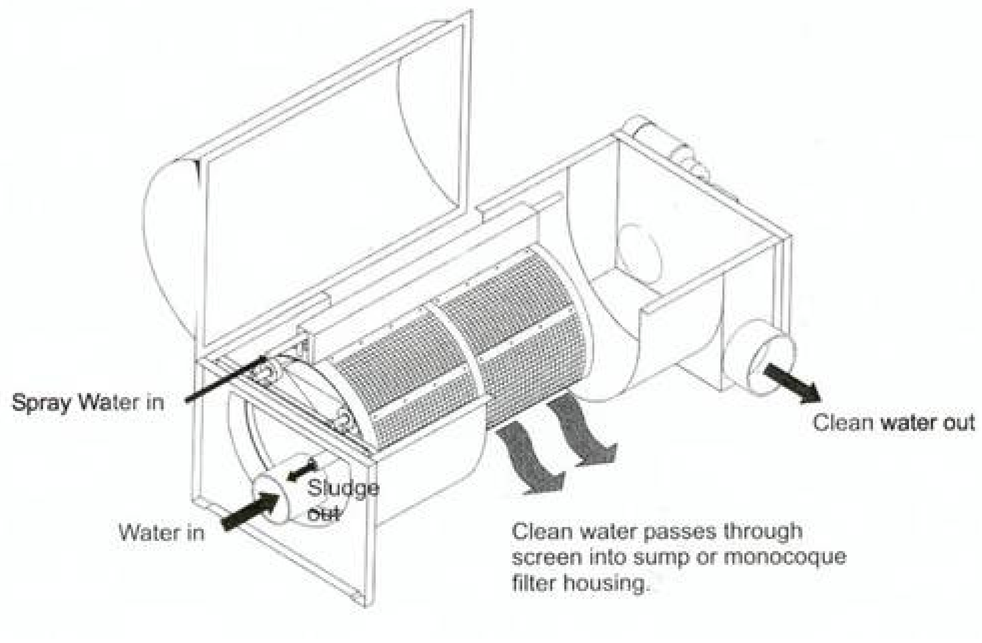
Advantages and Disadvantages of Radial-Flow Clarifiers
for Clarification of Aquaculture Effluents

Advantages	Disadvantages
▪ Small footprint ▪ Low pressure drop (hydraulic head) ▪ Rapid sludge removal at ~2-5% solid matter ▪ Reduces subsequent treatment needs ▪ No mechanical components ▪ Efficiencies similar to microscreen filtration	▪ Turbulence brakes up solids into smaller particles ▪ Treated effluent may still contain substantial solids concentration ▪ Only effective for large particles (typically > 100 µm)

5.4.2 Mechanical Filtration

Rotary drum filters provide an effective means to significantly reduce the concentration of discharged nutrients from fish culture operations (Figure 18). Process water flows into the center of the filtration drum, which is constructed from fine mesh stainless steel screen. As solid waste collects on the screen, the water level rises inside the drum, eventually activating a float switch that triggers the drum to rotate. While rotating, a high-pressure backwash spray releases the captured solids from the screen.

Figure 18: Schematic view and operational principles of a rotary drum filter. (Source: PRAqua Supplies Ltd.)



Advantages and Disadvantages of Rotary Drum Filters
for Clarification of Aquaculture Effluents

Advantages

- Very compact
- Supports high flows
- Pore size, drum speed and filter size can be adapted to the application
- Automatic backwash
- Low pressure drop (hydraulic head)
- No solid waste stored in system
- Effective to ~40 microns

Disadvantages

- Liquid backwash stream to be managed
- Variable efficiency depending on TSS concentration
- Backwash water is enriched having TSS concentrations in the range of 200 – 1,000 mg/L.
- High oil content of feeds plugs screens and requires periodic cleaning with warm water under high pressure

Belt filters are similar to drum and disk filters in that they employ fine mesh screens to trap particulate wastes. The filter "belt", however, is typically angled at approximately 30 degrees to enable the water flow to gently push accumulated solids up the belt, thus allowing them to "drip dry" for a period before the belt rotates and the sludge is discharged off of the end of the belt into a collection vessel (Figure 19). Belt filters are effective for thickening sludge and are commonly used to de-water the backwash flow from drum filters and from vacuumed settling basins. They can produce sludge with a dry matter content of 8% to 12%. They are not typically used for clarification of high volume process flows.

Figure 19: Commercially available belt filters.
(L: Hydrotech AS – R: PRAqua Supplies Ltd.)

Advantages and Disadvantages of Belt Filters
for Clarification of Aquaculture Effluents

Advantages

- Very compact
- Concentrated wastes
- Pore size, belt speed and filter size can be adapted to the application
- Automatic cleaning
- Low pressure drop (hydraulic head)
- No solid waste stored in system

Disadvantages

- Does not readily support high flows
- Variable efficiency depending on TSS concentration
- High oil content of feeds plugs screens and requires periodic cleaning with warm water under high pressure

5.5 Biofiltration

There is considerable debate as to which is the most appropriate biofilter technology for intensive aquaculture. Timmons et al. (2001) suggest that an ideal biofilter would remove 100% of inlet ammonia, produce no nitrite, have a small footprint, use inexpensive media, have a low operating head, require no maintenance and would not capture suspended solids. Since no single biofilter design meets all of these criteria, those criteria most important in a specific application must be reflected the biofilter selection process.

Additionally, an ideal biofiltration medium will have a high specific surface area capable of supporting a bacterial population, a high void space in operation, a low mass, be inert and have a low cost. Media can be manufactured structural support systems (e.g. BioBloc), random dump media (e.g. Kaldness, Flexi-Ring) or simple commodity products such as expanded polystyrene beads and sand (Figure 20).

Figure 20: Some examples of biofilter media.
Left - BioBloc Centre - Polystyrene beads Right - Random dump engineered media

5.5.1 Fixed Bed Filters

Fixed bed filters come in three basic designs – trickling towers, submerged bed filters and rotary biological contactors. The media can be a random dump medium or a structural block medium.

Trickling filters contain the biofiltration medium in a vessel or tank into which the process effluent flows. Such units are continuously wetted but never flooded and thus air is always present around the media.

Advantages and Disadvantages of Trickling Filters
for Aquaculture Biofiltration

Advantages	Disadvantages
Easy to construct and operate Low maintenance Self-aerating Effective at off-gassing CO_2 Self-cleaning (w high void space media) Moderate capital cost Medium head application $R_{TAN} = 0.1 – 0.9\ g/m^2/d$	Subject to plugging, requiring periodic cleaning Footprint can be large

5.5.2 Moving Bed Filters

In a moving bed filter, the media are continuously submerged in water. Having a specific gravity slightly greater than water, the media are easily mixed using aeration, thus providing sufficient oxygen, carbon dioxide stripping and effective exposure of the media to the influent. Random dump media such as Kaldness or BeeCell are typical (Figure 21).

Figure 21: Moving bed biofilter with Kaldness media.

Advantages and Disadvantages of Moving Bed Filters
for Aquaculture Biofiltration

<u>Advantages</u>	<u>Disadvantages</u>
▪ Easy to construct and operate	▪ Footprint can be large
▪ Medium-pressure aeration	▪
▪ Effective at off-gassing CO_2	
▪ Self-cleaning	
▪ Moderate capital cost	
▪ Low head application – energy-efficient	

5.5.3 Fluidized Bed Filters

Fluidized bed filters are frequently used in aquaculture recirculation systems. Two types are common – up-flow filters using sand as the biofiltration medium and down-flow filters using buoyant plastic beads. In both cases, the medium is small – usually less than 1.5 mm diameter. Such filters consist of a large vessel constructed of concrete, fibreglass or polyethylene into which the medium is placed.

In <u>fluidized sand filters</u>, water is injected into the bottom of the unit with sufficient energy to expand the sand bed, exposing the biofilm on the surface of the sand to the upward-flowing water. The energy requirements to maintain the fluidized bed can be high, although lower-energy, units with an inlet annulus structure are available (Figure 22).

Figure 22: Conventional up-flow fluidized sand biofilter (L – PRAqua Ltd.) and a lower-energy unit with an inlet annulus structure (R – Marine Biotech Inc.).

Advantages and Disadvantages of Fluidized Sand Filters for Aquaculture Biofiltration

Advantages

- Very high specific surface area
- Easy to scale-up to large sizes
- Moderate capital cost
- Compact design / small footprint
- $R_{TAN} = 0.2 – 0.4 g/m^2/d$

Disadvantages

- High head pressure / high pumping cost
- Requires aerated water supply
- Can be difficult to operate
- High maintenance costs
- Medium expulsion is common

Although similar in concept, down-flow plastic media filters operate at a greatly reduced head – typically only as much as the static lift and friction losses in the piping. Expanded polystyrene beads are used for the biofilm medium. Being buoyant, the beads float in the downward flowing water, which keeps the beads mixed and wetted (Figure 23).

Figure 23: Down-flow micro-bead plastic media biofiltration.
(L: Home-made biofilter – R: Holder-Timmons Engineering biofilter)

Advantages and Disadvantages of Micro-Bead Biofilters for Aquaculture Biofiltration

Advantages

- Very high specific surface area
- Low head pressure / low pumping cost
- Relatively low capital cost
- Compact design / small footprint
- Low medium expulsion rate
- Easy to operate
- Easy to scale-up to large size
- $R_{TAN} = 0.2 – 0.4 g/m^2/d$

Disadvantages

- Not self-aerating

5.6 Dissolved Gas Management

Dissolved gas management in recirculating aquaculture relates to provision of oxygen to meet the metabolic demands of the fish and the biofilter and the removal of soluble carbon dioxide which is released as a metabolic by-product.

5.6.1 Oxygenation

Aeration

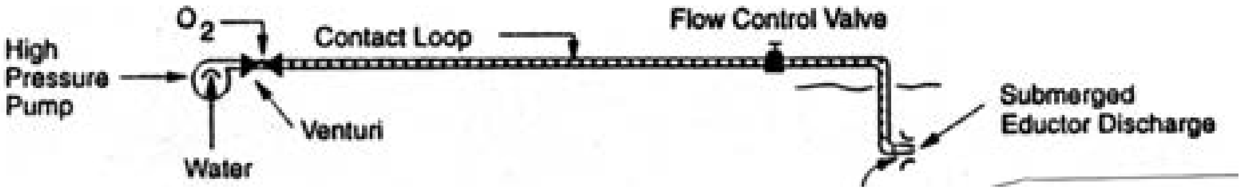
Injection of atmospheric air into culture tanks with the use of regenerative blowers has been applied in intensive aquaculture for decades. This simple technology has modest capital and operating costs, however, the concentration of oxygen in water cannot be super-saturated, thus limiting carrying capacity.

Figure 24: Atmospheric air injection

Side Stream Oxygen Injection

Side stream injection systems are capable of attaining very high levels of supersaturation (>300 mgO^2/L). Under such circumstances, oxygenation is achieved by injecting liquid (not gaseous) oxygen into only a portion of the process flow and then blending the highly supersaturated water back into the main water supply. Since pressures in excess of 80 psi are required, the pumping cost can become significant and hence it is beneficial to minimize pumping volumes. (Figure 25)

Figure 25: Schematic of Side Stream Oxygen Injection



<u>Oxygen Saturators</u>

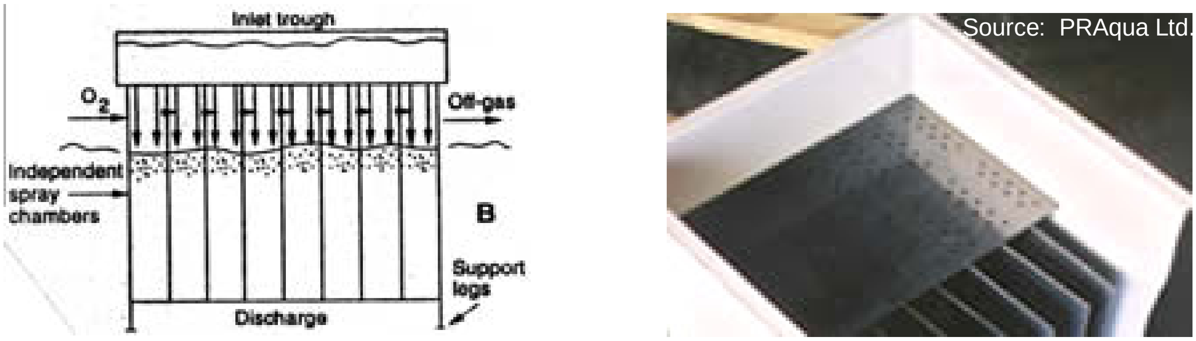
Oxygen saturators are sealed columns that increase in diameter with depth. They are either cone-shaped or are constructed of pipe sections of increasing diameter from top to bottom. Oxygen and water are introduced at the top of the column where the column diameter is narrow and water velocity (and hence turbulence and mixing) is greatest. As the water flows downward, the buoyancy of the oxygen bubbles struggle to rise against the current and thus the contact time between oxygen and water is maximized, increasing absorption efficiency. To enable super-saturation, saturators are operated under moderate pressure - typically around 15 psi (35').

Figure 26: Process flow diagram and photos of Oxygen Saturators

<u>Multi-Stage Low Head Oxygenator</u>

As their name implies, Low Head Oxygenators (LHOs) offer the advantage of delivering oxygenation at extremely low operating head - often as low as 0.3 meters. However, since LHOs are limited to achieving a maximum of ~170% to 180% saturation, it is typical to oxygenate the entire process flow. LHOs are often preceded by aeration / CO_2 stripping towers which serve two benefits - they remove excess dissolved CO_2 from the water and they can increase the oxygen concentration to approximately 90% saturation. The former enhances the biological performance of the fish and the latter reduces the amount of supplemental oxygen that must be added; pure oxygen is used solely to achieve super-saturation.

Figure 27: Process schematic and break-away illustration of an LHO



Source: PRAqua Ltd.

Micropore Oxygen Diffusers

Micropore diffusers introduce pure oxygen into water as minute bubbles - generally in a cloud of 100- to 500-micron diameter bubbles. Such small bubbles create a considerable surface area to volume ratio and thus significantly enhance oxygen transfer capability. An operating pressure of approximately 35 psig is required for optimal effectiveness. Micropore diffusers offer two advantages - low capital cost and no electrical or pumping requirements. Diffusers are simply placed on the bottom of the culture tanks and gaseous oxygen is fed directly to them, under pressure from the bulk storage facility. The principal disadvantage of diffusers is their low oxygen transfer efficiency. In 1.4 m of water, transfer efficiency can be expected to be only about 40%, therefore, diffusers would use almost 2½ times as much oxygen as a sealed packed column, which operates at close to 100% efficiency.

Figure 28: Micropore Oxygen Diffusers

Gas inFusion Technology[12]

Gas inFusion Technology is a global platform technology with numerous potential market uses, both stand alone and bundled with other technologies. The Technology is a unique method of infusing gas into liquids with demonstrated ability to:

- Effect rapid, no bubble, gas transfer (inFusion);
- Create ultra-saturation dissolved gas conditions, e.g., dissolved oxygen concentrations of hundreds of PPM;
- Allow long term retention of very high, dissolved gas concentrations;
- Eliminate most dissolved gas losses into the atmosphere;
- Achieve gas transfer efficiencies with respect to power used, of 7 to 9 times that of the best conventional methods;
- Produce less dense liquids;
- Enhance performance and increase capacity of existing process infrastructures;
- Be flexible and comparatively small to be fitted into, or parallel to, conventional process technologies; and
- Be easily operated and maintained.

Gas inFusion is a mass transfer operation whereby sparingly soluble gases are dissolved in liquids in a completely bubbleless fashion. The efficiency of this manner of mass transfer allows the production of stable liquid streams containing enormous quantities of dissolved gas on scales ranging from cc/min to thousands of GPM at a fraction of the energy cost normally associated with gas dissolution. The Gas inFusion system uses a hollow fibre membrane module to provide a very high surface area for gas transfer (Figure 29). The hydrophobic nature

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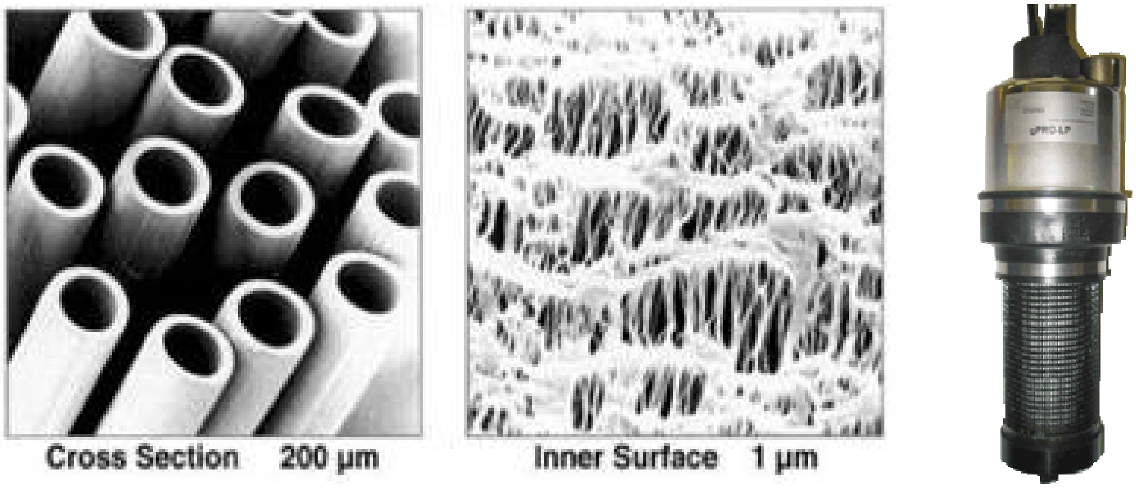
[12] Source: http://www.gasinfusion.com/html/GasInfusionTechnology.html

of the fibres allows the gas to be present within a fibre micropore at a lower pressure than the liquid it is transferring to. This means that the transfer can take without the formation of bubbles.

Figure 29: Hollow fibres used by inVentures Technologies within the PurGRO2® unit.



PurGRO2**®** is both a method and a system designed for use in aquaculture in order to improve and to optimize the raising, growing out and live shipment of fresh water and salt water species. It is comprised of low-pressure and high pressure components, which may be employed separately or in conjunction with one another.

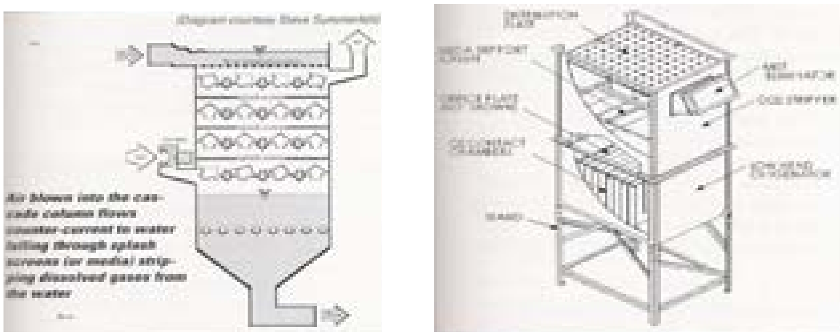
This improvement typically characterized by increasing growth rates, higher stocking densities and reduced mortality, is brought about by employing inVentures Technologies' innovative Gas inFusion Technology to optimize and enhance the 'atmosphere' at each stage in the aquaculture process.

5.6.2 Carbon Dioxide Stripping

Carbon dioxide is generated as a by-product of metabolism. Typically, it is produced at ~127% to 138% of the oxygen consumption rate. For salmonid fishes, the safe limit is generally accepted to be less than 30 mg/L, however systems are generally designed to keep CO_2 concentrations below 10-15 mg/L. If the biofilter is not a trickling filter and pure oxygen is the primary source of oxygen, then it is likely that a CO_2 stripper is necessary.

