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Feasibility Study of Closed-Containment Options for the British Columbia AQUACULTURE Industry

Canada

Feasibility Study of Closed-Containment Options for the British Columbia Aquaculture Industry

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September, 2010

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Executive Summary

Both government regulators and the Canadian salmon aquaculture industry face ongoing pressure to reduce the industry's potentially adverse effects on the surrounding natural aquatic environment. One option currently being considered is "closed-containment," a practice that involves enclosing fish in floating containers or land-based farms to minimize their impact on nearby waters.

Closed-containment can include a range of technologies and operating environments—from ocean- to land-based production systems—with varying degrees of isolation from the environment. Typically, the more "closed" a system is, the more complex its management becomes, since its energy requirements are greater and waste can be more of an issue.

Given this complexity, DFO decided that a thorough analysis of its technical and financial potential should be completed. The information yielded by such a study would benefit all stakeholders (government and industry, as well as the environmental community) by highlighting the technologies' potential benefits, fostering further innovation, and identifying possible gaps, limits and risks.

In 2008, the Canadian Science Advisory Secretariat (CSAS) published a report entitled *Potential Technologies for Closed-containment Saltwater Salmon Aquaculture*. That report identified a need to analyze closed-containment technologies, and included economic recommendations. The goal of the current study is to use financial analysis tools to respond to the CSAS report. This study is therefore limited to financial considerations.

The reference case for comparison in this analysis is conventional net pen systems, a type of containment aquaculture currently used in British Columbia and many other parts of Canada, as well as globally. The goal of this analysis is to compare the systems based on realistic, hypothetical operating conditions. But the analysis does *not* seek to provide potential investors with data that could be used to support future investment. These financial analyses represent a hypothetical venture for different production technologies, albeit based on currently accepted industry practices. The data should not be used to support future investment decisions, because this document is not intended to be a business plan. Business plans are unique to individual projects, and must be undertaken as an exercise beyond the scope of this financial analysis.

All scenarios described in this report were developed and analysed in the context of the current operating environment of the British Columbia industry (i.e., all the capital and operating costs reflect those of a West Coast venture). Further analysis and adaptation would be necessary to reflect a different operating environment accurately.

To begin the study, DFO conducted a preliminary financial assessment of all technology types identified by CSAS. The results indicated that only two of them—net pen and recirculating aquaculture systems (RAS)—were likely to show positive returns (see table below).

Technology	Initial investment	Third-year income	ROE
1. Net pen	$5,000,716	$2,641,147	52%
2b. Rigid–with aeration	$23,284,470	-$2,125,885	-10%
2c. Rigid–pure oxygen	$24,004,470	-$253,079	-2%
3c. Flexible–pure oxygen	$29,332,086	-$2,041,169	-9%
4a. Land-based grade	$72,352,066	-$17,417,907	-20%
4b. Land-based below grade	$67,748,173	-$13,496,265	-19%
4c. Land-based liquid oxygen injection	$19,628,900	-$403,142	-4%
4d. Land-based LOX Mechanical filtration	$18,858,685	-$260,773	-2%
4e. Recirculating aquaculture system	$22,622,885	$381,467	4%

Based on this preliminary assessment, DFO conducted more in-depth financial analyses, including sensitivity analyses, on net pens and RAS. The results demonstrate a positive net income for both technologies.

However, with capital expenses of $5.0 million and $22.6 million respectively for net pens and RAS, the analysis found a significant advantage for net pens in terms of pre-tax income. Although RAS production showed efficiencies in biological feed conversion ratio (FCR), temperature stability, and improved environmental control, the presence of higher capital costs, energy costs and labour requirements significantly affected its overall profitability.

The study results also showed that while both technologies are profitable on a pro-forma basis, with returns significantly higher for net pens, RAS technologies are likely to be considerably more sensitive to market forces that are beyond an operator's control (such as exchange rate and market price), and may prove non-profitable within a range of variability that has been experienced by the Canadian salmon aquaculture industry in the past. These sensitivities are due largely to the high initial capital investment and subsequent associated costs.

As with most emerging technologies, once wider uptake within the sector is achieved, capital and operating costs may go down. If closed-containment technologies achieve a critical mass of production, operators may benefit from economies of scale in the acquisition of capital items, and their increasing expertise could help reduce operating costs.

To conduct this analysis, DFO used costs for net pens that are the result of several decades of expertise and an industry that has achieved the advantages of critical mass. It is possible that RAS-based production systems could experience similar gains, but the scope and time frame of those gains are beyond the current analysis. It is also possible that certain intangible costs (e.g., environmental and social license) could affect the operations' profitability.

Overall, the analysis showed that RAS technology is marginally viable from a financial perspective, but that it presents a higher level of risk compared to net-pen systems. However, these findings still need to be assessed—and their assumptions validated—in a real-life scenario. Potential next steps could include a pilot scale or demonstration system capable of producing salmon at commercially viable levels (e.g., one module scalable to financially feasible levels) to demonstrate the technical and financial feasibility of closed-containment salmon rearing under real world conditions.

Life cycle analysis of such a demonstration facility should also be undertaken and compared with that of net pen production. Life cycle analysis quantifies and compares potential environmental impacts between systems, and is used to compare local ecological impacts to impacts that are more global in nature, such as climate change, non-renewable resource depletion and ocean acidification.

It would be necessary to know the outcomes of such further analyses in order to determine next steps and to guide government policy direction as it relates to closed-containment for salmon aquaculture.

Experts Consulted

DFO consulted a number of experts in order to obtain reliable, realistic views on the technical, scientific and financial assumptions used in this report. This input was invaluable, and resulted in iterative improvements of the report. The experts consulted offered diverse views on a range of topics; as a result, it was not always possible to incorporate all of the information offered.

The review of this document by the experts listed below does not necessarily represent their endorsement of it. The results of this study, along with any differences from peer-reviewed articles or errors, remain those of Fisheries and Oceans Canada. The authors of this report would like to thank the following individuals for their contributions:

- Bev Bacon, RDI Strategies
- John Colt, National Oceanographic and Atmospheric Administration
- Wayne Gorrie, PR Aqua
- Brad Hicks, Taplow Feeds
- Barry Hill, NB Department of Agriculture and Aquaculture
- John Holder, JLH Consulting
- KC Hosler, PR Aqua
- David Lane, T. Buck Suzuki Foundation
- John Lawrie, Independent Consultant
- Gary Myers, Myers Consulting
- David Minato, B.C. Salmon Farmers Association
- Michelle Molnar, David Suzuki Foundation
- Pam Parker, NB Salmon Growers Association
- Bill Robertson, Huntsman Marine Science Centre
- Gary Robinson, Independent Consultant
- Myron Roth, B.C. Ministry of Agriculture and Lands
- Ruth Salmon, Canadian Aquaculture Industry Alliance
- Daniel Stechey, Canadian Aquaculture Systems
- Steven Summerfelt, Freshwater Institute
- Michael Timmons, Cornell University
- Mary Ellen Walling, B.C. Salmon Farmers Association
- Andrew Wright, Save Our Salmon

List of Acronyms

CSAS	Canadian Science Advisory Secretariat
DFO	Fisheries and Oceans Canada
FCR_b	Biological Feed Conversion Ratio
FOB	Free on Board
FTE	Full-time Equivalent
HOG	Head-on Gutted
IRR	Internal Rate of Return
LOX	Liquid Oxygen
Lpm	Litres per Minute
NPV	Net Present Value
psi	Pounds per Square Inch
RAS	Recirculating Aquaculture Systems
ROE	Return on Equity
ROI	Return on Investment
t	Metric tonne
TGC	Thermal Growth Coefficient

Purpose

Both government regulators and the Canadian salmon aquaculture industry face ongoing pressure to improve production methods in order to reduce negative environmental impacts and limit potentially adverse interactions between aquaculture operations and the surrounding aquatic environment. "Closed-containment," a practice that involves enclosing fish on land-based farms or in floating containers, is a production option that could accomplish this.