Because CO_2 is extremely soluble in water, it is best managed by high-rate gas:liquid contact using G:L ratios between 4:1 and 10:1. This is considerably greater than that provided through aeration systems (< 3:1) and oxygenation systems (< 0.3:1). CO_2 can also be managed by addition of carbonate to increase pH. Counter flow systems (air up – water down) are the most efficient means for stripping CO_2 in aquaculture systems. Efficiency is largely determined by packing depth (1-2 m), packing type (porous media or screens), hydraulic loading rate (1.0-1.4 m^3/m^2/min) and G:L ratio (>4:1).

Figure 30 : Process concept and equipment configuration for CO_2 stripping



5.7 Heating / Cooling, Buildings & Infrastructure

Installation of an aquaculture facility within a building or structure typically addresses four principal functional considerations:

1) Biosecurity
  - minimize introduction of disease and/or parasites

2) General Security
  - protection of livestock from predation and theft
  - protection of property from theft and tampering

3) Temperature Control / Management
  - thermal insulating properties of the building should be considered
  - generally two factors – heating / chilling and heat loss / gain
  - heating from solar gain and/or combustion with heat recovery
  - insulating value of walls and ceiling
  - high humidity must be considered in materials selection

4) Specific Aquaculture Needs
  - sufficient room to tend to fish and service tanks
  - Allow space for filtration, O_2 systems, mechanical, back-up power, etc.
  - low-humidity area for feed storage and administrative functions
  - sufficient drainage to prevent standing water
  - electrical service sized to meet needs (current and future)

Basic structures used in aquaculture include greenhouses (free-standing or gutter-connected), pole barns and other pre-fabricated steel buildings and Cover-All^{TM} structures. Air inflated structures are less commonly used.

Figure 31 – Examples of Basic Structures

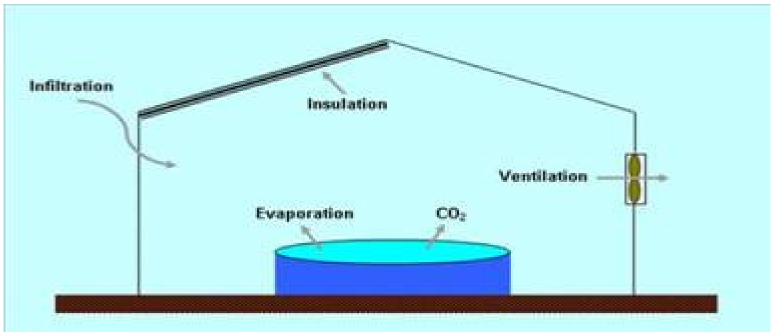
Gutter-Connected Greenhouses
- ✓ Relatively inexpensive
- ✓ Polycarbonate walls are fairly secure
- ✓ Internal walls can be added if needed
- ✗ Must work around internal supports
- ✗ Snow collects in gutters (heating req'd)

Cover-All^{TM} Structures
- ✓ Multi-purpose agricultural structures
- ✓ Clear-span widths from 18' to 160'
- ✓ Fabric has 15-year warranty

Pole Barn Structures
- ✓ Mulit-purpose agricultural structures
- ✓ Steel-clad inside and out
- ✓ Easy to insulate

Humidity (moisture) and CO_2 will accumulate within the building. At 100% RH, there will be little evaporative heat loss, but the building & equipment may deteriorate more quickly. In general, an air exchange rate of ~1–2 building volumes per hour should keep RH at ~80% and maintain CO_2 at healthy levels.

Figure 32 : Schematic of building ventilation



5.8 Disease Management

Disinfection of process water is generally required in intensive aquaculture to control bacterial and viral pathogens. Ozone injection and ultraviolet light are the two most common technologies.

5.8.1 Ozone

Ozone (O_3) is a powerful oxidizing agent that is relatively unstable in air and water. In air, it has a half-life of approximately 12 hours whereas in water its half-life is measured in seconds to minutes. Therefore, ozone must be generated on-site.

Ozone functions as a disinfectant by disrupting long-chain organic molecules. Bacteria and viruses can be destroyed and water quality can be improved since ozone reduces turbidity, colour, COD, BOD and total protein concentrations. Its efficacy as a disinfectant is a function of contact time and concentration. Ozone residuals in water can be harmful to fish (<0.01 mg/L for trout) but can be stripped by passing through a biofilter, charcoal, aeration column or UV sterilizer. Ozone is also harmful to people. It can be fatal at 20 mg/L for 1,000 minutes. Its pungent odour, however, can be detected at only 0.1 mg/L.

Ozone can effectively pre-condition water for biofiltration by splitting large organic compounds into smaller biodegradable materials that are more easily removed by heterotrophic biofilter bacteria. Biofilters generally operate more effectively and require less maintenance in ozonated systems, and water quality is noticeably improved.

5.8.2 Ultraviolet Irradiation

UV irradiation is a commonly used disinfection process in aquaculture systems. Wavelengths of 254 nm to 265 nm are most effective for disrupting and mutating the DNA of microbes. Efficacy is related to contact time and intensity (dose – measured in µW sec/cm^2). General protection is provided at doses of 30,000 to 35,000 µW sec/cm^2, however, specific pathogens, water turbidity & clarity will influence dosage.

Suggested UV Dosages
(µW sec/cm^2)

Pathogen	Dose	Pathogen	Dose
IHN Virus	30,000	Myxosoma	35,000
IPN Virus	150,000	Ceratomyxa	30,000
Aeromonas	3,620	Trichodina	159,000
Bacilus spores	22,000	Ichthyophthirius	100,000
Saprolegnia	39,600		

(Source: Rodriguez and Gregg 1993)

While off-the-shelf units are readily available making it easy to incorporate UV into system design, the units require routine maintenance and repair. The quartz tubes that house the lamps are subject to fouling and the lamps lose intensity as they age - up to 40% reduction within 6 months. Nevertheless, UV is effective against targeted pathogens at the proper dosage, convenient and affordable. Furthermore, it produces no toxic by-products or harmful effects for humans since the lamps are contained within sealed units.

5.9 Feeding Fish

Different feeding strategies are routinely applied in commercial aquaculture, including:

Satiation Feeding Fish are fed until their feeding behaviour stops or declines significantly. This can be accomplished manually by closely watching the feeding behaviour of the fish and/or by using technologies to detect when feed pellets are passing the fish and exiting the bottom of the cage or tank uneaten. At such time, feeding is terminated.

Demand Feeding Fish are able to trigger the release of feed from feeders on-demand. In demand feeding, however, the more aggressive fish dominate and it becomes difficult to get the entire population to feed to satiation. Consequently, the size distribution of the population is amplified resulting in reduced productivity.

Ration Feeding Fish are fed a prescribed daily ration according to standards for the size of fish and water temperature to produce the target growth response. Inaccuracies in the ration model can be significant due to poorly developed production models, inaccurate inventory records (fish size and number) and variability in appetite and can therefore result in substantial over- or under-feeding (Kimura et al. 1993). Moreover, to avoid wasting feed, rations are usually adjusted to a level just below the demand of the fish; consequently, productivity is compromised.

On most trout farms, feed is delivered under the direct control of farm workers either through hand-feeding or by directly controlled mechanized feeders. Visual monitoring of feeding activity is relatively easy in land-based farms where feed accumulating on the bottom of shallow tanks can be readily observed. Many factors combine to cause variation in fish feeding behaviour from day to day and, therefore, it is essential to monitor feeding activity and the effectiveness of the feed delivery method to ensure that feed is not wasted and that feed conversion efficiency and growth are optimized.

A variety of devices (air lifts, ultrasonic detectors, underwater cameras, etc.) have been developed and are marketed commercially to monitor feeding activity from below the surface as a means of improving growth and feed conversion efficiency and to reduce feed wastage. The more sophisticated systems involve use of Doppler, hydro-acoustic and ultrasonic systems to detect feed pellets. These systems use sensors located near or below the bottom of the deep rearing units or in the effluent piping from a land-based tank farm, to detect uneaten pellets or monitor feeding activity and provide feedback to a computer controlled mechanized feeding system (Alvarado 1997; Anon 1997; Lindem and Al Hourai 1993). Two such technologies are described below.

5.9.1 Hydro-Acoustic Systems

Hydro-acoustic systems utilize a wide-beam transducer located under the water to monitor the distribution of fish near the surface. Fish behaviour during feeding events is monitored and analyzed. Using a feedback mechanism, feeding is reduced or stopped as the fish reduce their feeding activity (Lindem and Al Hourai 1993).

Advantages

- Records total feeding time and feed consumed in each pen or tank
- Detects changes in biomass, indicating theft or escape through a damaged net

- Alarms for various conditions can be incorporated into the system
- Can be installed below the net to avoid interference with net changing activities
- Permits direct control of automated feeding systems

Disadvantages

- Does not directly detect pellet loss
- Malfunctions may not be immediately detectable

5.9.2 Ultrasonic Waste Feed Controller

Developed at the Freshwater Institute based on earlier Norwegian technologies, this device utilizes an ultrasonic probe to detect uneaten feed pellets in the effluent pipe from fish tanks (Summerfelt et al. 1995). The unit functions as a controller to terminate feeding from automatic feeders upon detecting a prescribed amount of waste feed. The unit also serves as a timer to start the automatic feeders at preset intervals.

Advantages

- Adaptable to any feeding system (i.e. hand delivery, demand, automatic with timed release, etc.)
- Almost completely eliminates waste feed
- Provides accurate information on feed dispensed to each tank
- Permits direct control of automated feeding systems

Disadvantages

- Malfunctions may not be immediately detectable

Hankins et al. (1995) monitored the performance of rainbow trout fed using different techniques (Table 1). While meticulous hand feeding produced the best performance, the ultrasonic waste feed controller produced better growth rate and equal or better feed conversion than either demand or ration feeding.

Table 1: Comparative performance of four feeding methods
with rainbow trout. Source: Hankins et al. (1995)

Feeding Method	Growth (g/d)	Feed Conversion (kg gain/kg feed)	Increase in Prod'n Efficiency (%)
Ration Diet	2.69	1.12	--
Demand Feeder	3.44	1.21	13
Ultrasonic Waste Feed Controller	4.37	1.15	29
Hand	5.12	1.15	51

5.10 Monitoring & Control

The move toward intensive, recirculating, controlled-environment production systems has greatly increased productivity – but is has also increased risk. Therefore, the need for back-up information, feedback and control systems cannot be overlooked. While some maintain that the best monitoring & alarm system is an experienced & awake human operator equipped with prescribed daily, weekly, monthly and seasonal routines to be observed and recorded /

reported, it is not possible for human oversight to be present at all places and at all times. Therefore, technological monitoring equipment is required.

Monitoring is a matter of timing. Alarms & back-up systems should reflect the level of risk and necessary response time (Timmons et al. 2001).

HIGH (respond in minutes)

- Electrical power supply
- Tank water levels
- Flow rates (on/off or continuous)
- Dissolved oxygen levels

MEDIUM (respond in hours)

- Temperature
- CO_2

LOW (respond in days)

- pH
- Alkalinity
- NH_3 / NO_2 / NO_3

5.11 Solid Waste & Effluent Management

A comprehensive waste management and environmental protection plan is an essential component of any farming operation and it must incorporate best management practices and nutrient management. Fundamental components include agricultural engineering, economics, aquaculture science and crop and soil sciences to maximize the value of the waste and minimize the potential for environmental degradation (Blake 1995).

Once the aquaculture manure has been removed from the process water and concentrated, there are few practical options for storage and disposal. Principally, this is due to the high moisture content of the waste (Chen 2001; Schwartz et al. 2004). The backwash from rotary drum filters can contain only 2% to 6% solids and is rich in organic nutrients. Consequently, it is sometimes further processed prior to discharge and the volume is generally small enough to be effectively managed using aerated lagoons, constructed wetlands, or anaerobic filters (Summerfelt and Vinci 2003).

Geotextile tubes may present a potential solution to the practical and economic challenges associated with concentrating aquaculture manure. Geotubes®[13] are tubular containers manufactured from a woven high-strength polyethylene material. When waste slurry is pumped into the tube, its porous structure enables rapid dewatering while containing solid matter (Miratech 2004). The practical application of Geotubes® for dewatering aquaculture wastes was evaluated at the Freshwater Institute in West Virginia. Schwartz et al. (2004) found that by hanging the bags vertically and pumping aquaculture wastewater backwashed from drum filters

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[13] Miratech – A Division of Ten Cate Nicolon Inc., 3680 Mount Olive Road, Commerce, GA 30567 USA. (706) 335-3400 Fax: (706) 335-3405 www.tcnicolon.com/geotube www.geotubes.com

into the tubes, more than 95% of solid wastes could be effectively contained. Polymers were found to enhance the removal rates of TN (79% to 85%) and TP (40% to 85%), however, performance differed substantially depending on the specific polymer used. When no polymer was added to the waste slurry, removal rates for TN and TP were less than 36% and 30%, respectively. Additional testing is required to gain further practical knowledge regarding:

- the selection of appropriate polymers;
- hydraulic loading and dewatering rates;
- management practices to enhance performance;
- operational efficiency;
- compostability of residual solids; and
- economics.

5.11.1 Manure Disposal

Summerfelt (1999) identified four alternatives for disposal of fish manure: (1) land application; (2) composting; (3) vermiculture (using worms to stabilize sludge); and (4) wetland application. Only land and wetland disposal are common, however.

The most suitable disposal method for aquaculture sludge is land application as a soil amendment. This is effective with both raw and stabilized manure and guidelines exist to govern the application of aquaculture manures on crop and pasture lands. Land application of fish manures does have limitations and challenges, however. For instance:

- Manure can only be applied during the frost-free growing season;
- Offensive odours may be produced;
- Applied too thickly, manure may form a crust that some seedlings cannot penetrate;
- Transportation of liquid manure is expensive; and
- The nitrogen in fish manure is released slowly (about 30% in the first year).

5.11.2 Constructed Wetlands

A higher level of treatment can be attained using constructed wetlands as a polishing stage. Several factors affect the performance of constructed wetlands including: free water surface area, submerged flow rate, water depth, planted area, wastewater characteristics and flow rates, nutrient load, hydraulic retention time and the population of wetland plants and micro-organisms. A number of studies have evaluated the effluent treatment and nutrient removal performance of constructed wetlands for aquaculture effluents (Table 2).

Table 2: Comparative performance of constructed wetlands for treatment of aquaculture wastewaters.

System	Loading Rate ($L/m^2/d$)	Removal Rate (%) TSS	TN	TP	COD	Source
▪ Horizontal flow mixed grass wetland	150 – 180	na	40-44	92-99	na	Adler et al. (1996)
▪ Horizontal flow subsurface root systems	1028 – 5143	96-97	21-42	49-68	64-74	Schulz et al (in press)
▪ Reciprocating wetlands with subsurface flow	380 - 2280	na	99.9	73.4	90.7	Behrends et al. (2002)
▪ Ebb-and-flow vetiver grass wetlands	11	96	82	82	72	Summerfelt et al. (1999)
▪ California bullrush constructed wetlands	77-91	75-87	51-75	59-84	na	Schwartz & Boyd (1995)

Small multi-stage wetlands can be applied to process backwash waters effectively. In general the more stages the more stable these systems are. As a rule, at least three stages are required for a stable system. It has also been shown that by initially planting a wide variety of plants, these systems stabilize and the most suitable species will thrive. A combination of species including water hyacinth, rooted submerged aquatic plants such as *Potamogeton* and *Elodea*, and cattails, bulrushes or phragmites should be included. The species composition will change with time until a stable equilibrium is reached.

In some operations, it may be possible to operate these systems indoors or in greenhouses to provide year-'round productivity. A peat bed could also be included as a final polishing step.

6.0 PRODUCTION STRATEGIES

Objective: *To present a production strategy that optimizes the productivity for rainbow trout and arctic char.*

6.1 Conceptual Facility Design

In March 2007, the Interprovincial Partnership for Sustainable Freshwater Aquaculture Development (IPSFAD) assembled a group of approximately two dozen recognized national and international authorities on the design, operation, management and regulation of land-based aquaculture systems. For two days, this group reviewed and discussed all aspects of intensive recirculating aquaculture systems including rearing unit design, hydraulics, solid waste management, biofiltration, gas exchange, fish health management, production planning, systems management and control, waste disposal, environmental controls, etc. The group discussed the advantages and disadvantages of available technologies and practices and reached consensus on most topics (the group agreed that both raceways and circular tank designs were practical if designed properly). The results of these discussions are reflected in the conceptual design for an intensive recirculating aquaculture facility for production of trout and/or char which is presented below.

The conceptual intensive RAS aquaculture facility (“Facility”) outlined herein can be used for either rainbow trout or Arctic char production. To capitalize on the superior hydraulics of circular tanks without forgoing the benefits of proven raceway technology, the system has been designed using octagonal tanks. The near-circular design allows for optimal hydraulics while removable gates between the tanks will allow for fish to be crowded and transferred between units.

The Facility consists of 4 early-rearing tanks measuring 5.5m diameter each and 6 grow-out tanks measuring 11.0m in diameter (Figure 33). All tanks are 1.68m deep. The total rearing volume in the system is 1,142 cubic meters. The facility also includes a 130 m^3 purge tank into which fresh, make-up water will be added to purge the fish of off-flavours prior to harvest (industry practice is to hold fish for 48 hours to two weeks). Total system volume is approximately 1,422 cubic meters.

The system is designed for a total recirculating flow of 31,800 Lpm (8,400 gpm) which provides a hydraulic exchange rate of 36 minutes in all tanks (Figure 34). With a make-up flow requirement of 397 Lpm (105 gpm), 40% of the total system volume is exchanged on a daily basis. The system operates at 99% recirculation based on hydraulic flow rate.

Water reconditioning systems consist of in-tank solids separation using dual drain technology with tank-side radial flow waste concentrators, rotary drum filtration, moving bed biofiltration, active carbon dioxide stripping and oxygen injection using low-head oxygenators (Figure 34). Ozone is also injected into the system as part of the water reconditioning process. Equipment specifications are detailed in Table 3.

System operating temperature is maintained using a natural gas or propane fired boiler. Prior to discharge, all process effluent passes through a heat exchanger to recover thermal energy, transferring it to the incoming make-up water supply.

Solid wastes removed via the tank-side clarifiers and the backwash from the drum filters are directed to on-site solids storage facilities.

The system requires a peak electrical demand of about 125 KW. In times of power failure, a diesel-powered back-up generator with an automatic transfer switch is available to maintain uninterrupted operations. The entire Facility is to be enclosed within a Cover-All®-type structure measuring 18.3 mW x 85.3 mL (60' x 280').

Figure 33: Conceptual layout of an intensive recirculating aquaculture facility for production of rainbow trout or Arctic char.

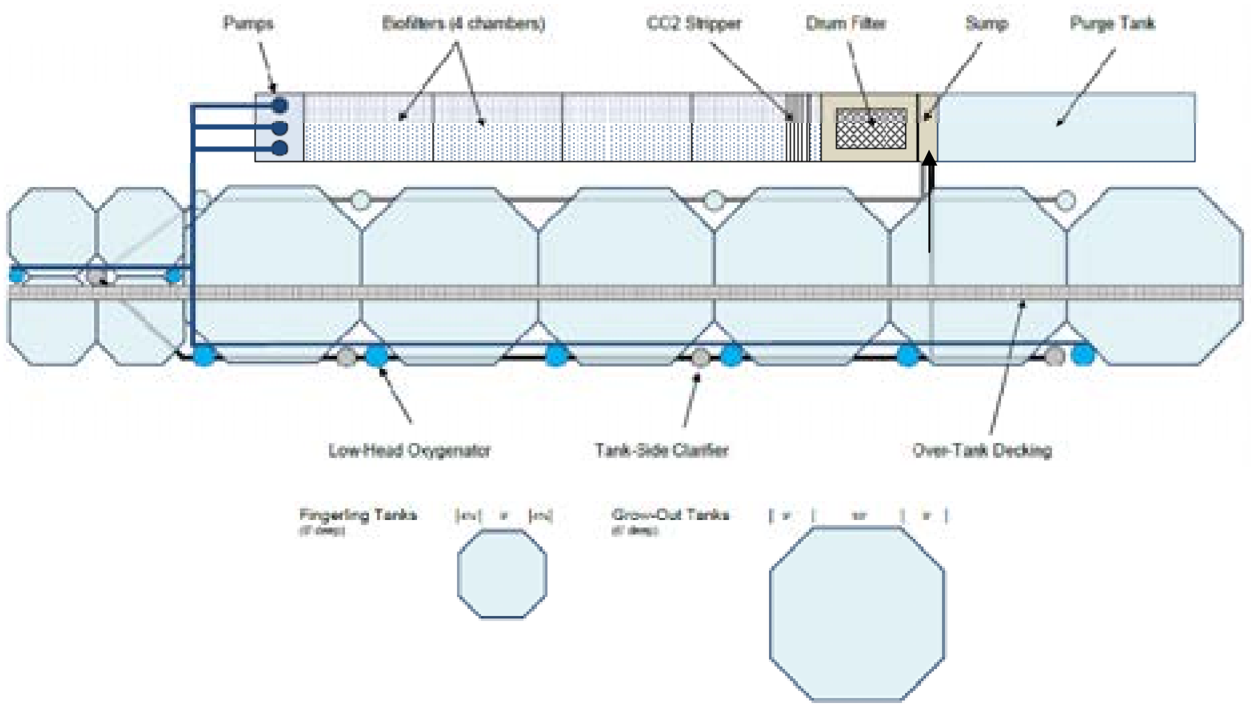


Figure 34: Process flow diagram for the conceptual rainbow trout / Arctic char facility.

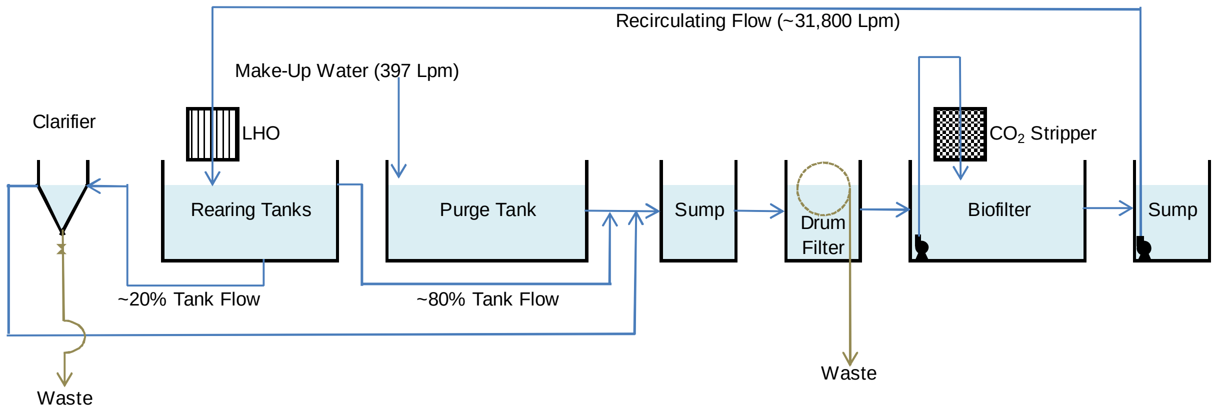


Table 3: Equipment specifications for the conceptual land-based recirculating aquaculture facility for production of rainbow trout and/or Arctic charr.

Tanks				
	Early Rearing (4)		38 m^3	1,056 Lpm / 279 gpm
	Grow-Out (6)		165 m^3	4,583 Lpm / 1,211 gpm
	Purge (1)		130 m^3	2,900 Lpm / 766 gpm
Feeders				
	Auger Feeders w Spreader		40 kg Capacity (4 units)	
	Auger Feeders w Spreader		60 kg Capacity (12 units)	
Water Treatment Systems				
	Clarifiers - Early Rearing		1.68m dia.	
	Clarifiers - Grow-Out		2.13m dia.	
	Drumfilter		Hydrotech Model 2007-2H, 60 µm	
	Biofilter		MB3 BioMedia (133m^3 - Trout / 153m^3 - Char)	
	CO_2 Stripper		4.3m x 1.7m x 1.4m	
	Circulating Pumps (3)		20 HP Vertical Propeller Pumps, 575V, 3Ph	
	LHOs - Early Rearing		0.9m dia.	
	LHOs - Grow-Out		1.4m dia.	

6.2 Production Modeling

To optimize productivity, separate production plans have been developed for rainbow trout and Arctic char. For both species, however, performance was modeled using the same intensive recirculation system to enable a comparison of performance between the species.

Assuming the use of standard farm management inputs including water temperature, maximum desired rearing density, number and size of early rearing and grow-out tanks, stock characteristics for expected growth and mortality rates, the models project the number and weight of fish that can be reared in the Facility. Fish growth is projected using a bioenergetics model that predicts fish size based on water temperature, feed consumption and a 'performance' factor. The latter is more commonly termed the temperature growth coefficient (TGC) and is a dimensionless number that measures the change in mass of a species based on time and temperature. Using historical data, TGC can be used to effectively project growth rates for fish under differing time frames and temperature regimes. The models are an effective management tool, enabling the scheduling for fingerling purchases, the projections of fish size and feed requirements, as well as the creation of harvest schedules required to maintain the size and quality parameters. The fundamental assumptions for each species are outlined in the following sections.

6.2.1 Rainbow Trout Production Plan

Production Strategy:

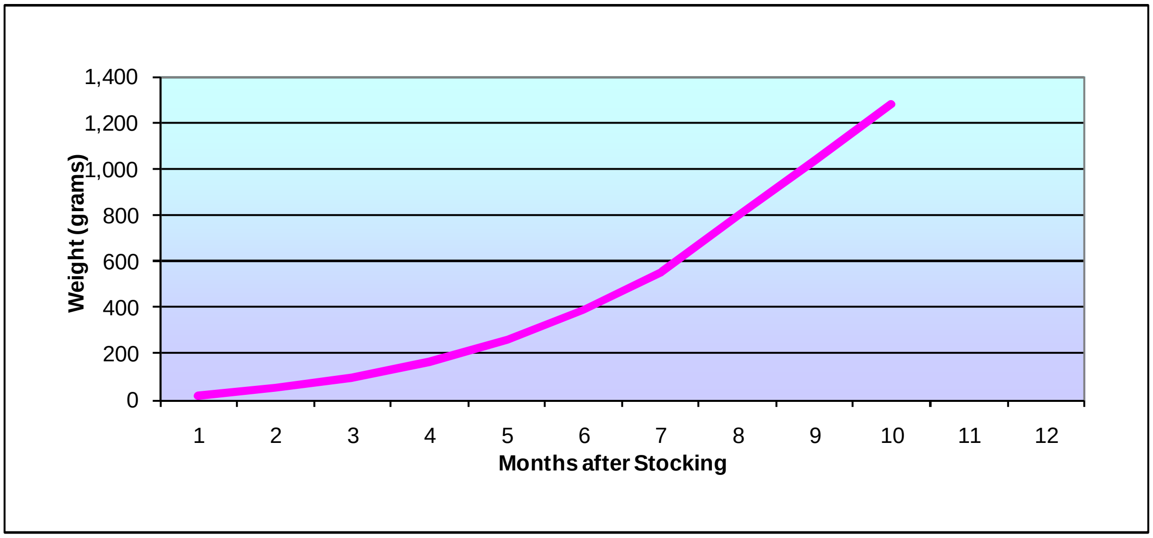
A strategy to produce 1,000-gram marketable fish within approximately 8 months of stocking fingerlings has been targeted. Water temperature, the initial stocking size of fingerlings (small fish) and husbandry techniques will all influence attainment of this strategy.

TGC:

Canadian experience with rainbow trout production suggests that a TGC between 1.8 and 2.2 is the norm. It is not unusual, however, to observe periods when the TGC falls well below 1.8 or exceeds 2.7. Lower-than-normal TGCs are usually encountered when fish are placed under considerable distress (e.g. low oxygen, high levels of soluble ammonia or CO_2, frequent disturbance, etc.) while higher TGCs are generally the result of optimal, experienced management.

With water temperatures maintained at a constant 15 degrees, the desired harvest size can be attained in approximately 9 months- starting with 20-gram fingerlings at a TGC of 2.0. Nine months is a practical growth period that enables efficient utilization of tank space throughout the production cycle. Therefore, production for the Facility has been modeled at 15 degrees and a TGC equal to 2.0. The growth of Rainbow trout is reflected in Figure 35.

Figure 35: Projected growth of rainbow trout at 15^{o}C with a TGC = 2.0. Growth is curtailed at the end of the cycle to accommodate harvest schedules.



Fingerling Availability:

The production plan calls for stocking 55,000 20-gram fingerlings every third month throughout the year. Eyed eggs are available year-round from Troutlodge (WA) and fingerlings can be secured from a number of Canadian hatcheries to meet the production schedule. This strategy enables fish to be harvested continuously over twelve months.

Harvest Size:

The commercial objective for the venture is the production of 224 – 265 gram (8-9 oz.) single-side fillets for North American food markets. A harvest size of approximately 1,000 grams per fish will yield this product, assuming a 53% fillet yield. To reflect the varied growth that occurs within a lot (cohort) of fish, harvesting has been staggered. In the month that the average fish exceeds 1,000 grams, 33% of the stock will be harvested. The remaining two-thirds of the lot will be harvested in equal amounts in the month immediately preceding and immediately following the month in which the average fish size exceeds 1,000 grams. This strategy should enable producers to supply fish geared toward a market demand. Monthly harvests of 16,700 kilograms of whole fish are projected, yielding an annual production capacity of 200 tonnes.

Rearing Density:

The maximum desired rearing density has been set to 70 kilograms of fish per cubic metre of rearing space. Although this peak is attained briefly during each production cycle, the average rearing density is 55 kg/m^3 in the system.

Monthly Mortality:

For the first two months following initial stocking of fingerlings, monthly mortality is modelled at 2.0%. In the subsequent months, it is reduced to 1.5%, 1.0% and then 0.75% for the balance of the rearing period. This relatively high average monthly mortality rate results in 91% of the fish stocked into the system being harvested.

Feed Requirements:

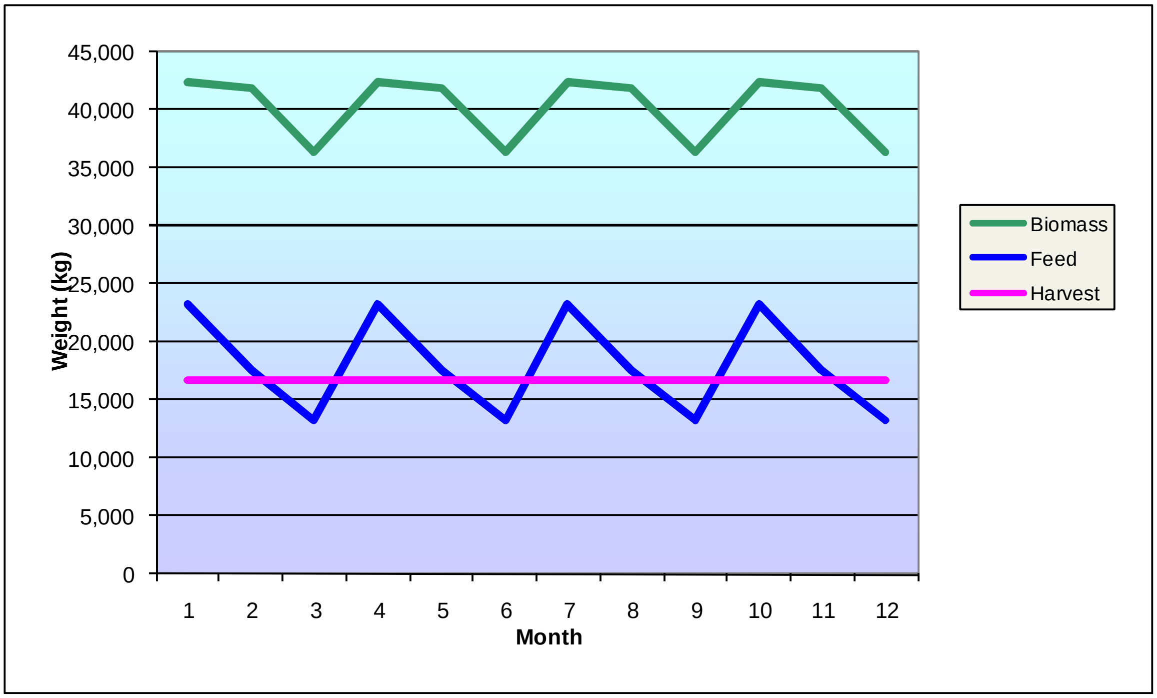
Using nutrient-dense (high energy) feed formulations, the monthly feed ration has been calculated by determining the amount of feed required to meet the growth projections given a Feed Conversion Ratio of 1.08 (that is, 1.08 kg feed used per 1.0 kg fish biomass gain).

A summary of this production scenario for rainbow trout is presented in Table 4. Overall biomass, feed and harvest schedules are summarized in Figure 36.

Table 4: Production summary for cultivation of rainbow trout

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Year 1													
Fingerlings (no)	55,000	0	0	55,000	0	0	55,000	0	0	55,000	0	0	220,000
Biomass (kg)	2,575	4,951	8,455	15,898	24,676	36,300	42,447	41,957	36,306	42,447	41,957	36,306	334,274
Harvest (kg)	0	0	0	0	0	0	16,700	16,700	16,700	16,700	16,700	16,700	100,200
Feed (kg)	1,504	2,424	3,574	6,718	9,280	12,270	23,216	17,618	13,285	23,216	17,618	13,285	144,010
Year 2													
Fingerlings (no)	55,000	0	0	55,000	0	0	55,000	0	0	55,000	0	0	220,000
Biomass (kg)	42,447	41,957	36,306	42,447	41,957	36,306	42,447	41,957	36,306	42,447	41,957	36,306	482,837
Harvest (kg)	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	200,400
Feed (kg)	23,216	17,618	13,285	23,216	17,618	13,285	23,216	17,618	13,285	23,216	17,618	13,285	216,479
Year 3													
Fingerlings (no)	55,000	0	0	55,000	0	0	55,000	0	0	55,000	0	0	220,000
Biomass (kg)	42,447	41,957	36,306	42,447	41,957	36,306	42,447	41,957	36,306	42,447	41,957	36,306	482,837
Harvest (kg)	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	16,700	200,400
Feed (kg)	23,216	17,618	13,285	23,216	17,618	13,285	23,216	17,618	13,285	23,216	17,618	13,285	216,479

Figure 36: Projected biomass, feed and harvest schedules for rainbow trout production.



6.2.2 Arctic Char Production Plan

Production Strategy:

A strategy to produce 1,000-gram marketable fish within approximately 12 months of stocking fingerlings has been targeted. Water temperature, the initial stocking size of fingerlings (small fish) and husbandry techniques will all influence attainment of this strategy.

TGC:

Growth trials with Arctic char conducted at the Alma Aquaculture Research Station, University of Guelph in Ontario, have achieved growth with an average TGC of 1.35 over a five year period, while a TGC of 2.01 has been achieved at the Coastal Zone Research Institute (CZRI) in New Brunswick, in a single lot of fish reared to over 800 grams. It is important to note that fish at the Alma Aquaculture Research Station, the CZRI and the Conservation Fund Freshwater Institute (Viginia, USA) were reared by staff with excellent fish culture skills. In comparison, growth of Arctic char in some commercial operations has demonstrated considerably lower TGCs as illustrated in Table 5.

Table 5: Available Temperature Growth Coefficient Information for Arctic Char.

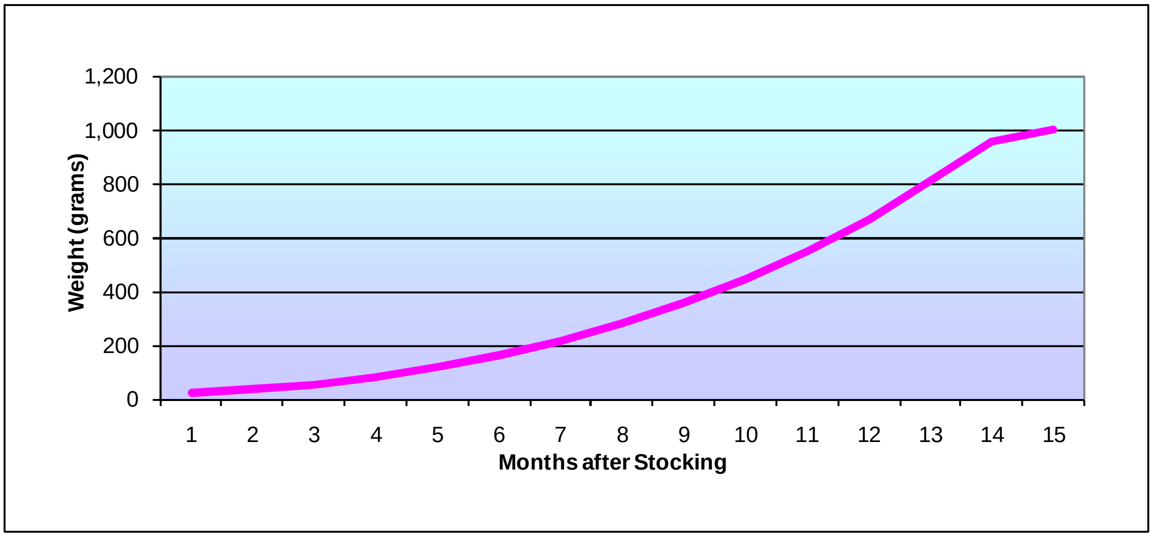
Source		**Fish Size (g)**	**TGC**
FR90		1 – 62.2	1.26
FR91		0.2 – 67.2	1.18
Pisciculture d'Alleghanys		0.7 – 1000	1.38
AARS – Univ. of Guelph		0.05 – (100-1200) **	1.35 (1.28 – 1.41)*
McGeachy & Delabbio 1989		5.7 – 172	1.35
Papst & Hopky 1989		10 – 183	1.39
Iwama (in Johnson 2002)		na	1.27
CZRI, Shippagan		20 - 280 347 - 865	1.55 1.18
Summerfelt et al. 2004	Nauyuk	(15.9-21.5) – (129-154)	1.36 (1.32-1.41)
	Tree River x Nauyuk	(16.9–51.5) – (175–294)	1.60 (1.41-1.73)

* Mean (range) of five year classes.
** Represents five year classes with varying final weights.
McGeachy & Delabbio (1989). Bull. Aquacult. Assoc. Can. 89(3):40-42.
Papst & Hopky (1989). Bull. Aquacult. Assoc. Can. 89(2):15-19.
Johnston (2002). Arctic Char Aquaculture. Blackwell Scientific.
CZRI (2003). Personal communication. Single tank of fish.
Summerfelt et at. (2004) Aquacultural Engineering 31:157-181

At a constant 12 degrees and with a TGC of 1.5, the harvest of 1,000-gram fish can begin in approximately 12 months after stocking 20-gram fingerlings. This production schedule enables efficient utilization of tank space throughout the production cycle.

Applying a constant TGC over the entire grow-out period is practical from a planning perspective, however, it is important to recognize that Arctic char do not feed and grow at a constant rate. Growth is a discontinuous process in Arctic char, which have evolved to deal with long periods of fasting during winter months followed by short bouts of heavy feeding and rapid growth during the summer (B.Glebe, pers comm.). The growth of Arctic char is reflected in Figure 37.