Closed-containment includes a range of technologies and operating environments, from ocean- to land-based production systems, with varying degrees of isolation and environmental interaction. Typically, the more closed a system is, the more complex it becomes, since its energy requirements are often greater and waste can be more of an issue.

This is why a thorough analysis of the technical and financial potential of closed-containment technologies is needed. The resulting information will benefit all stakeholders (government, industry and the environmental community) by highlighting the technologies' potential benefits, fostering further innovation, and identifying possible gaps, limits and risks. This analysis is a two-step process, involving 1) an overview of existing and developing technologies, along with a complete evaluation of the technical aspects and external risks of the most promising technologies; and 2) a financial assessment of the most promising technologies identified in the first stage.

The Canadian Science Advisory Secretariat (CSAS) coordinates the peer review of scientific issues for the Department of Fisheries and Oceans (DFO). In the March 2008 report, *Potential Technologies for Closed-containment Saltwater Salmon Aquaculture*, CSAS summarized the review of a series of working papers on this subject. This review provided the basis for scientific advice to government, industry and other interested stakeholders on the development of closed-containment technologies on a commercial scale. The review identified a number of economic, technological, fish health and environmental research priorities for stakeholders to consider.

The goal of this study was to use financial analysis tools to respond to the CSAS economic recommendations and to conduct an analysis of previously identified technologies for salmon farming. For the purpose of this study, only financial elements were considered.

The reference case for comparison in this analysis is conventional net pen systems, which are currently used in British Columbia and many other parts of

Canada, as well as globally. The goal of the analysis is *not* to provide potential investors with data that could be used to support future investment decisions, but rather to conduct an exploratory analysis of the potential commercial viability of closed-containment technologies and a preliminary comparison of systems based on hypothetical, realistic operating conditions. The outcomes of this financial analysis could be useful in determining next steps (e.g., pilot scale or demonstration system) and in guiding government policy direction.

It is important to note that all scenarios examined in this report have been developed and analyzed in the context of the current operating environment of the British Columbia industry (i.e., all capital and operating costs reflect those of a West Coast venture). Further analysis and adaptation would be necessary to reflect a different operating environment accurately.

1.0 Introduction

Salmon farming began in the early 1970s when farmers focused their efforts on two Pacific salmon species: coho (*Oncorhynchus kisutch*) and chinook (*Oncorhynchus tshawytscha*). But the focus soon shifted to Atlantic salmon (*Salmo salar*), which could grow more quickly than Pacific salmon in salt water and withstand higher densities in cages. Although the first successful farming of Atlantic salmon took place in NB in 1979, the practice grew much more quickly in B.C. during the next decade (Anderson, 2007; Robson, 2006).

Atlantic salmon are not native to British Columbia. Eggs of this species were first imported into the province from Scotland, and later from Washington state. Today, Canadian operators on both coasts produce juveniles from brood stock at their own hatcheries, and Canada's salmon farmers grow mainly Atlantic salmon, as in other salmon farming regions around the world.

Salmon sets the production trend in Canadian aquaculture, accounting for 70 per cent of total aquaculture production and over 80 per cent of the value. Production grew at an annual average rate of 7.5 per cent over the past decade. Globally, Canada ranks as the fourth-largest producer of farmed salmon, holding a production share of 8 per cent, but trails far behind the two leading producers (Chile, at 35 per cent, and Norway, at 43 per cent). After peaking in 2002, Canadian production declined for several years before trending upward again, reaching 117,306 tonnes in 2007; however, this level of production was still nearly 13,000 tonnes lower than the 2002 level. The value of total salmon production increased from US$236 million in 1987 to US$744 million in 2007. Since 2005, increasing demand and a limited supply have increased world salmon prices.

The industry structure of the sector is mixed. Salmon operations are large and vertically integrated (GSGislason & Associates Ltd, 2004). The integration comprises all four phases of the aquaculture value chain, namely hatchery, grow-out, processing, and marketing. Typically, integrated salmon operations raise eggs into smolts at their own hatcheries, then transfer the smolts to the grow-outs. If a company does not operate its own processing facilities, it pays a processing enterprise for custom processing. The salmon companies also allocate resources for research and development (R&D).

Marine cage culture is the main method for farming salmon. Nearly all of the cages used in Canada can be classified as gravity type cages[1] (Masser and

[1] Gravity type cages comprise a system with a surface collar from which nets are supported and hung in the water column.

Bridger, 2007). Marine cages are moored as a group, or flotilla, typically within submerged grid mooring systems.

Producers stock their marine cages with salmon smolts from freshwater hatcheries. The smolts are nurtured and fed in these cages for 15 to 20 months, until they reach the desired harvest size. The use of automatic feeders that rely on underwater cameras to monitor feeding behaviour and control feed delivery helps to insure the fish have enough to eat while minimizing waste and reducing the impact of uneaten feed on water quality.

1.1 Technology Assessment: Canadian Science Advisory Secretariat

In June 2007, DFO organized a steering committee composed of broad stakeholders in the salmon aquaculture industry to develop objectives for reviewing closed-containment technologies. The Canadian Science Advisory Secretariat (CSAS)[2] was mandated to perform a review of closed-containment technologies and provide scientific advice on their status.

CSAS developed a series of working papers on the subject of closed-containment finfish-rearing technologies, the results of which were reviewed and discussed at a workshop held in Sidney, B.C. in January 2008. The documentation from this inclusive process informed DFO, other federal departments and agencies, provincial governments, First Nations, industry, and the environmental community about the development of closed-containment technologies as applied to commercial-scale salmon aquaculture.

The review had the following specific objectives (DFO, 2008):

1. To define the strengths and weaknesses of various system designs and technologies in the context of their potential use for commercial-scale, closed-containment salmon rearing;
2. To identify performance parameters and criteria for design evaluation, biological and ecological performance, associated cost (capital and variable), and logistic support to be used in subsequent economic analyses;
3. To evaluate what unit processes are required to provide the water quality conditions necessary to optimize fish growth and welfare while minimizing the impact on the external aquatic environment;

[2] CSAS coordinates the peer review of scientific issues for the Department of Fisheries and Oceans. The different regions of Canada conduct their resource assessment reviews independently, tailored to regional characteristics and stakeholder needs. CSAS facilitates these regional processes, fostering national standards of excellence and exchange and innovation in methodology, interpretation, and insight.

4. To document and assess current technologies that can be used for each unit process (component) and to evaluate how each technology affects the system's dynamics;
5. To provide technical background to aid in system integration and experimental design for future research and pilot projects;
6. To develop a "gap analysis" that might be used to assess future closed-containment research needs;
7. To provide a knowledge base on which an economic analysis of closed-containment could be built; and
8. To generate dialogue with industry, environmental non-governmental organizations (ENGOs), governments, First Nations and academia.

After an initial review of 40 closed-containment systems, CSAS analyzed five types of production systems in depth:

1. Conventional net pens;
2. Floating closed-containment systems with rigid walls;
3. Floating closed-containment systems with flexible walls;
4. Land-based flow-through systems; and
5. Land-based recirculating aquaculture systems (RAS).

A more detailed examination of each production system can be found in Section 3 of this study.