Figure 37: Projected growth of Arctic char at 12^{o}C with a TGC = 1.5. Growth is curtailed at the end of the cycle to accommodate harvest schedules.



Fingerling Availability:

The production plan calls for stocking 100,000 20-gram fingerlings every six months. Eyed eggs are currently only available to Canadian farmers twice annually (Spring and Fall) from Troutlodge (WA), Icy Waters (YT) and a small number of other hatcheries. Eyed eggs are available from Icelandic producers up to eleven (11) times/yr. These stocks however are not currently allowed for farming in Canada (D.Roberts, pers comm.). Fingerlings can also be secured from Canadian hatcheries to meet the production schedule. This strategy enables fish to be harvested continuously over twelve months.

Harvest Size:

The target is to produce 1,000-gram fish to meet the needs of the foodservice market. To reflect the varied growth that occurs within a lot (cohort) of fish, harvesting has been staggered. In the month that the average fish exceeds 1,000 grams, one-sixth (16.7%) of the stock will be harvested. The remaining fish will be harvested in equal monthly amounts beginning two months before the month in which the average fish size exceeds 1,000 grams and continuing for three months afterward. This strategy is necessary to support a relatively uniform monthly harvest schedule that will enable producers to supply fish geared toward a market demand. Monthly harvests of 11,850 kilograms of whole fish are projected, yielding an annual production capacity of 142 tonnes.

Rearing Density:

The maximum desired rearing density has been set to 90 kilograms of fish per cubic metre of rearing space. Although this peak is attained briefly during each production cycle, the average rearing density is 77 kg/m^3 in the system.

Monthly Mortality:

For the first two months following initial stocking of fingerlings, monthly mortality is modelled at 2.0%. In the subsequent months, it is reduced to 1.5%, 1.0% and then 0.75% for the balance of the rearing period. Additionally, successful commercial production of Arctic char requires that each cohort be culled heavily to remove the very slow growing fish that inevitably will never reach harvestable size. Therefore, in the fifth production month for each cohort, when the average fish size is approximately 160 grams, the smallest 20% of the population is culled. Together, the average monthly mortality rate and the culling result in only 71% of the fish stocked into the system being ultimately harvested. This is consistent with commercial experience in Atlantic Canada (J.Carpenter, pers comm.).

Feed Requirements:

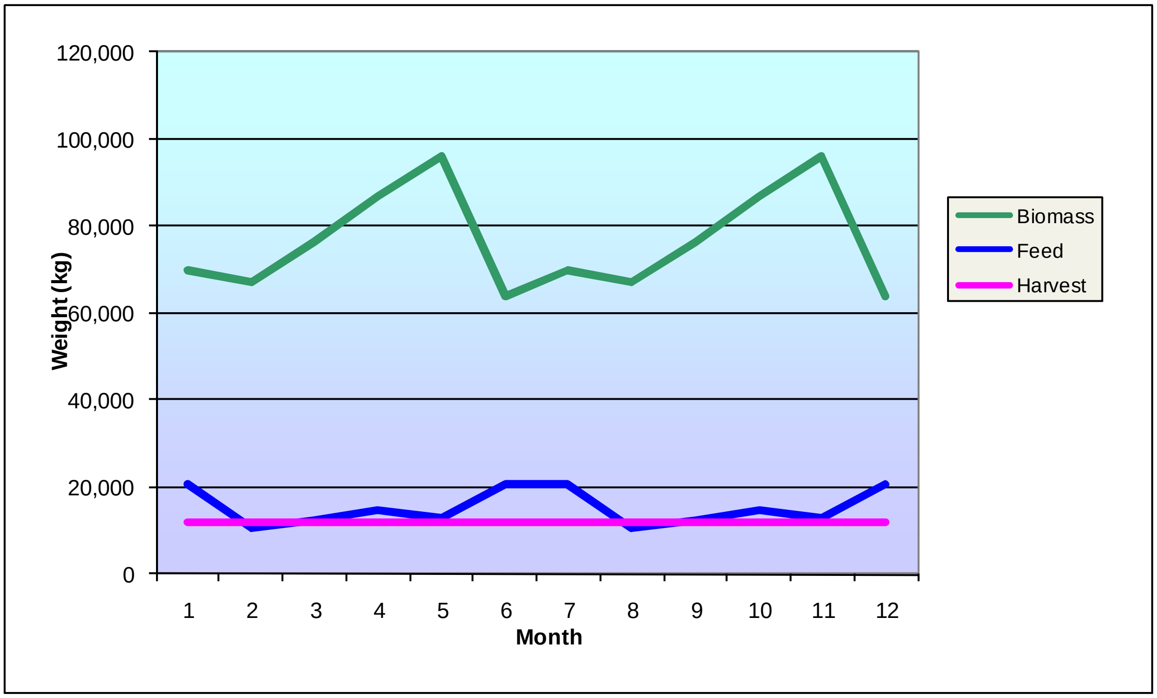
Using nutrient-dense (high energy) feed formulations, the monthly feed ration has been calculated by determining the amount of feed required to meet the growth projections given a Feed Conversion Ratio of 1.30 (that is, 1.30 kg feed per kg gain). This is consistent with commercial experience in Atlantic Canada.

A summary of this production scenario for Arctic char, including average monthly standing crop biomass, harvest, feed consumption and fingerling purchases is presented in Table 6. Overall biomass, feed and harvest schedules are summarized in Figure 38.

Table 6: Production summary for cultivation of Arctic char

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Year 1													
Fingerlings (no)	100,000	0	0	0	0	0	100,000	0	0	0	0	0	200,000
Biomass (kg)	3,404	5,317	7,839	11,074	12,084	15,987	24,082	31,504	40,414	50,973	60,300	64,090	327,066
Harvest (kg)	0	0	0	0	0	0	0	0	0	0	0	11,850	11,850
Feed (kg)	1,862	2,536	3,345	4,290	1,338	5,175	8,082	9,842	11,815	14,002	12,367	20,738	95,392
Year 2													
Fingerlings (no)	100,000	0	0	0	0	0	100,000	0	0	0	0	0	200,000
Biomass (kg)	69,671	67,210	76,120	86,680	96,006	64,090	69,671	67,210	76,120	86,680	96,006	64,090	919,554
Harvest (kg)	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	142,200
Feed (kg)	20,462	10,562	12,535	14,722	13,088	20,738	20,462	10,562	12,535	14,722	13,088	20,738	184,215
Year 3													
Fingerlings (no)	100,000	0	0	0	0	0	100,000	0	0	0	0	0	200,000
Biomass (kg)	69,671	67,210	76,120	86,680	96,006	64,090	69,671	67,210	76,120	86,680	96,006	64,090	919,554
Harvest (kg)	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	11,850	142,200
Feed (kg)	20,462	10,562	12,535	14,722	13,088	20,738	20,462	10,562	12,535	14,722	13,088	20,738	184,215

Figure 38: Projected biomass, feed and harvest schedules for Arctic char production.

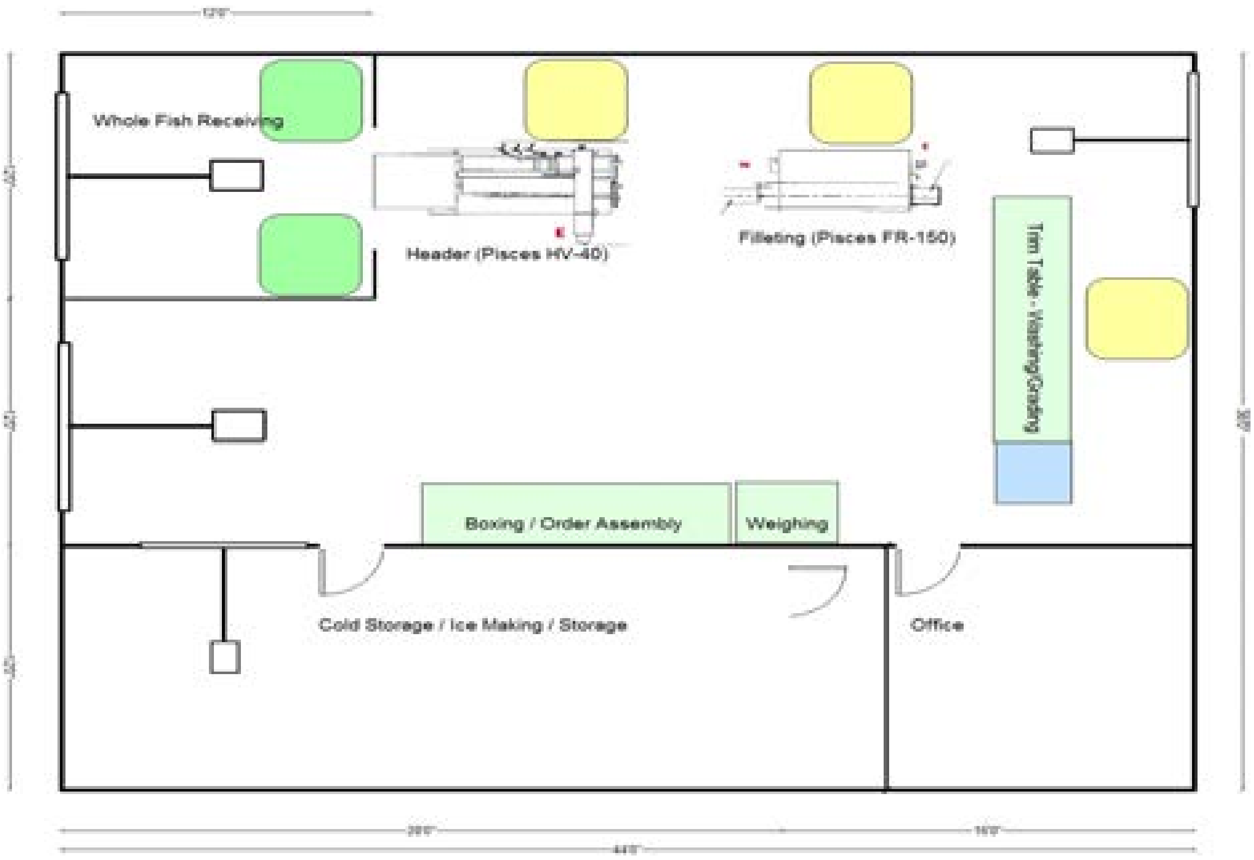


6.3 Processing Factors

A 145 m^3 (1600 sq ft) conceptual processing facility is presented (Figure 39) which can be used for either rainbow trout or Arctic char. The basic layout is presumed to be a stand-alone operation. The capital costs for a building that will meet current CFIA QMP and HACCP standards will cost approximately $150/ sq ft. This level of investment is sufficient to provide a concrete floor with and anti-slip coating, walls made with non-porous materials, and proper lighting. The standard equipment shown (Pisces HV-40 and FR-150, stainless steel Trim Table, etc.) would cost approximately $100,000.

The facility presented has a whole fish receiving area where totes of harvested fish are staged. Typically rainbow trout and Arctic char are not exsanguinated or bled out (as with Atlantic salmon) but are instead placed whole into a slurry of ice and water. The animals expire due to thermal shock. Fish are typically processed in a pre-rigour state.

Figure 39: Conceptual Processing facility



A typical process flow for rainbow trout processing would be as follows:

- The fish are removed from the totes and de-headed using a heading machine (Pisces HV-40 is shown) or done manually.
- The headed fish is fed into a filleting machine (Pisces FR-150 is shown). The filleting machine can handle 20 fish per minute and requires 12 Lpm of freshwater (chlorinated) as well as 80 psi of compressed air. The fish are split into two sections, the offal is removed, the backbone and rib bones are also removed
- Product is moved to the Trim Table where trimming is done by hand. Pin bones are removed using small hand held pin bone removers and the product is placed into pans
- Product is washed (rinsed, chlorinated fresh water) and graded according to colour of flesh, firmness, size and overall appearance. Sorting according to quality occurs at this stage.
- Product is then weighed, boxed (typically a styro box), and re-iced.
- The box is labeled, sealed and set onto a pallet for order assembly.
- Bills of landing and other pertinent shipping information are prepared.
- Product is moved to storage area (typically refrigerated).
- Shelf life of this product is 12 days (post harvest).

This process produces a pin-bone out (boned), skin-on, fillet. Current rainbow trout processors indicate that the primary market is for fillets (skin-on or skin off).

A typical process flow for Arctic char would be as follows:

- The fish are removed from the totes transferred to the Trim Table. The product is eviscerated by hand.
- Product is washed (rinsed, chlorinated fresh water) and graded according to colour of flesh, firmness, size and overall appearance. Sorting according to quality occurs at this stage.
- Product is then weighed, boxed (typically a styro box), and re-iced.
- The box is labeled, sealed and set onto a pallet for order assembly.
- Bills of landing and other pertinent shipping information are prepared.
- Product is moved to storage area (typically refrigerated).

This process produces a dressed, head-on product. Current and former Arctic char processors indicate that the primary market is for dressed, head-on product. Re-processors are hand filleting this product and moving it into the Food Service sector. It is possible to calibrate the filleting machines to handle Arctic char but the body shape affects the yield (A. Wright – personal communication). In addition, Arctic char have very fine pin-bones and processors typically resort to a V-cut in the flesh to remove them, which reduces product yield.

Product that has not been exsanguinated at harvest but has been properly refrigerated can last up to 6 hours in a pre-rigour state and without any noticeable changes in quality. This presents the farmers with an option of transporting product to a processing facility that is within a 6 hour radius of the farm.

A processing cost model would look as follows:

Fish Cost/Purchase from far	$1.85
Fish Weight (round)	2.2 Lbs/1 Kg
Processing Costs	$0.40
Lg Dressed Yeild	85.0%
Regular Trim	52.5%
PROCESSING COSTS	
Labour	$0.18
Expense & Supplies	$0.04
Power & Heat	$0.01
Packaging	$0.15
Indirect Expenses	$0.02
Total Processing Cost/Lb	$0.40

	HOG	Boneless Fillet
Fish Cost (round)	$4.07	$4.07
Fish Cost (processed	$0.75	$1.42
Weight Sold	1.87	1.16
Selling Price/Lb	$2.90	$5.18
Total Product Sold	$5.42	$5.98
commissions	-$0.27	-$0.30
distribution	-$0.28	-$0.17
Net	$4.87	$5.51
Margins	$0.05	$0.02

6.4 In-House Hatchery vs. Fingerling Purchase

The notion to produce fingerlings in-house as opposed to purchasing them from other commercial hatcheries is often considered by investors. Therefore, capital and operating budgets were developed for an in-house hatchery to produce enough fish to service the stocking schedule for the conceptual rainbow trout venture outlined in this report. The hatchery would be required to purchase approximately 244,000 eyed eggs annually from a certified supplier (e.g. Troutlodge); no provisions were made for holding broodstock.

Since the hatchery is an add-on to the existing facility, capital costs could be kept to a minimum. For example, the facility would be located within the CoverAll^{TM} structure but enclosed within an insulated and light-tight room. Well water would be supplied first to the hatchery and then to the grow-out operation. Nevertheless, since the hatchery would also be operated as an intensive recirculation facility, the capital budget still amounts to more than $173,000.

Inter-company sales (transfer pricing) from the hatchery division to the grow-out division was modelled at the purchase price of 20-gram fingerlings from commercial hatcheries (i.e. $0.28 / 20-gram fish). Labour was budgeted for one ½-time employee for the hatchery; no management fees were allocated. Eggs were modelled at $0.06 each. Feed (27%), eggs (27%) and labour (28%) were the largest direct expenses, followed by electricity (14%). Depreciation (20%), professional services (11%) and interest (9.5%) were the largest indirect expenses.

The analysis suggests that an intensive recirculating hatchery producing 220,000 20-gram fingerlings per year would have insufficient economies of scale to be profitable. Nearly every financial ratio is negative, as is the average return on sales at -27%. Therefore, at this scale, it is in the producer's financial interest to purchase fingerlings from larger commercial hatcheries.

6.5 Financial Factors

Objective: To evaluate the scale and economic viability of the conceptual design.

Based on the technological requirements of the operation as outlined in the preceding sections of this report, and the economic objective for the venture to be at a scale that is independently viable, separate capital and operating budgets have been prepared for rainbow trout and Arctic char. Budgetary quotations have been obtained from equipment manufacturers and suppliers for major capital requirements.

The same basic operation has been modeled for rainbow trout and for Arctic char. Due principally to the difference in operating temperature between the two systems, minor differences were found to be necessary. Most notably, the Arctic char venture requires a larger biofilter with approximately 14% more media to achieve acceptable water quality. As a result, the capital budget for the char facility is 2% greater than that for the rainbow trout operation.

For both species, separate economic analyses have been conducted using industry-based cost-of-production data (e.g. number and cost of fingerlings, feed costs, labour, etc.). Nevertheless, some of the fundamental assumptions applied in economic modeling are essentially the same for both species. These are presented in Table 7. A glossary of the financial terminology and ratios used in this report is provided in Table 8.

Table 7: Financial forecasting assumptions for production of rainbow trout and Arctic char in an intensive recirculating aquaculture facility in New Brunswick.

PRODUCTION	
Cost of Feed (weighted average)	$1,582 / tonne (delivered; 4% discount off list)
Feed Conversion Ratio	
Rainbow Trout	1.08 kg feed per kg gain
Arctic char	1.29 kg feed per kg gain
Cost of Fingerlings	
Rainbow Trout	20 g @ $0.28 each (delivered)
Arctic Char	20 g @ $0.56 each (delivered)
Mortality	
Rainbow Trout	91% of all fish stocked become harvested
Arctic Char	71% of all fish stocked become harvested
Labour	1½ Fish Culture Technicians @ $15 / hr 1 Farm Manager @ $30 / hr
Electricity	$0.09 / Kwhr
Maintenance & Repairs	$0.035 / kg biomass
Supplies	$0.015 / kg biomass
Stock Insurance	5% of inventory valuation
FINANCING	
Selling Price of Fish	
Rainbow Trout	$4.08 / kg (1.85 / lb) farm gate, round
Arctic Char	$6.61 / kg (3.00 / lb) farm gate, round
Currency Exchange	$CDN 1.05 = $US 1.00[14]
Equity Financing	50%
Debt Financing[15]	50% at 7.0% interest amortized 120 mo.

NOTES:

- The economic scenarios presented herein are sensitive to changes in the principal assumptions. Most notably, should input costs increase (e.g. expenses associated with feed, labour, direct supplies and/or services) or output and revenue decrease (e.g. greater mortality, lower selling price, lower densities) then profitability can be expected to decline accordingly. Experience suggests that changes in feed costs, survival to market and selling price impart the greatest leverage on operating margins.

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[14] Currency exchange rates influence capital purchases as some of the equipment if of US origin. In Q1 2010, the Canadian dollars has strengthened considerably. Consensus amongst financial forecasters (Scotia Economics April 2010) suggests an exchange rate of $CDN 1.03 to 1.06 = $US 1.00 through the remainder of 2010 and 2011.

[15] Securing 50% debt financing for a stand-alone aquaculture operation may be untenable.

Table 8: Glossary of Financial Terms

Cost of Capital In this simple exercise, capital investment consists of two sources of funds – debt and equity. The cost of capital is the weighted average cost of these sources of funds. The cost of debt is equal to the interest rate; i.e. 7.0%. The cost of equity specifies the owners required rate of return and presumes that this rate could be earned by investing elsewhere. The cost of equity has been estimated at 12%. Therefore, the weighted average cost of capital is:

Source	Rate of Return	Proportion	Total Cost
Equity	12.0%	50%	6.0%
Debt	7.0%	50%	3.5%
Total		100%	9.5%

This 9.5% discount rate has been applied to calculate the projected returns generated within each scenario.

Internal Rate of Return A method to evaluate investment proposals based on the present value (PV) of future cash flows generated by the venture, less the initial cost of the investment plus its residual (salvage) value at the end of its useful life. In this exercise, residual value is calculated as Receivables + Inventory – Payables. The IRR reflects the long-term rate of return generated by the equity investment in the project.