The CSAS evaluation identified a number of steps that would be necessary to properly evaluate any proposal for the closed-containment culture of salmon. The evaluation concluded that (DFO, 2008):

1. There should be a review of any proposed business plan to determine the objectives, rationale and work plan. The business plan should contain background information about the proponents as well as a sensitivity analysis of market factors, including average and non-optimal operating conditions and global market trends. The business case should account for the true costs of operations, including evidence of system reliability, backups, and the use of realistic past and current business models and environmental impacts.
2. Proposals should be evaluated with reference to the systems mentioned above, specifying the environmental and site characteristics, culture technique, water source, and treatment components. A comprehensive and accurate environmental monitoring program should be a component of any proposal.
3. Proposals should be evaluated based on the process and procedures used in the engineering analysis, including aspects such as the structural stability and integrity of containers, mooring systems, and construction and decommissioning processes.

4. Proposals should be evaluated based on the conditions of their biological operating parameters, which need to be stated explicitly and justified. It should describe the unit processes that would be used to reach these operating conditions, and provide details on system reliability, including backups and proper use of bio-security technologies and practices.
5. Proposals should be evaluated based on their management, operational and animal husbandry practices.
6. Proposals should identify how the project is intended to be sustainable. Factors to consider may include, for example, accounting for all energy costs, greenhouse gas emissions, and environmental costs using an Environmental Cost Accounting approach.
7. Proposals should be evaluated based on a detailed risk analysis in association with the estimated costs and environmental impacts.
8. All proposals should include funding for a separate and independent monitoring and evaluation team.
9. The evaluation team should post quarterly and yearly reports on a government website.

In addition to these recommendations, the CSAS process identified a number of research priorities in the areas of economics, technology, fish culture, health and welfare, waste and other environmental effects.

1.2 Process

As part of the original CSAS objectives, and building on the technical review, a DFO team initiated a financial analysis of the five main technologies (and alternate or sub-technologies) in November 2008. The team met with stakeholders to discuss the development of a financial evaluation model based on the assumptions and data sources from the CSAS process. A draft model, developed by Gardner Pinfold Consulting Economists, was presented, and it led to discussion and the identification of gaps and areas for further revision. This model was constructed using generally accepted accounting principals, and integrated into an MS Excel spreadsheet.

DFO presented a revised model to a group of experts, many of whom had participated in the original CSAS review, at a stakeholder meeting on March 24 and 25, 2009 in Nanaimo, B.C. Following an overview of the model and an in-depth technical discussion, the group identified further areas for refinement, particularly the recirculating aquaculture systems (RAS) element. Due to the shortened production cycle, many of the assumptions used for the other four technologies within the financial model did not fit well with the RAS component. In the fall of 2009 a new version of the model was produced, incorporating a new RAS “add-on” element, taking into consideration many of the unique RAS-specific elements. Several subject matter expert committees, composed of participants from government, industry and academia, validated the main assumptions used in the model and identified possible areas of uncertainty.

After validating the assumptions and inputs, DFO ran a preliminary financial analysis and shared it with subject matter experts. The results of the preliminary analysis served as discussion points to identify any potential gaps or errors in the model's inputs or outputs. An iterative process was used, followed by a public presentation and discussion of the results (Vancouver, B.C. – April 26, 2010 and St. John's, N.L. – May 19, 2010). This resulted in the current report detailing the financial comparisons between various closed-containment scenarios. A copy of the financial model (as an MS Excel spreadsheet) used for this report is available from DFO upon request.

2.0 Methodology

This section details the methods and theoretical background used in the financial analysis. It begins with a brief overview of the fundamentals of a financial analysis, followed by a summary of the five main production systems (see Section 3). Next, it outlines the basic parameters for the model's production system, along with more detailed technical information (biological, technical and economic assumptions and capital costs—see Section 4) focusing on comparisons between conventional net pens and RAS.

2.1 Fundamentals of Financial Analysis

A financial feasibility study is an assessment of a technology's potential under certain market and economic conditions. It often has to be performed considering local production constraints or advantages (such as the availability of sites, temperature, etc.) and operating criteria. This particular report deals only with operating conditions relevant to British Columbia. The output can represent either a dollar value (profit, gross profit, net income, net present value) or a proportion (financial ratios). Information such as revenue, initial capital investment, general operating costs, financing costs and other direct and indirect costs (e.g., administrative expenses, depreciation, etc.) are used in the analyses.

Two important outputs used in the current financial analysis are the third-year income and the net present value (NPV). Because it is difficult to assess costs and revenues over the long term, the income at the third year of operation is considered a good approximation of the profit an investor can expect for a single year of operation. This is because at that time the scenarios involved have reached a steady state of production—that is, costs and revenues have stabilized around a relatively constant value for the subsequent years. While financing costs tend to vary over time, revenues and operating costs only vary significantly during years one and two, and are relatively stable after that. Income is calculated as follows:

Income = Farm gate revenues - operating costs (fixed, labour, production-based, feed costs) - administrative costs - straight-line depreciation of assets - interest charges (loan and line of credit)

The advantage of this method is that it includes the costs that are assumed throughout the life of the project (capital expense, re-investment, financing) in the yearly results.

The other output used is the net present value of cash flows (NPV). By calculating the NPV of a project, one discounts (brings back to present value) a series of future net cash flows that will result from an investment. The advantage of this approach is that it offers a global idea of the project's value. That is, any cost or revenue occurring during the life of the project is summed to calculate its worth in the current period (considering inflation, for instance). A discount rate (required rate of return) of 7 per cent, similar to what has been used in other studies of this kind, is used. In addition, the internal rate of return (IRR)—that is, the discount rate at which the NPV is equal to zero—is calculated. The formulas to calculate the NPV and IRR are as follows:

$$NPV = \sum [Flows_t /(1+ i)^t] - C$$

$$IRR = i \mid \sum [Flows_t /(1+ i)^t] - C = \$0$$

$Flows_t$: The net increase /decrease in cash occurring at one period ($)
i: The discount rate chosen to calculate NPV or the time value of money (per cent)
t: The period at which the flows are discounted (years)
C: The initial cost of the project

Two key financial ratios used in this analysis are return on investment (ROI) and return on equity (ROE). Depending on the application, these ratios may be calculated slightly differently. For the purpose of this exercise:

ROI = Income before tax /capital investment

ROE = Income before tax /total equity

Total equity refers to the capital investment realized by the owners. Equity is assumed to be utilized for acquiring capital goods (e.g., equipment and machinery), and for providing working capital while the enterprise does not generate sufficient funds for meeting cash flow needs. Cash flow needs that are not covered by the investment in equity are assumed to be satisfied through a bank line of credit.

2.2 Basic Production Parameters

For this analysis, the general production parameters established by the CSAS process were used to maintain consistency between scenarios (Table 1). Fish would be stocked at an initial weight of 75 grams—either purchased from outside providers or produced internally as part of a vertically integrated operation—and then grown in net pens, enclosed floating facilities, or tanks on land to reach a target weight of 5.65 kilograms. At this stage, the entire crop would be harvested and sold, removing the costs of processing, packaging and transportation from the market price. Therefore, the selling price will be lower than the free on board (FOB) market price, and labelled "farm-gate price" in the analysis.

Table 1. Basic Production Parameters

Item	Unit	Value
Total production weight	t	2,500
Initial smolt weight	g	75
Target fish weight	kg	5.65
Project length / amortization period	Years	19
Loan/equity ratio	-	2 : 1

The CSAS process initially established total production at 2,500 t every two years for each scenario. At this level, it was assumed that the potential of each technology could be assessed without omitting possible economies of scale. This level of production was further modified (following recommendations from the March 2009 Nanaimo meeting) to 1,250 t every year to create a more consistent revenue scheme. However, at this level of production, concerns over economies of scale emerged, particularly with regards to the potential of RAS facilities. To address this issue, the scale of the analysis was changed to a two-site design producing 2,500 t every year for floating systems (including net pens) and one installation producing 2,500 t yearly for land-based facilities. The goal of this new approach was to reflect existing production models (net pens) more accurately while considering economies of scale for proposed closed-containment production scenarios.