Payback The number of years required to return the original investment in the project.

Current Ratio A measure of the firm's ability to pay any bills due over the next twelve months (near term costs) with assets on hand.

Current Ratio = Current Assets / Current Liabilities

Quick Ratio A measure of the firm's ability to pay its bills using only cash on hand or cash already due from accounts receivable without consideration for monies anticipated from the sale of inventory.

Quick Ratio = (Cash + Receivables) / Current Liabilities

Debt Ratio A measure of the amount of funds provided by creditors.

Debt Ratio = Total Debt / Total Assets

Inventory Turnover A measure of the average number of days required to turn inventory into cash.

Inventory Turnover = (Inventory / Cost of Goods Sold) x 365

Times Interest Earned A measure of a company's ability to generate sufficient cash flow to meet short-term fixed interest payments.

Times Interest Earned = EBIT[1] */ Interest*

Gross Margin A measure of how much revenue is left after all the direct costs of producing and selling the product have been subtracted

Gross Margin = Gross Profit / Sales

Return On Sales A measure of how efficiently a company is running its operations by measuring the profit produced on each dollar of sales.

Return on Sales = EBITD[2] */ Sales*

Cash Earnings on Sales A measure of the net cash flow generated from sales.

Cash Return on Sales = Net Cash Flow / Sales

ROI (Cash in to Cash out) A measure of the rate of return on shareholder direct investment.

Cash *Return on Investment = (Net Cash Flow + Wages) / Equity Invested*

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[1] Earnings before interest & tax

[2] Earnings before interest, tax & depreciation

6.5.1 Rainbow Trout[16]

Financial projections indicate that an investment of $1,770,000 is required to establish a 200-tonne per year rainbow trout aquaculture operation. Of this, $1,480,000 is required to finance capital equipment (i.e. tanks, water filtration equipment, pumps, fish culture equipment, building infrastructure, etc.), including 10% contingency (Table 9). The venture requires approximately 8 hectares (20 acres) of land - 7 hectares for land application of trout manure and 1 hectare for the intensive recirculation facility. An additional $290,000 is required for working capital to finance feed and fingerling purchases and other operating expenses.

The *pro forma* financial statements reflect a 50% equity investment ($885,000) which is leveraged with an $885,000 debenture financed at 7% interest annually. The amortization schedule is set to retire the loan over 120 months in equal blended monthly payments of interest and principal. Steady-state operations are attained in the third quarter of the first year of operations, when consistent monthly harvests of 16,700 kilograms of whole trout commence.

By the second year, annual cash flow of approximately $14,500 is generated (Table 10). Debt is being retired in blended monthly payments (Tables 10 and 11). Net cash flow is supplementary to the $62,352 annual salary paid to the Farm Manager - who presumably is the owner of the venture, yielding a total annual cash flow to the producer of approximately $77,000. By year 5, the direct cost of production is projected to be $2.96 per kilogram, generating a gross margin of $1.12 per kilogram. Indirect costs (e.g. depreciation, interest, insurance, vehicle and administrative expenses) add an additional $1.09 per kilogram, bringing the total cost of production to $4.05 per kilogram and yielding a net profit of only $0.03 per kilogram (Table 12).

Analysis of financial performance suggests that, at this scale, the venture generates an annual return on sales of almost 17% by year 3 and approximately 9% return on equity (based on cash-in and cash-out). Key financial ratios are acceptable once the venture reaches stable production after year 2 (Table 13). Based on an equity investment of $885,000, the payback period is projected to be just over 11 years. The Internal Rate of Return for the project is projected to be -0.6% based on a 20-year stream of discounted cash flows. Over 20 years, the venture is projected to generate a cumulative stream of cash flow in excess of $1.53 million to the owner (including management salary). Financial analyses are presented in Tables 9 through 13.

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[16] **NOTE**: These financial results are for illustration purposes only and are derived using the assumptions provided in Table 7 as well as the conceptual design found in Section 6.1 of this report.

Table 9: Capital budget for a 200-tonne recirculating rainbow trout venture

	Unit Price	Number	Budget
Infrastructure			
Land (Ac)	$ 2,000	20.0	$ 40,000
Manure Pond Excavation	$ 20	500	$ 10,000
Water Supply (Well)	$ 6,000	2	$ 12,000
Well Pump	$ 1,000	2	$ 2,000
Water Heater	$ 4,000	1	$ 4,000
Site Preparation	$ 0.50	30,000	$ 15,000
CoverAll Structure	$ 10.50	16,800	$ 176,400
Footings	$ 60.00	680	$ 40,800
Electrical Servicing	$ 40,000	1	$ 40,000
Eng'g & Contingency (10%)			$ 30,020
Subtotal			$ 370,220
Culture Tanks			
Excavation	$ 20	750	$ 15,000
Concrete Rearing Tanks, Treatment Units	$ 245,000	1	$ 245,000
Purge Tank Circulation / Aeration	$ 2,025	1	$ 2,025
Piping & Accessories	$ 24,500	1	$ 24,500
Eng'g & Contingency (10%)			$ 26,203
Subtotal			$ 312,728
Water Reconditioning System			
Tank Drain Assembly (Sm tanks)	$ 489	4	$ 1,957
Tank Drain Assembly (Lg tanks)	$ 814	5	$ 4,069
Radial Flow Clarifier (Sm tanks)	$ 1,404	1	$ 1,404
Radial Flow Clarifier (Lg tanks)	$ 1,794	3	$ 5,383
Surface Water Drain (Sm tanks)	$ 1,025	4	$ 4,099
Surface Water Drain (Lg tanks)	$ 1,388	6	$ 8,329
Drum Filter (Hydrotech Model 2007-2H)	$ 68,720	1	$ 68,720
High-Pressure Rinse System	$ 4,494	1	$ 4,494
Motor Control Panel	$ 13,164	1	$ 13,164
CO2 Stripper (14' x 5')	$ 13,074	1	$ 13,074
CO2 Pumps (v-150)	$ 5,116	5	$ 25,578
Biofilter Media (MB3)	$ 21	4,700	$ 98,700
Biofilter Retaining Screens	$ 3,649	4	$ 14,595
Biofilter Aeration Grids	$ 580	54	$ 31,298
Biofilter Aeration Blowers & Accessories	$ 7,985	3	$ 23,956
LHO (Sm tanks)	$ 3,407	2	$ 6,815
LHO (Lg tanks)	$ 5,043	6	$ 30,259
Oxygen Control Panel	$ 5,171	1	$ 5,171
Oxygen Generator	$ 39,113	1	$ 39,113
Ozone Generator	$ 22,265	2	$ 44,530
Main Recirculation Pumps	$ 19,216	3	$ 57,648
Main Pumps - Spare Motor	$ 3,374	1	$ 3,374
Monitoring Pkg (DO/Temp/CO2/pH/ORP)	$ 35,000	1	$ 35,000
Fixed Media Chamber Assembly	$ 18,806	1	$ 18,806
Technical Assistance w Installation	$ 840	15	$ 12,600
Eng'g & Contingency (10%)			$ 57,213
Subtotal			$ 629,347
Fish Culture Equipment			
Feeders (Sm tanks)	$ 767	4	$ 3,069
Feeders (Lg tanks)	$ 1,323	12	$ 15,875
Fish Grader Screen	$ 5,000	1	$ 5,000
Nets, Totes, Tools, Etc.	$ 20,000	1	$ 20,000
Contingency (10%)			$ 4,394
Subtotal			$ 48,339
Other Equipment			
Office Equipment	$ 5,000	1	$ 5,000
Back-Up Generator	$ 35,000	1	$ 35,000
Over-Tank Decking	$ 125	310	$ 38,750
Manure Handling Equipment	$ 10,000	1	$ 10,000
Pickup Truck	$ 20,000	1	$ 20,000
Contingency (10%)			$ 10,875
Subtotal			$ 119,625
TOTAL PRODUCTION CAPITAL			$ 1,480,259

Table 10: 5-Year *pro forma* Cash Flow Statement for a 200-tonne recirculating rainbow trout venture

	Initial	Year 1	Year 2	Year 3	Year 4	Year 5
Cash Receipts						
Harvest (kg)		100,200	200,400	200,400	200,400	200,400
Sales		$408,664	$817,328	$817,328	$817,328	$817,328
TOTAL RECEIPTS		**$408,664**	**$817,328**	**$817,328**	**$817,328**	**$817,328**
Cash Disbursements						
Direct Expenses		($451,942)	($593,416)	($593,355)	($593,354)	($593,354)
Indirect Expenses		($151,695)	($141,114)	($136,202)	($130,935)	($125,288)
(Increase) Decrease in Receivables		($68,111)	$0	$0	$0	$0
Increase (Decrease) in Payables		$49,225	$375	($423)	($453)	($486)
Taxes		$0	$0	$0	$0	$0
TOTAL CASH DISBURSEMENTS		**($622,523)**	**($734,155)**	**($729,980)**	**($724,742)**	**($719,127)**
OPERATING CASH FLOW		**($213,859)**	**$83,173**	**$87,348**	**$92,586**	**$98,201**
Capital Expenditures (see detailed list)		($1,480,259)	$0	$0	$0	$0
NET CASH		**($1,694,118)**	**$83,173**	**$87,348**	**$92,586**	**$98,201**
FUNDING SOURCES						
Equity Investment	$885,000	$885,000	$0	$0	$0	$0
New Financing (Loan 1)	$885,000	$821,635	($67,945)	($72,857)	($78,124)	($83,771)
New Financing (Loan 2)		$0	$0	$0	$0	$0
TOTAL FUNDING		**$1,706,635**	**($67,945)**	**($72,857)**	**($78,124)**	**($83,771)**
Increase (Decrease) in cash position		$12,518	$15,228	$14,491	$14,462	$14,429
CASH (DEFICIENCY) at beginning		$0	$12,518	$27,745	$42,237	$56,699
CASH (DEFICIENCY) at end of period		**$12,518**	**$27,745**	**$42,237**	**$56,699**	**$71,128**

Table 11: 5-Year *pro forma* Balance Sheets for a 200-tonne recirculating rainbow trout venture

	Year 1	Year 2	Year 3	Year 4	Year 5
Assets					
Current Assets					
Cash	$12,518	$27,745	$42,237	$56,699	$71,128
Accounts Receivable	$68,111	$68,111	$68,111	$68,111	$68,111
Inventory - Production	$113,373	$109,085	$109,016	$109,015	$109,015
Total Current Assets	$194,002	$204,941	$219,363	$233,824	$248,254
Capital Assets					
Production	$1,191,535	$978,771	$820,050	$699,950	$607,605
Total Assets	**$1,385,536**	**$1,183,712**	**$1,039,413**	**$933,774**	**$855,859**
Liabilities & Shareholders Equity					
Current Liabilities					
Accounts payable and accrued liabilities	$49,225	$49,599	$49,176	$48,723	$48,237
Total Current Liabilities	$49,225	$49,599	$49,176	$48,723	$48,237
Long Term Debt					
New Financing (Loan 1)	$821,635	$753,690	$680,833	$602,710	$518,938
New Financing (Loan 2)	$0	$0	$0	$0	$0
Total Long Term Debt	$821,635	$753,690	$680,833	$602,710	$518,938
Total Liabilities	$870,860	$803,290	$730,010	$651,433	$567,176
Shareholders' Equity					
Equity Investment	$885,000	$885,000	$885,000	$885,000	$885,000
Investment Capital					
Retained Earnings	($370,324)	($504,578)	($575,597)	($602,659)	($596,317)
Total Equity	$514,676	$380,422	$309,403	$282,341	$288,683
Total Liabilities & Equity	**$1,385,536**	**$1,183,712**	**$1,039,413**	**$933,774**	**$855,859**

Table 12: 5-Year *pro forma* Income Statement for a 200-tonne recirculating rainbow trout venture

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	$/kg
Harvest (kg)	100,200	200,400	200,400	200,400	200,400	
TOTAL REVENUES	**$408,664**	**$817,328**	**$817,328**	**$817,328**	**$817,328**	$4.08
Cost of Production						
Opening Inventory	$0	$113,373	$109,085	$109,016	$109,015	$0.54
Feed	$227,824	$342,469	$342,469	$342,469	$342,469	$1.71
Fingerlings	$61,600	$61,600	$61,600	$61,600	$61,600	$0.31
Electricity	$90,749	$90,749	$90,749	$90,749	$90,749	$0.45
Heating	$11,983	$11,983	$11,983	$11,983	$11,983	$0.06
Labour	$31,200	$46,800	$46,800	$46,800	$46,800	$0.23
Maintenance & Repairs	$6,685	$9,657	$9,657	$9,657	$9,657	$0.05
Supplies	$16,714	$24,142	$24,142	$24,142	$24,142	$0.12
Stock Insurance	$5,187	$6,016	$5,955	$5,954	$5,954	$0.03
	$451,942	$706,789	$702,439	$702,370	$702,368	$3.50
Closing Inventory	$113,373	$109,085	$109,016	$109,015	$109,015	$0.54
Cost of Sales	**$338,569**	**$597,704**	**$593,424**	**$593,355**	**$593,354**	$2.96
Gross Margin	**$70,095**	**$219,624**	**$223,904**	**$223,973**	**$223,974**	$1.12
Indirect Costs						
Depreciation	$288,724	$212,764	$158,721	$120,100	$92,345	$0.46
Professional Services	$15,000	$9,000	$9,000	$9,000	$9,000	$0.04
Insurance	$2,400	$2,400	$2,400	$2,400	$2,400	$0.01
Interest	$59,943	$55,362	$50,450	$45,183	$39,536	$0.20
Telecommunications	$2,400	$2,400	$2,400	$2,400	$2,400	$0.01
Management	$62,352	$62,352	$62,352	$62,352	$62,352	$0.31
Office Expense	$3,600	$3,600	$3,600	$3,600	$3,600	$0.02
Lease	$0	$0	$0	$0	$0	$0.00
Vehicle Expenses	$6,000	$6,000	$6,000	$6,000	$6,000	$0.03
Total Indirect	**$440,419**	**$353,878**	**$294,923**	**$251,035**	**$217,633**	$1.09
Profit/(Loss) before taxes	**($370,324)**	**($134,254)**	**($71,019)**	**($27,062)**	**$6,341**	$0.03
Taxes	**$0**	**$0**	**$0**	**$0**	**$0**	$0.00
Profit/(Loss) after taxes	**($370,324)**	**($134,254)**	**($71,019)**	**($27,062)**	**$6,341**	$0.03
Retained Earnings	**($370,324)**	**($504,578)**	**($575,597)**	**($602,659)**	**($596,317)**	

Table 13: 5-Year financial performance data for a 200-tonne recirculating rainbow trout venture

RATIO	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**5-Year Avg**
Liquidity						
Current Ratio (times)	3.9	4.1	4.5	4.8	5.1	
Quick Ratio (times)	1.6	1.9	2.2	2.6	2.9	
Assets Management						
Inventory Turnover (days)	122	67	67	67	67	
Debt Management						
Debt Ratio	59%	64%	66%	65%	61%	
Times Interest Earned	-5.18	-1.43	-0.41	0.40	1.16	
Profitability						
Gross Margin	17.2%	26.9%	27.4%	27.4%	27.4%	25.2%
Return on Sales	-5.3%	16.4%	16.9%	16.9%	16.9%	12.4%
Cash Earnings on Sales	3.1%	1.9%	1.8%	1.8%	1.8%	2.0%
ROI (Cash in - Cash out)	8.5%	8.8%	8.7%	8.7%	8.7%	8.7%

6.5.2 Arctic Char[17]

Financial projections indicate that an investment of $2,140,000 is required to launch a 142-tonne per year Arctic char aquaculture operation. Of this, $1,503,000 is required to finance capital equipment, including 10% contingency (Table 14). The venture requires approximately 7 hectares (17 acres) of land - 6 hectares for land application of char manure and 1 hectare for the intensive recirculation facility. An additional $636,000 is required for working capital to finance feed and fingerling purchases and other operating expenses.

The *pro forma* financial statements reflect a 50% equity investment ($1,070,000) which is leveraged with a $1,070,000 debenture financed at 7% interest annually. The amortization schedule is set to retire the loan over 120 months in equal blended monthly payments of interest and principal. Steady-state operations are attained in the first quarter of the second year of operations, when consistent monthly harvests of 11,850 kilograms of whole char commence.

By the second year, annual cash flow of approximately $78,000 is generated (Table 15). Debt is being retired in blended monthly payments (Tables 16 and 17). Net cash flow is supplementary to the $62,352 annual salary paid to the Farm Manager - who presumably is the owner of the venture, yielding a total annual cash flow to the producer of approximately $140,000. By year 5, the direct cost of production is projected to be $4.41 per kilogram, generating a gross margin of $2.20 per kilogram. Indirect costs (e.g. depreciation, interest, insurance, vehicle and administrative expenses) add an additional $1.60 per kilogram, bringing the total cost of production to $6.01/kilogram and a net profit of $0.60/kilogram (Table 17).

Analysis of financial performance suggests that, at this scale, the venture generates an annual return on sales greater than 23% by year 3 and a 12% return on equity (based on cash-in and cash-out). Key financial ratios are acceptable once the venture reaches stable production after year 2 (Table 18). Based on an equity investment of $1,070,000, the payback period is projected to be 8 years. The Internal Rate of Return for the project is projected to be 3.56% based on a 20-year stream of discounted cash flows. Over 20 years, the venture is projected to generate a cumulative stream of cash flow in excess of $2.76 million to the owner (including management salary). Financial analyses are presented in Tables 14 through 18.

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[17] **NOTE**: These financial results are for illustration purposes only and are derived using the assumptions provided in Table 7 as well as the conceptual design found in Section 6.1 of this report.