The financial analysis assumes the investor will obtain a loan for two-thirds (66 per cent) of the investment required, making up the additional amount with an equity investment. This loan would be obtained at standard business rates, or possibly at higher rates due to the risks inherent in new technology ventures. DFO acknowledges that a variety of financing schemes may be considered when venturing into aquaculture. By choosing a split between private equity and a bank loan in the proportions detailed above, DFO intends to represent a general case, with levels of participation from investors and lending institutions that are commonly seen. It should be noted that differences in such ratios would not influence the return on investment (ROI) for a given technology, but they would have an effect on return on equity (ROE), because the total equity would change. A line of credit is also needed to cover operating shortfalls during the first few years of operation.

3.0 Technologies Evaluated

The technologies discussed below and on the following pages are based on an analysis of systems from the CSAS technology review (DFO, 2008), and form the basis for production systems evaluated in the financial model. The CSAS process has identified them for their potentially promising performances from a technical perspective. Technical specifications for each system can be found in the appendix at the end of this report.[3]

Some of the systems presented (e.g., System 2—floating, rigid wall; or System 3—floating flexible walls) are still very much at the conceptual or pre-developmental stage, and have yet to be proven technically feasible at commercial levels. Some of the illustrations represent an interpretation of what that particular system may look like (as opposed to an actual production system).

System 1[4]: Conventional net pen aquaculture

The commercial production of fish in floating net pen systems has been conducted in Canada since the late 1970s. In British Columbia today, it is common to deploy 30-by-30-metre steel cage systems. For the purposes of this study, therefore, DFO applied this configuration as the base cage culture model for comparison to other technologies. This production scenario does not incorporate mechanical aeration, oxygen supplementation or solid waste management into system design or operations. Natural currents are relied upon to bring fresh, oxygenated water to the net pens and to dissipate soluble wastes. Solid wastes in the form of organic fecal material and uneaten feed settle to the ocean bottom near the cage site.

[3] The specifications and information for each system are largely provided by the respective suppliers and have not been verified by CSAS.
[4] To maintain consistency, this report uses the same numbering system as the CSAS report. Where a numbered system is missing, it is due to the fact that the scenario is not practically achievable.

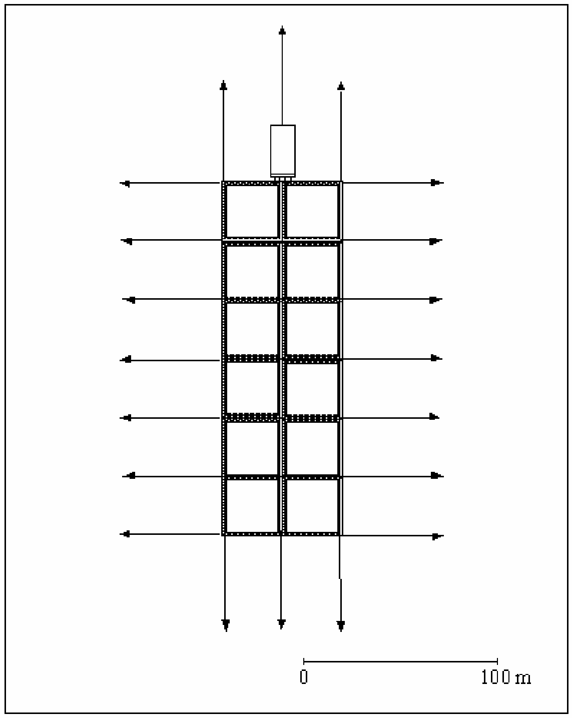

Figure 1. Conceptual Layout of a 12-Cage Salmon Aquaculture Site (Source: Canadian Aquaculture Systems Inc. (2008))