Table 14: Capital budget for a 142-tonne recirculating Arctic char venture

	Unit Price	Number	Budget
Infrastructure			
Land (Ac)	$ 2,000	17.0	$ 34,000
Manure Pond Excavation	$ 20	500	$ 10,000
Water Supply (Well)	$ 6,000	2	$ 12,000
Well Pump	$ 1,000	2	$ 2,000
Water Heater	$ 4,000	1	$ 4,000
Site Preparation	$ 0.50	30,000	$ 15,000
CoverAll Structure	$ 10.50	16,800	$ 176,400
Footings	$ 60.00	680	$ 40,800
Electrical Servicing	$ 40,000	1	$ 40,000
Eng'g & Contingency (10%)			$ 30,020
Subtotal			$ 364,220
Culture Tanks			
Excavation	$ 20	750	$ 15,000
Concrete Rearing Tanks, Treatment Units	$ 252,000	1	$ 252,000
Purge Tank Circulation / Aeration	$ 2,025	1	$ 2,025
Piping & Accessories	$ 25,200	1	$ 25,200
Eng'g & Contingency (10%)			$ 26,903
Subtotal			$ 321,128
Water Reconditioning System			
Tank Drain Assembly (Sm tanks)	$ 489	4	$ 1,957
Tank Drain Assembly (Lg tanks)	$ 814	5	$ 4,069
Radial Flow Clarifier (Sm tanks)	$ 1,404	1	$ 1,404
Radial Flow Clarifier (Lg tanks)	$ 1,794	3	$ 5,383
Surface Water Drain (Sm tanks)	$ 1,025	4	$ 4,099
Surface Water Drain (Lg tanks)	$ 1,388	6	$ 8,329
Drum Filter (Hydrotech Model 2007-2H)	$ 68,720	1	$ 68,720
High-Pressure Rinse System	$ 4,494	1	$ 4,494
Motor Control Panel	$ 13,164	1	$ 13,164
CO2 Stripper (14' x 5')	$ 13,074	1	$ 13,074
CO2 Pumps (v-150)	$ 5,116	5	$ 25,578
Biofilter Media (MB3)	$ 21	5,400	$ 113,400
Biofilter Retaining Screens	$ 3,649	4	$ 14,595
Biofilter Aeration Grids	$ 580	62	$ 35,935
Biofilter Aeration Blowers & Accessories	$ 7,985	3	$ 23,956
LHO (Sm tanks)	$ 3,407	2	$ 6,815
LHO (Lg tanks)	$ 5,043	6	$ 30,259
Oxygen Control Panel	$ 5,171	1	$ 5,171
Oxygen Generator	$ 39,113	1	$ 39,113
Ozone Generator	$ 22,265	2	$ 44,530
Main Recirculation Pumps	$ 19,216	3	$ 57,648
Main Pumps - Spare Motor	$ 3,374	1	$ 3,374
Monitoring Pkg (DO/Temp/CO2/pH/ORP)	$ 35,000	1	$ 35,000
Fixed Media Chamber Assembly	$ 18,806	1	$ 18,806
Technical Assistance w Installation	$ 840	15	$ 12,600
Eng'g & Contingency (10%)			$ 59,147
Subtotal			$ 650,618
Fish Culture Equipment			
Feeders (Sm tanks)	$ 767	4	$ 3,069
Feeders (Lg tanks)	$ 1,323	12	$ 15,875
Fish Grader Screen	$ 5,000	1	$ 5,000
Nets, Totes, Tools, Etc.	$ 20,000	1	$ 20,000
Contingency (10%)			$ 4,394
Subtotal			$ 48,339
Other Equipment			
Office Equipment	$ 5,000	1	$ 5,000
Back-Up Generator	$ 35,000	1	$ 35,000
Over-Tank Decking	$ 125	310	$ 38,750
Manure Handling Equipment	$ 10,000	1	$ 10,000
Pickup Truck	$ 20,000	1	$ 20,000
Contingency (10%)			$ 10,875
Subtotal			$ 119,625
Currency Exchange			
TOTAL PRODUCTION CAPITAL			$ 1,503,929

Table 15: 5-Year *pro forma* Cash Flow Statement for a 142-tonne recirculating Arctic char venture

		Year 1	Year 2	Year 3	Year 4	Year 5
Cash Receipts						
Harvest (kg)		11,850	142,200	142,200	142,200	142,200
Sales		$78,373	$940,476	$940,476	$940,476	$940,476
TOTAL RECEIPTS		**$78,373**	**$940,476**	**$940,476**	**$940,476**	**$940,476**
Cash Disbursements						
Direct Expenses		($422,032)	($628,106)	($627,271)	($627,120)	($627,093)
Indirect Expenses		($164,225)	($152,687)	($146,748)	($140,381)	($133,552)
(Increase) Decrease in Receivables		($78,373)	$0	$0	$0	$0
Increase (Decrease) in Payables		$64,098	$157	($540)	($553)	($588)
Taxes		$0	$0	$0	$0	$0
TOTAL CASH DISBURSEMENTS		**($600,531)**	**($780,635)**	**($774,560)**	**($768,054)**	**($761,233)**
OPERATING CASH FLOW		**($522,158)**	**$159,841**	**$165,916**	**$172,422**	**$179,243**
Capital Expenditures (see detailed list)		($1,503,929)	$0	$0	$0	$0
NET CASH		**($2,026,088)**	**$159,841**	**$165,916**	**$172,422**	**$179,243**
FUNDING SOURCES	Initial					
Equity Investment	$ 1,070,000	$1,070,000	$0	$0	$0	$0
New Financing (Loan 1)	$ 1,070,000	$993,390	($82,148)	($88,087)	($94,455)	($101,283)
New Financing (Loan 2)		$0	$0	$0	$0	$0
TOTAL FUNDING		**$2,063,390**	**($82,148)**	**($88,087)**	**($94,455)**	**($101,283)**
Increase (Decrease) in cash position		$37,302	$77,693	$77,829	$77,968	$77,960
CASH (DEFICIENCY) at beginning		$0	$37,302	$114,995	$192,824	$270,792
CASH (DEFICIENCY) at end of period		**$37,302**	**$114,995**	**$192,824**	**$270,792**	**$348,752**

Table 16: 5-Year *pro forma* Balance Sheets for a 142-tonne recirculating Arctic char venture

	Year 1	Year 2	Year 3	Year 4	Year 5
Assets					
Current Assets					
Cash	$37,302	$114,995	$192,824	$270,792	$348,752
Accounts Receivable	$78,373	$78,373	$78,373	$78,373	$78,373
Inventory - Production	$356,176	$323,468	$317,533	$316,456	$316,261
Total Current Assets	$471,851	$516,836	$588,730	$665,621	$743,386
Capital Assets					
Production	$1,209,088	$992,075	$830,403	$708,255	$614,486
Total Assets	**$1,680,939**	**$1,508,910**	**$1,419,133**	**$1,373,876**	**$1,357,872**
Liabilities & Shareholders Equity					
Current Liabilities					
Accounts payable and accrued liabilities	$64,098	$64,256	$63,716	$63,163	$62,574
Total Current Liabilities	$64,098	$64,256	$63,716	$63,163	$62,574
Long Term Debt					
New Financing (Loan 1)	$993,390	$911,241	$823,154	$728,700	$627,417
New Financing (Loan 2)	$0	$0	$0	$0	$0
Total Long Term Debt	$993,390	$911,241	$823,154	$728,700	$627,417
Total Liabilities	$1,057,488	$975,497	$886,870	$791,862	$689,991
Shareholders' Equity					
Equity Investment	$1,070,000	$1,070,000	$1,070,000	$1,070,000	$1,070,000
Investment Capital					
Retained Earnings	($446,550)	($536,587)	($537,737)	($487,986)	($402,119)
Total Equity	$623,450	$533,413	$532,263	$582,014	$667,881
Total Liabilities & Equity	**$1,680,939**	**$1,508,910**	**$1,419,133**	**$1,373,876**	**$1,357,872**

Table 17: 5-Year *pro forma* Income Statement for a 142-tonne recirculating Arctic char venture

	Year 1	Year 2	Year 3	Year 4	Year 5	
						$/kg
Harvest (kg)	11,850	142,200	142,200	142,200	142,200	
TOTAL REVENUES	**$78,373**	**$940,476**	**$940,476**	**$940,476**	**$940,476**	$6.61
Cost of Production						
Opening Inventory	$0	$356,176	$323,468	$317,533	$316,456	$2.23
Feed	$150,910	$291,428	$291,428	$291,428	$291,428	$2.05
Fingerlings	$106,000	$106,000	$106,000	$106,000	$106,000	$0.75
Electricity	$90,749	$90,749	$90,749	$90,749	$90,749	$0.64
Heating	$11,212	$11,212	$11,212	$11,212	$11,212	$0.08
Labour	$31,200	$46,800	$46,800	$46,800	$46,800	$0.33
Maintenance & Repairs	$6,541	$18,391	$18,391	$18,391	$18,391	$0.13
Supplies	$16,353	$45,978	$45,978	$45,978	$45,978	$0.32
Stock Insurance	$9,066	$17,547	$16,713	$16,562	$16,534	$0.12
	$422,032	$984,281	$950,739	$944,653	$943,549	$6.64
Closing Inventory	$356,176	$323,468	$317,533	$316,456	$316,261	$2.22
Cost of Sales	**$65,856**	**$660,813**	**$633,206**	**$628,197**	**$627,288**	$4.41
Gross Margin	**$12,517**	**$279,663**	**$307,270**	**$312,279**	**$313,188**	$2.20
Indirect Costs						
Depreciation	$294,842	$217,013	$161,671	$122,148	$93,769	$0.66
Professional Services	$15,000	$9,000	$9,000	$9,000	$9,000	$0.06
Insurance	$2,400	$2,400	$2,400	$2,400	$2,400	$0.02
Interest	$72,473	$66,935	$60,996	$54,629	$47,800	$0.34
Telecommunications	$2,400	$2,400	$2,400	$2,400	$2,400	$0.02
Management	$62,352	$62,352	$62,352	$62,352	$62,352	$0.44
Office Expense	$3,600	$3,600	$3,600	$3,600	$3,600	$0.03
Lease	$0	$0	$0	$0	$0	$0.00
Vehicle Expenses	$6,000	$6,000	$6,000	$6,000	$6,000	$0.04
Total Indirect	**$459,067**	**$369,700**	**$308,420**	**$262,529**	**$227,321**	$1.60
Profit/(Loss) before taxes	**($446,550)**	**($90,037)**	**($1,150)**	**$49,750**	**$85,867**	$0.60
Taxes	**$0**	**$0**	**$0**	**$0**	**$0**	$0.00
Profit/(Loss) after taxes	**($446,550)**	**($90,037)**	**($1,150)**	**$49,750**	**$85,867**	$0.60
Retained Earnings	**($446,550)**	**($536,587)**	**($537,737)**	**($487,986)**	**($402,119)**	

Table 18: 5-Year financial performance data for a 142-tonne recirculating Arctic char venture

RATIO	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**5-Year Avg**
Liquidity						
Current Ratio (times)	7.4	8.0	9.2	10.5	11.9	
Quick Ratio (times)	1.8	3.0	4.3	5.5	6.8	
Assets Management						
Inventory Turnover (days)	1,974	179	183	184	184	
Debt Management						
Debt Ratio	59%	60%	58%	53%	46%	
Times Interest Earned	-5.16	-0.35	0.98	1.91	2.80	
Profitability						
Gross Margin	16.0%	29.7%	32.7%	33.2%	33.3%	29.0%
Return on Sales	-101.1%	20.6%	23.6%	24.1%	24.2%	-1.7%
Cash Earnings on Sales	47.6%	8.3%	8.3%	8.3%	8.3%	16.1%
ROI (Cash in - Cash out)	9.3%	13.1%	13.1%	13.1%	13.1%	12.3%

6.5.3 Economies of Scale

Economies of scale serve to reduce the total cost of production as total output volume increases. In many circumstances, as the scale of a production facility increases, production cost will decrease. Common factors that serve to reduce costs as output volume increases include purchasing power (bulk buying), management (reduced management per unit output or management specialization), financing (lower interest rates due to scale of business) and marketing (reduced cost per unit output).

The conceptual rainbow trout / Arctic char venture is modular in design. As such, the level of output is proportional to the scale of the tanks and water filtration equipment. Therefore, increased output will require a concomitant increase in the size of the rearing tanks and water filtration equipment. That is, in this venture, as output increases, associated increases in capital are also required to accommodate the expanded production. Moreover, the common factors associated with achieving economies of scale noted above are not applicable in the conceptual business model presented here. The one exception would be economies due to management - constructing two 200-tonne trout production modules on the same property would not require a second Manager; an additional Aquaculture Technician would suffice. However, the incremental cost benefit would be marginal at $31,152 per year (manager's salary - technician wage).

Nevertheless, increasing the scale of the venture could offer economic advantages through vertical integration. At the economic scale modelled in this review (200 tonnes trout; 142 tonnes char), it was found that in-house production of fingerlings and processing were not viable business opportunities. These opportunities, however, would become viable at a larger scale of operation.

7.0 CONCLUSIONS

7.1 There is sufficient knowledge about the biology of the species and the current market situation for both Arctic char and rainbow trout that a new entrant into the sector can have a reasonable expectation of success.

7.2 The production facility used in this analysis requires 397 Lpm of water and approximately one hectare (10,000 m^2) of land with access to three phase power. In addition, the model requires an additional seven hectares of land for manure disposal.

7.3 There is a minimum size threshold for a production unit to be profitable. Using the variables that were used in this analysis (Tables 4-7), a land-based, recirculation facility should not be less than 142 metric tonnes per annum for Arctic char and 200 metric tonnes per annum for rainbow trout.

7.4 Financial projections indicate that an investment of $1,770,000 is required to establish a 200-tonne per year rainbow trout aquaculture operation. Of this, $1,480,000 is required to finance capital equipment (i.e. tanks, water filtration equipment, pumps, fish culture equipment, building infrastructure, etc.), including 10% contingency (Table 9). An additional $290,000 is required for working capital to finance feed and fingerling purchases and other operating expenses.

7.5 The *pro forma* financial statements (Tables 10-13) reflect a 50% equity investment ($885,000) which is leveraged with an $885,000 debenture financed at 7% interest annually. The amortization schedule is set to retire the loan over 120 months in equal blended monthly payments of interest and principal. Steady-state operations are attained in the third quarter of the first year of operations, when consistent monthly harvests of 16,700 kilograms of whole trout commence.

7.6 Financial projections indicate that an investment of $2,140,000 is required to launch a 142-tonne per year Arctic char aquaculture operation. Of this, $1,503,000 is required to finance capital equipment, including 10% contingency (Table 14). An additional $636,000 is required for working capital to finance feed and fingerling purchases and other operating expenses.

7.7 The *pro forma* financial statements (Tables 15-18) reflect a 50% equity investment ($1,070,000) which is leveraged with a $1,070,000 debenture financed at 7% interest annually. The amortization schedule is set to retire the loan over 120 months in equal blended monthly payments of interest and principal. Steady-state operations are attained in the first quarter of the second year of operations, when consistent monthly harvests of 11,850 kilograms of whole char commence.

7.8 The land based, recirculation facilities demonstrated in this report do not produce enough volume alone to justify the additional capital required to invest in an automated fish processing facility.

7.9 The analyses indicate that these ventures do not warrant additional investment into in-house fingerling production. At this scale, producers do not benefit from the economies of scale available to large, commercial hatcheries. Therefore, it is financially prudent to purchase fingerlings from specialty producers.

7.10 This analysis confirms what many people understand intuitively - that is, on paper, Arctic char looks like an attractive and profitable aquaculture species. Nevertheless, less than 6,000 tonnes of Arctic char are produced in aquaculture operations worldwide and there are no known profitable Arctic char aquaculture ventures in Canada. Therefore, one is left to question why there is such a discrepancy between pro forma projections for Arctic char production and experiential results. Unfortunately, the scope of data available from current and past Arctic char aquaculture ventures has been insufficient to enable a robust and conclusive assessment of the performance of Arctic char in intensive aquaculture operations. The best means to fully comprehend char production could be through development of a model-farm type facility.

APPENDICES

Suppliers of Certified Eggs for Canadian Operations

What follows is a list of certified suppliers of trout and char eggs. The list is not intended to be a comprehensive listing but is provided by way of illustrating the availability.

Rainbow Trout

Troutlodge, Inc.
PO Box 1290
Sumner, WA 98390 USA
Tel: +1 253.863.0446
Fax: +1 253.863.4715
E-mail: trout@troutlodge.com
Web: www.troutlodge.com

Troutlodge, Inc. is the world's leading producer of eyed salmonid eggs, shipping nearly 400 million eggs to over 50 countries each year. In operation since 1945, they specialize in Rainbow trout eggs, Silver steelhead eggs, and Atlantic salmon eggs, and offer all-female and triploid eggs for each species. Eggs are available from their production sites in the USA and Europe (Isle of Man). Rainbow trout eggs are available every week of the year. Through a comprehensive genetic selection program, all eggs are designed to maximize value to customers by optimizing hatch-out rates, feed conversion, growth, and marketability. These superior eggs are backed-up by personalized customer and technical services, and are certified disease-free through independent testing that meets and exceeds OIE guidelines. (Adapted from the Troutlodge website).

Aquaseed Corporation
2301 NE Blakeley St., Seattle, WA 98105
Tel. +1 206.527.6696
www.aquaseed.com

AquaSeed Corporation is an international leader in the supply of genetically superior Pacific salmon seedstocks such as its Domsea® Coho and Donaldson steelhead. With more than 15 generations of selective breeding, the Domsea strains represent the most successful pedigreed breeding program in the salmon livestock industry. Its domesticated Coho and Donaldson steelhead strains supply farms worldwide. The Donaldson strain has been bred for high growth rates. The growth rates are very uniform and little grading is required. This strain of Donaldson performs well on regular trout diets. The small head and high meat-to-bone ratio yields a fillet of at least 5 percent more weight than a similar-sized Atlantic salmon. Similarly, the Donaldson produces a relatively wide fillet for its weight due to its deep body form. (Adapted from the Aquaseed website).

Lyndon Fish Hatcheries
1738 Queen Street
New Dundee, Ontario
N0B 2E0
Tel. 519.696.3076
www.lyndonfishhatcheries.com

Lyndon Fish Hatcheries is an integrated producer of Rainbow Trout and Arctic Char, servicing the aquaculture and food services industry, as well as the general public. Founded in 2000, we are a family business with two sites in New Dundee and one on Manitoulin Island. We hatch our fish from the renowned Lyndon Rainbow Trout and Lyndon Arctic Char strains of Rainbow Trout and Arctic Char, with fingerlings going to customers at a 20-30 gram size, and others being raised to market size and sold to restaurants and the general public. We also have license to ship our eggs worldwide, and are continuing to develop that market. (Adapted from the Lyndon Fish Hatcheries website).

Other Suppliers

Dover Fish Hatchery
RR # 2,
Dover, PEI
C0A 1W0
Tel. 902.962-3446
Key contact :Leon Moyaert – Owner & Manager

Aqua Bounty Farms
RR #4 ,
Fortune, PEI
C0A 2B0
Tel. 902.687.2600
Key contact :Dawn Runnigan– Manager

Pisciculture des Alléghanys Inc
2755 route 281
Saint-Philemon QC, G0R 4A0
Phone #: 418-469-2823
Fax #: 418-469-2872
Key contact: Yves Boulanger , Président

Arctic Char

Icy Waters Ltd.
279 King St. W., Suite 201
P.O Box 276
Kitchener, ON
N2G 3X9
Tel: 1.519.745.4050
Fax: 1.519.745.4941

Farm Location : 4.5 Km Fish Lake Road
P.O Box 21351
Whitehorse, YT
Y1A 6R7
Tel: 1.867.668.7012
Fax: 1.867.668.70

Developed by Icy Waters Ltd. over the past twenty years, Yukon Gold™ Certified Ova is Icy Waters Ltd.'s peerless proprietary strain of commercially available Arctic Char (Salvelinus Alpinus). Successfully grown on four continents, Yukon Gold™ Certified Ova is selectively chosen to provide year after year performance improvement, including high hatch-out rates, good growth, disease tolerance, low maturation, unparalleled flesh quality and yield. All Yukon Gold™ Ova are inspected and certified under schedule II of the Canadian Department of Fisheries and Oceans Fish Health Protection Regulations. Triploidy Yukon Gold™ Arctic Char are available in both our Spring (May/June) and Fall (November/December) seasons. An All-Female strains of Triploidy Yukon Gold™ Arctic Char is available in the Fall season only. (Adapted from the Icy Waters website).

Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

The SWOT Analysis is a robust, strategic tool that requires reflection on a broad range of considerations which can influence the success of a project. The SWOT acronym refers to the Strengths, Weaknesses, Opportunities, and Threats involved in a project. Strengths and weaknesses are internal considerations for which means to impose control and direction can be potentially developed. Opportunities and threats, however, are factors that are external to the project but which must, nevertheless, be considered in the planning and development process since they have a real capacity to influence success or failure.

When conducted thoroughly, a SWOT Analysis will reveal key strengths to build upon and opportunities to exploit while simultaneously focusing attention on those areas where improvement is necessary and where external factors may impose additional constraints to be addressed. In short, the SWOT approach guides the compilation of necessary information in a way that enables development of structured response plans to resolve underlying critical issues that must be addressed to generate the intended results – the essence of new species development. From the perspective of new species development for commercial aquaculture, the following questions define the overall scope of considerations within the SWOT framework.

Strengths:

- What advantages does the candidate species have for commercial aquaculture (i.e. why is it being considered as a good candidate)?

Weaknesses:

- What needs to be improved or resolved before the species can be commercially cultured?
- What areas of technology and expertise are lacking in the sector to develop the species?

Opportunities:

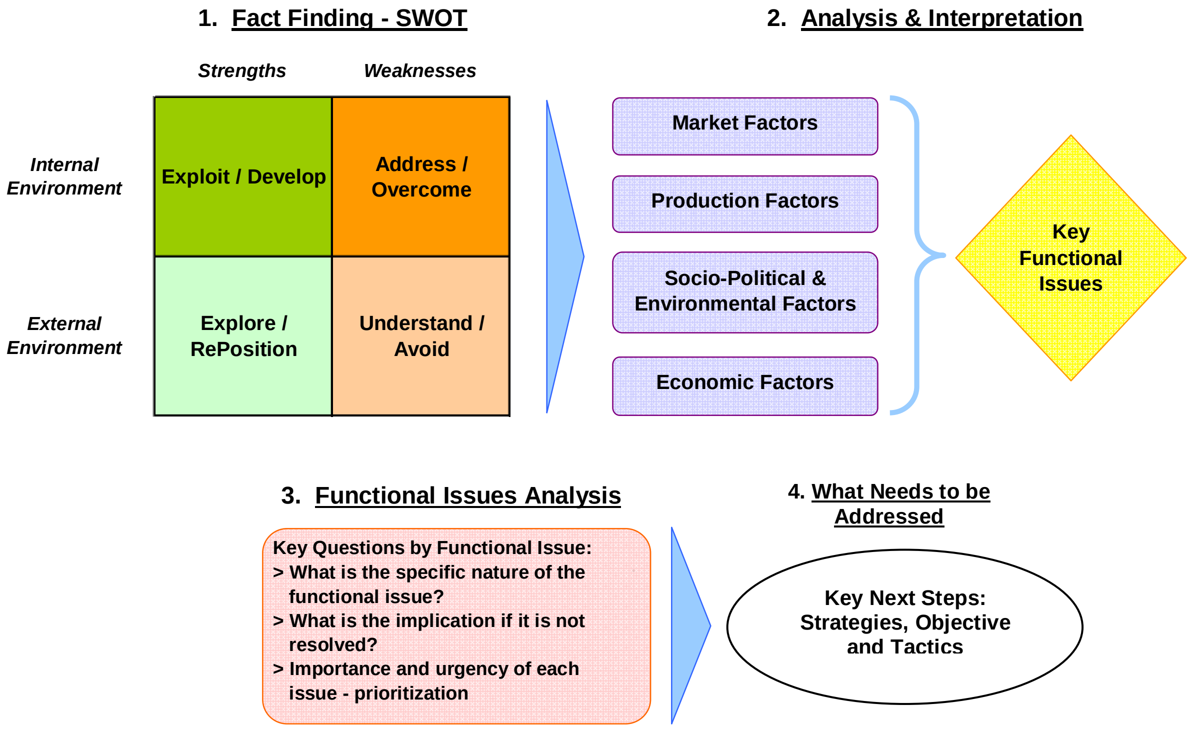
- What opportunities exist to transfer knowledge or technology for the species from other jurisdictions where research, development or commercialization precedes progress in Canada?
- What opportunities exist to transfer knowledge or technology from other similar species to the candidate species?

Threats:

- What external factors may compromise the capability to successfully culture and market the candidate species in an environmentally and economically sustainable manner?

Completion of the SWOT analysis requires collection and compilation of information collected using a combination of primary research (interviews with researchers, producers and regulatory authorities) and secondary research (literature search, accessing previously published reports, etc). The nature of the information determines whether the specific issue is a Strength, Weakness, Opportunity or Threat. Where information is unknown or uncertain it needs to be identified and interpretation of the analysis judged accordingly.

The figure below presents a schematic outline of the entire analysis process.



The SWOT tables are used to compile pertinent facts and information. At this stage, it is imperative to assemble factual information and to avoid a preliminary interpretation of the information (this is a common shortcoming in the application of SWOT). That is, information gathering and information analysis are separate exercises and, therefore, it is important to not interpret the information when populating the tables.

Market Factors, Production Factors, Socio-Political and Environmental Factors and Economic Factors are compiled. Interpretation of this information leads to a comprehensive understanding of trout and char farming as it applies to commercial aquaculture development. It is important to develop a clear understanding of (a) those aspects of the species life cycle and production that can be effectively managed and (b) what remains unknown and/or under-developed. An identification of the issues that are most pertinent to further development of the species for commercial cultivation is required.

The culmination of this review exercise is the development of a What Needs to be Addressed Statement resulting in the development of a strategic plan. A rational strategic plan enhances the chances for successful development of trout and char aquaculture by assuring that all pertinent issues are addressed. Constructed around the principles of strategic opportunism, the Plan will enable developers to build on strengths and opportunities while responding to external developments and forces, effectively balancing short-term demands with long-term direction.

SWOT Tables

	Market Factors
Strengths/ Positives	▪ NB trout and char are able to compete in the served markets based on product quality and service. Proximity to major markets / distribution points in Canada and the USA ▪ Trout is recognized as a healthy, quality product (retail).Charr is recognized as a premium food service product ▪ NB producers are well-positioned to supply growing U.S. demand for high-quality fresh seafood
Opportunities	▪ Char is being marketed primarily in food service; the product has excellent uptake and the market is under developed ▪ Entrance of discount chains to the sector – e.g. Costco, Sam's Club and Wal-Mart's Supercenters, supporting large volume sales of farmed trout. ▪ Increasing health concerns and positive perception of seafood as a healthy food choice. ▪ Domestic production in the US has a limited growth outlook and recent increases in the cost of transportation is making supplies from South America more expensive. ▪ At the same time that seafood consumption has grown in the U.S., trout consumption has been flat due to lack of supplies, not lack of markets. ▪ At current price levels (> $5/lb) for fresh boneless trout fillets, producers in Canada appear to have margins to explore more exports to the U.S. ▪ Based on population growth only, US demand for trout is expected to grow by 6,000 tonnes (round weight equivalent) over the coming decade ▪ With strategic marketing / promotion, consumption could increase by more than 14,000 tonnes in the next decade
Threats	▪ Chile, Argentina and Peru are leading exporters of trout to the US (principally frozen). ▪ In a marketplace driven by widespread emergence of new products, private labels, and low profit margins, retailers are increasingly by-passing the wholesaler-dealer to buy directly from producers. Estimates suggest that producers directly supply 25 to 35% of the products that retailers sell. ▪ Buyer power is increasing while supplier power is decreasing.
Problems/ Challenges/ Weaknesses	▪ Insufficient product to meet customer requirements at times; undisciplined increase in supply will result in lower selling prices ▪ Inability to expand production to meet growing customer demands; will lead to loss of customers over time as supply is sourced elsewhere ▪ Development of a "marketing" approach within the sector as opposed to the more traditional "order taking" or "selling" approach could also boost sales. ▪ Sector is not large enough (product volume) to service large US retail accounts ▪ Currency exchange (strong Canadian dollar) is impacting margins

	Production Factors
Strengths/ Positives	▪ More than 40 years of experience in land-based operations ▪ Coastal Zone Research Institute is working on F5 generation Char program (Fraser River stock) ▪ Producers of trout and char have access to more than one supplier of eggs and more than one stock. ▪ On-going development and implementation of environmentally sustainable technologies and practices
Opportunities	▪ Plentiful biophysical resource base (i.e. water supplies, etc.) ▪ Specialized R&D capacity at DFO SABS, Huntsman Marine Science Centre, Univ. of New Brunswick and Univ. of Moncton’s Coastal Zone Research Institute. ▪ US trout production is unlikely to increase substantially in the future due to lack of additional water in Idaho and the marginal economics for small scale operators outside Idaho ▪ Expansion of marine cage aquaculture is focused on Atlantic salmon
Threats	▪ There is no freshwater aquaculture development policy for the Province. ▪ Carnivorous species such as trout require a significant amount of fish meal and fish oil in their diets. With industrial (reduction) fisheries unlikely to increase, development of alternative feed ingredients will be necessary to support longer-term growth in the sector. ▪ Due to the concerns with wild Atlantic salmon, rainbow trout aquaculture development in the Province is restricted.
Problems/ Challenges/ Weaknesses	▪ Trout and char producers don't have critical mass in NB ▪ Cost of producing Char is impacted by continued productivity issues of survival to market size and precocious maturation; there is no clear understanding if one stock of char is better; Canadian experience with hybrid stocks has not been as successful as EU producers ▪ Lake culture of trout or char (freshwater cages) is not permitted in the Province; marine culture (saltwater cages) is not well developed for trout and char ▪ Industry is dependent on US supplies of eyed eggs. There is no formal trout broodstock development programs in the Province ▪ Genetics of strains of trout and char need to be improved through selection to provide competitive advantage to domestic producers (e.g. survival to market, disease resistance, improved yield, etc.) ▪ Efficiency and effectiveness of aquaculture diets (reduced waste output, improved productivity) still needs to improve ▪ Industry-developed Codes of Practice are not widely adopted

	Socio-Political & Environmental Factors
Strengths/ Positives	▪ Economic multipliers from aquaculture production are substantial: o employment multiplier of 4.5; every job in cage culture production sustains an additional 3.5 jobs in the wider economy o sales expenditure multiplier of 4; every dollar in farm gate sales generates an additional 3 dollars in the wider economy ▪ Aquaculture plays an important role in providing stable employment in small communities and rural areas of New Brunswick ▪ Environmental effects of aquaculture are reversible within a short time following termination of operations
Opportunities	▪ Such a broad, horizontal file requires effective and efficient intra-departmental and inter-departmental coordination and cooperative federal–provincial relations ▪ Specialized R&D capacity at DFO SABS, Huntsman Marine Science Centre, Univ. of New Brunswick and Univ. of Moncton's Coastal Zone Research Institute. ▪ A planned approach to watershed zone use is required so that common property resources can be allocated in a manner that generates optimum value for New Brunswick
Threats	▪ The shared federal / provincial policy and regulatory framework governing the sector is cumbersome to implement and enforce, imposing a serious constraint on sectoral development ▪ Public opinion regarding the environmental effects of aquaculture is shaped largely by media reports of salmon farming issues ▪ There are no service standards for approvals required from government; government timelines are not reflective of business cycles in the sector ▪ Insufficient research into the social aspects of aquaculture development ▪ Economics of char farming does not have a solid record
Problems/ Challenges/ Weaknesses	▪ Industry-developed Codes of Practice have not been widely adopted in the sector ▪ The sector has not established effective and on-going channels of communications with community and public interests, both regionally, provincially and elsewhere ▪ Insufficient attention to social and socio-economic aspects of aquaculture development ▪ Most research capabilities in the sector are technical and natural-sciences oriented; social scientists / researchers have not been effectively engaged to study the sector

	Economic Factors
Strengths/ Positives	▪ Land based production technologies have improved productivity and environmental performance of salmonid systems ▪ Trout and Char lend themselves well to intensive land based production systems and have good market uptake
Opportunities	▪ NB has a stable aquaculture supplier's network; e.g. feed, consumables, processing / packaging materials and supplies, etc. ▪ Specialized R&D capacity at DFO SABS, Huntsman Marine Science Centre, Univ. of New Brunswick and Univ. of Moncton's Coastal Zone Research Institute ▪ trout production is unlikely to will increase in the future due to lack of additional water in Idaho and the marginal economics for small scale operators outside Idaho ▪ Competitiveness can be enhanced through economies of scale; e.g. labour efficiency, work / product specialization, buyer power, etc.
Threats	▪ Erosion of competitiveness due to inability to expand output to serve growing markets ▪ Fluctuating Canadian dollar exchange rates affects sales margins ▪ Competition from other farmed species is increasing as the US market remains attractive ▪ Increased buying power of foodservice and retail players requires product conformity ▪ Access sites and capital continue to hamper development of the sector
Problems/ Challenges/ Weaknesses	▪ There is no formal trout broodstock program in NB ▪ Industry-developed Codes of Practice have not been widely adopted in the sector. ▪ The NB freshwater aquaculture sector is having difficulty to attract investment to finance industry expansion and diversification ▪ Few individuals can afford to enter the sector today

Horizontal Analysis

Market Factors

Identified Problems	How is the issue manifest?	Why is it happening? Underlying causes?	Why is it important? (Opportunities & Repercussions)
The US market continues to attract competitors	▪ S. America exports more volume of trout in to US markets than Canada	▪ Production from S. America is expanding faster than in Canada ▪ Frozen product does not compromise shelf-life and reduces transportation costs	▪ Loss of market share in domestic and US markets
Increasing buyer power / Decreasing supplier power	▪ Buyers contracting directly with producers that can meet their volume and product type requirements	▪ Consolidation of buyers (retail & food service) leading to high volume accounts	▪ Loss of market share if production volumes do not increase to service buyers' requirements ▪ Capacity to displace imports in Cdn and US markets
Price point competition from beef, pork, poultry	▪ Lower price/kg for many alternative protein sources at retail and foodservice	▪ High cost of production for trout (e.g. feed costs) and char (e.g. survival, maturation, etc) ▪ Neither Trout nor Char have ever been properly promoted as a centre of plate food staple.	▪ Lower costs resulting from technological improvements and a critical mass could boost profits and increase demand
Insufficient Production Capacity	▪ Insufficient product to meet demand from large customers ▪ Continuity of supply is compromised at times	▪ Inability to expand output at existing sites or via development of new sites due to regulatory constraints	▪ Loss of customers over time as supply is sourced elsewhere ▪ Loss of potential to increase volume and socio-economic benefits in rural NB

Production Factors

Identified Problems	How is the issue manifest?	Why is it happening? Underlying causes?	Why is it important? (Opportunities & Repercussions)
Inability to expand production capacity	▪ Limited number of new freshwater site tenures being developed	▪ Current policy & regulatory framework not conducive to freshwater aquaculture development ▪ Focus is on Atlantic salmon production ▪ Access to development capital is a barrier to entry	▪ Inability to improve competitiveness through economies of scale. Sector runs the risk of becoming marginalized. ▪ Loss of potential to increase socio-economic benefits in rural NB
Fingerling supply in NB may become limited	▪ Limited number of hatcheries ▪ Performance of some stocks is not economically viable	▪ Aging producers seeking to retire ▪ Market demand is limited	▪ Reduced production capacity if key biological resource is limited ▪ Significant risk to expansion
Dependence on supply of eggs from outside the region	▪ No formal NB trout broodstock program ▪ Increased egg imports	▪ Lack of a robust genetic selection process to improve quality and traits of trout and char stocks ▪ Perceived quality from US suppliers (trout) ▪ Year-round availability from US suppliers (trout) ▪ Performance of stocks is variable	▪ Border closure for disease control could cripple the sector – significant reduction in output until alternative suppliers can become established ▪ Insufficient domestic capacity to replace imports in a timely manner ▪ Lost opportunity to enhance capacity of NB sector ▪ Potential to enhance genetic traits for benefit of producers
Ecological challenges and pressures	▪ Organic loading; esp. phosphorus and sediments ▪ Escaped fish ▪ Disease and use of therapeutic agents	▪ Occasional loss of fish ▪ Codes of Practice not fully implemented with performance audits ▪ Best diets and feeding strategies not used by all	▪ Continued opposition to industry development
Production Management	▪ Economic viability of char farming is variable	▪ Lack of effective management regimens for performance metrics of survival and maturation	▪ Reduced capacity to lower overall cost of production and improve competitiveness

Socio-Political & Environmental Factors

Identified Problems	How is the issue manifest?	Why is it happening? Underlying causes?	Why is it important? (Opportunities & Repercussions)
Public opposition to aquaculture	▪ Lack of social licence for aquaculture development	▪ Public opinion is shaped by media reports of west coast salmon farming issues ▪ Poor communication of objective information re aquaculture to stakeholders ▪ Insufficient research into social aspects of the sector; social scientists are not effectively engaged to study the sector ▪ Codes of Practice not fully implemented with performance audits	▪ Inability to secure a social licence to enable industry to develop & prosper ▪ Continued opposition to industry development
Lack of public confidence in government stewardship & enforcement	▪ Public opposition to marine aquaculture has a spill over effect ▪ Aquaculture is the only agri-food sector not covered by the Nutrient Management Act and Nutrient Management Plans	▪ Shared federal / provincial policy and regulatory framework is cumbersome to implement and enforce ▪ Mandated monitoring & reporting done largely for compliance, not used for adaptive management ▪ Lack of a clear policy position on commercial rainbow trout farming	▪ Continued opposition to industry development ▪ Continued inability to secure access to sites for cage culture ventures ▪ Loss of potential to increase socio-economic benefits in rural NB

Economic Factors

Identified Problems	How is the issue manifest?	Why is it happening? Underlying causes?	Why is it important? (Opportunities & Repercussions)
Difficult to enhance competitiveness & lower cost of production	▪ Inability to expand via organic growth ▪ Loss of market share to competitive production from outside the region	▪ Producers not able to access safety net programs available to agriculture ▪ Lack of a clear policy position on commercial rainbow trout farming ▪ Lack of a robust genetic selection process to improve quality and traits of stocks ▪ Cannot take advantage of economies of scale	▪ Loss of potential to increase socio-economic benefits in rural NB ▪ Reduced competitiveness vis-a-vis S. American producers ▪ Erosion of market share
Lack of investor confidence in the sector	▪ Inability to access capital ▪ High borrowing costs ▪ Few players are able to enter the sector (entry barrier)	▪ Producers not able to access safety net programs available to agriculture ▪ Codes of Practice not fully implemented with performance audits ▪ No industry benchmarking system to support performance improvement	▪ The Sector will not achieve its potential to enhance its footprint as a sustainable generator of wealth for the citizens of the Province.
Industry Contraction	▪ Reduced product output ▪ Loss of major accounts	▪ Inability to grow the sector ▪ Economic challenges favour consolidation amongst players	▪ Reduced competitiveness of remaining players
Currency Fluctuations	▪ Variability in gross revenue	▪ Global economic forces beyond influence of sector ▪ Inadequate use of hedge-funding	▪ Operational consistency & stability

Vertical Causal Analysis

The vertical causal analysis identifies the key causal factors from the preceding horizontal analysis.

- The low cost producers of larger trout biomass in Canada in cage culture systems. These open systems are under pressure from ENGO's and regulatory authorities to address issues of environmental concern.
- Consolidation of seafood buyers (retail & food service) means key accounts are demanding larger and more consistent (year round) volumes from suppliers.
- Cost of production for land based trout and char has been variable depending on the region and the scale of the operation. The difficulty is accessing good quality performance data from Canadian char systems makes proper evaluation incomplete. Most of these land based operations appear to be below a minimum production threshold required for a consistent financial return.
- Current aquaculture related policies & regulatory framework not focussed on freshwater development. Shared federal / provincial policy and regulatory framework is cumbersome.
- Opposition from environmental & other specific interest groups affects the political mood of the country. Part of this is driven by the fact that industry bets practices are not consistently followed by farmers
- Lack of a robust national/regional genetic selection program to improve quality and traits of stocks available to farmers
- Public opinion is often shaped by media reports of west coast salmon farming issues "Sustainable Development " is based on three pillars: Economic Prosperity, Environmental Protection and Social Well-Being. There is insufficient research into social aspects (good/bad) of the freshwater aquaculture sector
- Producers not able to access safety net programs
- Global economic forces such as exchange rates and access to credit are beyond the influence of the freshwater aquaculture sector

What Needs to be Addressed

- The number and output of freshwater aquaculture operations in Canada is approximately 8,300 tonnes with a farm-gate value of $44 million (2006). Salmonid species account for more than 91% of the production tonnage and 89% of the sector value. It is estimated that more than 1,000 jobs are created by freshwater aquaculture throughout Canada. In spite of its leading status in marine aquaculture, New Brunswick is a relatively minor player in freshwater aquaculture. Moreover, New Brunswick's output is not commensurate with the inherent potential of the province, given the competitive advantage presented by a plentiful resource base, proximity to the U.S. market which is increasingly dependent on imported seafood, and existing aquaculture (marine) infrastructure. Successful and sustainable freshwater aquaculture development in New Brunswick will dependent upon the implementation of a strategic approach to generate the knowledge, technologies and practices necessary to resolve these challenges.

- There is sufficient knowledge about the biology of the species and the current market situation for both Arctic char and Rainbow trout that a new entrant into the sector can have a reasonable expectation of success. However, there is a minimum size threshold for a production unit to be profitable. Using the variables that were used in this analysis, a land-based, recirculation facility should not be less than 142 metric tonnes per annum for Arctic char and 200 metric tonnes per annum for Rainbow trout.
    - Financial projections indicate that an investment of $1,770,000 is required to establish a 200-tonne per year rainbow trout aquaculture operation.
    - Financial projections indicate that an investment of $2,140,000 is required to launch a 142-tonne per year Arctic char aquaculture operation.

- The cost of production for land based Arctic char ventures seems to be quite variable. There is a lack of good quality performance data from commercial char systems which makes proper evaluation incomplete. Most of the current land based operations appear to be below a minimum production threshold and appear seem to have inconsistent stock performance between lots (e.g. survival, growth, feed conversion) required to produce a consistent financial return. Part of this issue is a result of a lack of a robust national/regional genetic selection program to improve quality and traits of Rainbow trout and Arctic char stocks available to farmers

- With the development of the production model and the review of the current technology that is available for Canadian producers, there is an opportunity to assess the production capacity for the Province of New Brunswick

INTERVIEWS

Individuals contacted for this review:

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- Research: Dr. Jim Duston (Char & Trout) - NSAC
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- Research : Mr. Claude Pelltier (Charr) - CZRI

- Producer: Mr. Dave Roberts (Char - Millbrook, NS)
- Producer: Mr. Jamie Carpenter (Char – Pennfield, NB)
- Producer: Mr. Yves Boulanger (Char & Trout – QC)
- Producer: Mr. Francis Dupuis (Char & Trout – QC)
- Producer: Mr. Al Wright (Char & Trout – ON)
- Producer: Mr. Dale Jordison (Char & Trout – ON)
- Producer: Mr. Lynn Rieck (Char & Trout – ON)
- Producer: Mr. Rick MacDonald (Char – MB)
- Producer: Mr. Jacob Brengballe, (Trout & Char - DK)

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LITERATURE CITED / BIBLIOGRAPHY

Adler, P.R., S.T. Summerfelt, D.M. Glenn and F. Takeda (1996). Evaluation of a wetland system designed to meet stringent phosphorus discharge requirements. Water Environ. Res. 68(5):836-840.

Alvarado, J.L. 1997. Aquafeeds and the environment. CIHEAM – Options Mediterraneennes. p. 275-289 In: Tacon A.G.J. (ed.), Basurco B. (ed.) Feeding tomorrow's fish Zaragoza: CIHEAM-IAMZ, 1997. 307 p. (Cahiers Options Méditerranéennes ; v. 22). Workshop of the CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM), 1996/06/24-26, Mazarrón (Spain)

Anon. 1997. Doppler technology may gain big saving in costs. Fish Farming Int. 24(4).

Aquaculture Association of Canada – Bulletin. March (1993). Arctic Char Culture. Edition 93-1.

Aquaculture Association of Canada – Bulletin. June(1993). Proceedings of the Canadian Arctic Char Conference – November,1992. Edition 93-2.

Bebak, J., J.A. Hankins & S.T. Summerfelt. 2000. Effect of water temperature on survival of eyed eggs and alevins of Arctic char. North American J. Aquaculture 62:139-143

Bernatchez, L., H. Glemet, C.C. Wilson and R.G. Danzmann. 1995. Introgression and fixation of Arctic char (Salvelinus alpinus) mitochondrial genome in an allopatric population of brook trout (Salvelinus fontinalis). Can. J. Fish. Aquat. Sci. 52:179-185

Blake, J.P. (1995). How poultry wastes are managed. NRAES-90 Aquaculture Eng'g and Waste Mgmt. p. 331-341.

Boersen, G. and H. Westers (1985). Waste solid control in hatchery raceways. Prog. Fish Cult. 48:151-154.

Brooks, Kenneth M. (2001). Assessing the Risks: A comparison between the environmental impacts of aquaculture and traditional agriculture. Northern Aquaculture, December 2001

Burke, M.G., M.R. Kirk, N.A. MacBeth, D.J. Bevan and R.D. Moccia. 2005. Influence of photoperiod and feed delivery on growth and survival of first-feeding Arctic char. North Am. J. Aquaculture 67:344-350

Canada Seafood Industry Report (2006). Glitnir Seafood Team, Glitnir Canada, Halifax NS. 56 p. www.glitnir.is/seafood

Canadian Aquaculture Systems Inc. (2003). Millbrook First Nation Arctic Char Aquaculture Project. Technical Report prepared for the Atlantic Canada Opportunities Agency - ACOA (www.acoa.ca)

Canadian Aquaculture Systems Inc. (2003). Seafood Situation and Outlook – 2003. Prepared for Agriculture and Agri-Food Canada, Market & Industry Services Branch, Fish and Seafood Sector Roundtables. 71 p. + Appendices.

Canadian Aquaculture Systems Inc. (2003). Seafood Roundtable Committee – Holistic Government Response. Agriculture and Agri-Food Canada, Food Bureau. 32 p. + Appendix.

Canadian Aquaculture Systems Inc. (2008). Aquaculture in Ontario. Situation Assessment and Industry Outlook. Technical Report prepared for Northern Ontario Aquaculture Association-NOAA (www.ontarioaquaculture.com)

Canadian Aquaculture Systems Inc. (2008). Canadian Model Aqua-Farm Initiative. Technical and Operational Assessment for the Canadian Model Aqua-Farm. Technical Report prepared for the Interprovincial Partnership for Sustainable Freshwater Aquaculture Development- IPSFAD (www.ipsfad.ca)

Chiasson, M., C.S. Pelletier, T.I.Benfey. (2009). Triploidy and full-sib family effects on survival and growth in juvenile Arctic Char (Salvelinus alpines). Aquaculture. Vol 289. Pages 244-252.

Chen. S. (2001). Current Knowledge and research need for recirculation system nutrient management. p. 3-7 in Proceedings, 2001 Aquaculture Engineering Society Issues Forum. NRAES-157.

Connors, S. (2005). Canadian Fish & Seafood Industry. (Manuscript). Prepared for Fisheries and Oceans Canada, Strategic Priorities & Planning, Ottawa.

Davidson, J. and S. Summerfelt (2004). Solids removal from a coldwater recirculating system – comparison of a swirl separator to a radial-flow settler. Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 293-302.

DFO (2010). National Aquaculture Strategic Action Plan Initiative. Strengthening Sustainable Aquaculture Development in Canada. Discussion Document. Fisheries and Oceans Canada, Communications Branch, Ottawa. 27 p.

Dumas, S., J.M. Blanc, F. Vallee, C. Audet and J. De La Noeue. 1996. Survival, growth, sexual maturation and reproduction of brook char, Salvelinus fontinalis (Mitchill), Arctic char, Salvelinus alpinus L. and their hybrids. Aquaculture Res. 27:245-253

Dumas, S., C. Audet, J.M. Blanc and J. de la Noue. 1995a. Seawater acclimation of diploid and triploid brook char (Salvelinus fontinalis), diploid Arctic char (Salvelinus alpinus) and their diploid and triploid hybrids. J. Fish Biol. 46:302-316

Ebeling, J.M., J.A. Joiner, R.A. Labatut, and M.B. Timmons (2004). Hydraulic characterization of a mixed-cell raceway. Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 556-563.

Erkiksson, L-O., A. Alanara, E. Brannas, J. Nilsson & A. Kiessling. 1993. Arctic char faming in Sweden. Bull. Aquacult. Assoc. Canada 93(1):18-24.

Glebe, B. 2006. Introduction of exotic salmonids to aquaculture in eastern Canada and Maine. Bull. Aquacult. Assoc. Canada 106(1,2):20-29

Gross, R., B. Gum, R. Reiter and R. Kuhn. 2004. Genetic introgression between Arctic char (Salvelinus alpinus) and brook trout (Salvelinus fontinalis) in Bavarian hatchery stocks inferred from nuclear and mitochondrial DNA markers. Aquaculture International 12:19-32

Halweil, B. (2008). Farming fish for the future. Worldwatch Report 176. Worldwatch Institute, Washington DC. 48 p.

Hankins, J.A., S.T. Summerfelt and M.D. Durant (1995). Impacts of feeding and stock management strategies upon fish production within water recycle systems. NRAES-90 Aquaculture Eng'g and Waste Mgmt. p. 70-86.

Harry Cummings & Associates (2007). Economic Impact of the Cage Culture Industry in Ontario. Prepared for Northern Ontario Aquaculture Association. 51 p.

HM Johnson & Associates (2007). 2006/2007 Annual Report on the United States Seafood Industry (Fourteenth Edition). 101 p.

HM Johnson & Associates (2008). U.S. Market Opportunity Assessment - Freshwater Trout. Fisheries and Oceans Canada, Aquaculture Management Directorate, Ottawa. 32 p.

Hutchinson, W, M. Jaffery, D. O'Sullivan, D. Casement and S. Clarke. 2004. Recirculating Aquaculture Systems: Minimum Standards for Design, Construction and Management. Inland Aquaculture Association of South Australia inc. RAS MSCDCM V2 040220.

IPSFAD (2007). Ontario R&D Workshop Summary. Interprovincial Partnership for Sustainable Freshwater Aquaculture Development in Canada, Quebec, QC. 11 p.

Jansson, K. 2008. NOBANIS – Invasive Alien Species Fact Sheet – Salvelinus fontinalis. From: Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS www.nobanis.org. Date of access 01/03/2010,

Jonsson, Jon Kjartan. (2009). Global Marketing of Arctic Char- Arctic Char Farming on the Nordic Countries – powerpoint presentation. www.bioforsk.no

Johnston, G. (2002). Arctic char aquaculture. Fishing News Books, Oxford UK.

- De March, Dr. Brigitte. Arctic char culture. Pages 25-30
- Erickson, Dr. Lars-Ove., et al. Arctic char farming in Sweden. Pages 18-24
- Glebe, Dr.Brian, T.Turner. Alternate commercial rearing strategy for Arctic char. Pages 2-10.
- Tabachek, Dr.Jo-Anne. A review of feeding and nutrition of Arctic char and priorities for future research. Pages 10-17.

Johnson, B., Johnson, B. and Chen, S. (2002). Characterization and influence of factors affecting the discharge of phosphorus from flow-through aquaculture facilities. Proceedings 4th Int'l Conf. Recirc. Aquaculture. Roanoke, VA.

Johnson, W. and S. Chen (2004). Performance evaluation of radial flow clarification applied to recirculating aquaculture systems. Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 303-310.

Kimura, R., S. Kawaguchi, and S. Sugitani (1993). Automatic feeding control system for fish. In: Reinertsen, H. et al. (Eds) Fish Farming Technology. Balkema, Rotterdam. p. 217-225.

Labatut, R.A., M.B. Timmons and J.M. Ebeling (2004). Simulation of a mixed-cell raceway using computational fluid dynamics (CFD). Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 259-268.

Lindem, T. and D. Al Houari. 1993. Hydroacoustic monitoring of fish in aquaculture – a method for automatic feeding control by detection of fish behaviour. ICES Statutory Meeting 1993 C.M. 1993/F:45/ Session T

Lundrigan, T.A., J.D. Reist and M.M. Ferguson. 2005. Microsatellite genetic variation within and among Arctic char (Salvelinus alpinus) from aquaculture and natural populations in North America. Aquaculture 244:63-75

McGowan, C., J. Lucan, E. Keddie, J. Rose, E. Davidson, N. Quinn and W.S. Davidson. 2009. Application of salmonid genomic research in a mid-sized commercial broodstock facility: The Icy Waters Arctic char experience. Bull. Aquacul. Assoc. Canada 107(3):31-43

Moccia, R. D. and D. J. Bevan (2006). Aquastats 2004 – Ontario Aquacultural Production in 2004. University of Guelph, Aquaculture Extension Centre Factsheet, No. 06-001.

Moccia, R. D. and D. J. Bevan (2007). Aquastats 2005 – Ontario Aquacultural Production in 2005. University of Guelph, Aquaculture Extension Centre Factsheet, No. 07-001.

Molleda, M. I., H. Thorarensen and R. Johannson. 2007. Water Quality in Recirculating Aquaculture Systems for Arctic Char (*Salvelinus alpinus*) Culture.The United Nations University. Fisheries Training Program. Reykjavik, Iceland. 54 p.

National Agricultural Statistics Service (2008). Trout Production. Agricultural Statistics Board, U.S. Department of Agriculture, Washington DC. 20 p.

Noble, A.C., M.M. Garner and R.W. Nordhausen. 2005. Chronic diarrhea in Arctic char (Salvelinus alpinus) cultured in a semi-closed recirculation system. Bull. Eur. Ass. Fish Pathol. 25(6):248-255

Prince Edward Island Agriculture and Forestry. (2000). Agriculture Based Profile on Land Based Farming of Arctic Char.

Rasmussen, M.R., J. Laursen and E. McLean (2004). Development of Efficient Sludge Collection Cones for Concentration of Raceway-Derived Solids in Recirculating Aquaculture Systems. Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 400-410.

Rimmer, M. West Virginia Aqua's Arctic Char Production Continues to Increase. Fish Tales Newsletter No. 3 Fall 2003. Extension Service, West Virginia University

Rodriguez, J. and T. Gregg (1993). Considerations for the use of ultraviolet in fish culture. P. 481-485 in: Wang, J-K (Ed.) Techniques for Modern Aquaculture, Proc. of an Aquacult. Engineering Conf., June 21-23, 1993, Spokane WA.

Rogers, Brian., W.Davidson. (2001).Arctic Char (Salvelinus alpines), Aquaculture Review. Technical Report prepared for the Prince Edward Island Aquaculture Alliance and the Aquaculture Association of Nova Scotia.

Scarratt, D.J. 1996. Atlantic aquaculture; Arctic char. Department of Fisheries and Oceans

Schwartz, M.F. and C.E. Boyd (1995). Constructed wetlands for treatment of channel catfish ponds effluents. Prog. Fish-Cult. 57(4):255-266.

Schwartz, M.F., J.M. Ebeling, and S.T. Summerfelt (2004). Geotextile tubes for aquaculture waste management. Proceedings, 5th Int'l Conf. Recirculating Aquaculture, Roanoke, VA. p. 385-390.

Shulz, C.J., Gelbrecht and B. Rennert (in press). Treatment of rainbow trout farm effluents in constructed wetland with emergent plants and subsurface horizontal water flow. Aquaculture.

Siikavuopio, S.I., S. Skybakmoen and B-S. Saether. 2009. Comparative growth study of wild- and hatchery-produced Arctic char (Salvelinus alpinus L.) in a coldwater recirculation system. Aquacultural Engineering 41:122-126

Skulason, S., S.S. Snorrason, D.L.G. Noakes and M.M. Ferguson. 1996. Genetic basis of life history variations among sympatric morphs of Arctic char, Salvelinus alpinus. Can. J. Fish. Aquat. Sci. 53:1807-1813

Skybakmoen, S., S.I. Siikavuopio and B-S. Saether. 2009. Coldwater RAS in an Arctic char farm in Northern Norway. Aquacultural Engineering 41:114-121

Somorjai, I.M.L. 2001. Quantitative trait loci for fitness traits in Arctic char: Conservation in rainbow trout and correlations among traits. M.Sc. Thesis. University of Guelph.

Snow, M., R. S. Raynard and D. W. Bruno. (2001). Comparative susceptibility of Arctic char (*Salvelinus alpinus*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) to the Scottish isolate of infectious salmon anaemia virus. Aquaculture. Vol 196. Pages 47-54.

Species-of-the-Month at SeaFood Business Online. Arctic Char
http://www.seafoodbusiness.com/

Stechey, D., J. Linquist & B. Bowman (2005). Wastewater management & best practices of the aquaculture sector. Queen's Printer for Ontario. 236 p.

Stechey, D. and W.D. Robertson (2006). Evaluation of Emerging Technologies for Waste Management in Land-Based and Open-Water (Cage) Aquaculture. Queen's Printer for Ontario. 123 p.Adams, Colin E. F.A. Huntingford. (1996). What is a successful fish ? Determinants of competitive success in Arctic Char (salvelinus alpines) in different social contexts. Canadian Journal of Fisheries and Aquatic Sciences. 53. Pages 24460-2450.

Stechey, D., L. Albright, D. Foss, E. Gilbert, S. Lareau, J. Maheu, M. McNaughton, M. Meeker, and W.D. Robertson (2008). Status and Outlook for Freshwater Aquaculture in Canada: Regional Perspectives. Proc. 2007 Meeting of the Aquaculture Association of Canada (in press).

Summerfelt, S.T., K.H. Holland, J.A. Hankins and M.D. Durant (1995). A hydroacoustic waste feed controller for tank systems. Wat. Sci. Tech. (10):123-129.

Summerfelt, S.T. (1999). Waste-Handling Systems, In: (Bartali and Wheaton, eds) CIGR Handbook of Agricultural Engineering, Vol. II: Animal Production and Aquacultural Engineering. p. 309-350. American Society of Agricultural Engineers, St. Joseph, MI.

Summerfelt, S.T., P.R. Adler, D.M. Glenn and R.N. Kretschmann (1999). Aquaculture sludge removal and stabilization within created wetlands. Aquacult. Eng'g 19(2):81-92.

Summerfelt, S.T. and B.J. Vinci (2003). Best management practices for recycle systems. Proceedings – Aquaculture Effluents: Overview of EPA Guidelines and Standards and BMPs for Ponds, Raceways and Recycle Culture Systems. p. 110-133.

Summerfelt, S.T, J.W. Davidson, T.B. Waldrop, S.M. Tsukuda, J. Bebak-Williams. 2004. A partial-reuse system for coldwater aquaculture. Aquacultural Engineering 31:157-181

Summerfelt, S.T., G. Wilton, D. Roberts, T. Rimmer & K. Fonkalsrud. 2004. Developments in recirculating systems for Arctic char culture in North America. Aquacultural Engineering 30:31-71.

Tao, W.J. and E.B. Boulding. 2003. Associations between single nucleotide polymorphisms in candidate genes and growth rate in Arctic char (Salvelinus alpinus L.) Heredity 91:60-69

The Char Network. Hybridisation between Arctic char (Salvelinus alpinus) and other salmonides. The Char Network. (downloaded Mar 1, 2010) www.charrnet.org/charrnet?id=3586&template=page%2CViewPage.vm

The FishSite News Desk (2008). U.S. fish farms lagging behind. http://www.thefishsite.com/fishnews/7649/us-fish-farms-lagging-behind

Timmons, M.B., J.M. Ebling, F.W. Wheaton, S.T. Summerfelt and B.J. Vinci. Recircultating Aquaculture Systems. NRAC Publication No. 01-002. 650 p.

Treidlinger, M. (2002). The Canadian Fish and Seafood Industry – Sub-Sector Profile. (Manuscript). Agriculture and Agri-Food Canada, Food Bureau, Ottawa. 13 p.

True, B., W. Johnson and S. Chen (2004). Reducing phosphorus discharge from flow-through aquaculture II: Hinged and moving baffles to improve waste transport. Aquaculture Engineering 32:145-160.

Veerapen, J.P, B.J. Lowry and M.F. Couturier (2003). Solids removal in recirculating aquaculture systems – modelling and experiments. Aquacult. Assoc. of Canada Spec. Publ. No. 6:81-83.

Watten, B.J. and D.C. Honeyfield (1995). Hydraulic characteristics of a rectangular mixed-cell rearing unit. Aquaculture Expo 8 and Aquaculture in the Mid-Atlantic Conference, June 24-25. 1995, Washington DC

Watten, B.J., D.C. Honeyfield and M.F. Schwartz (2000). Hydraulic characteristics of a rectangular mixed-cell rearing unit. Aquacultural Engineering, 24:59-73.