System 2: Closed-containment systems with rigid walls

Established in 1994, Mariculture Systems, Inc. of Edmonds, Wash., has developed and patented the enclosed SARGO™ Fin Farm System (see Figure 2) for intensive finfish production in both marine and freshwater environments. The floating, rigid-wall tanks receive a continuous supply of water pumped from 20- to 100-metre depths in the surrounding water column. The basic system consists of four reservoirs assembled around floating walkways and a service platform containing pumps, controls, power generators, feeding equipment, feed storage, oxygen supply equipment, solid waste processing systems, and other support equipment. Each tank is 20 metres in diameter by 8 metres deep and has a rearing volume of approximately 2,500 m^3. At the manufacturer's recommended flow rate of 28,388 litres per minute (Lpm), the hydraulic exchange rate is about 88 minutes.

System 2a utilizes 80 Mariculture tanks and operates on a flow-through basis. The influent water supply is the only source of oxygen for the fish, so hydraulic loading is substantial. To maintain the minimum dissolved oxygen concentrations for the fish, a flow rate of 548,000 Lpm per tank is required, resulting in an exchange rate of under five minutes. Such a flow rate is practically unattainable.

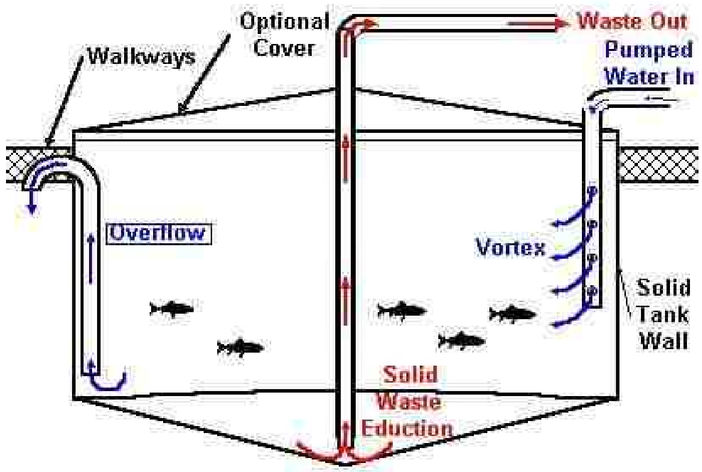

Figure 2. Mariculture Systems, Inc.'s SARGO™ Fish-Rearing Unit. Cross Section of Tank (Reproduced with permission from Mariculture Systems, Inc. © 2007)

System 2b utilizes 48 Mariculture tanks and operates on a flow-through basis. To complement the oxygen supply from the inlet water, mechanical aeration introduces atmospheric air into the tank via medium-pore ceramic diffusers. Solid wastes in this system are collected via a double drain system that directs a small fraction of the total flow out a central bottom drain. The remainder of the flow is relatively clear, and overflows into the surrounding waters from the surface of the tank. Under-drain flows will flow into on-site solids settling and storage basins consisting of eight additional tanks (with the same dimensions as production tanks) located in the centre of the production site. Each settling /storage tank will receive solids-laden water from six production tanks and will generate a clarified discharge (overflow) to the surrounding waters. The particulate waste removal efficiency has not been demonstrated in a commercial-scale system of this type.

System 2c utilizes 32 Mariculture tanks and also operates on a flow-through basis. To complement the oxygen supply from the inlet water, liquid oxygen is injected into the tank influent via ultra-fine bubble diffusers introduced at a depth of 10 to 20 metres. All other technical aspects are similar for systems 2b and 2c, except that in system 2c, central settling tanks receive inflows from four tanks each instead of six.

System 3: Closed-containment systems with flexible walls

Future SEA Technologies, based in Nanaimo, B.C., has developed a flexible, round enclosure constructed from a heavy-gauge polyvinyl chloride that is impermeable to water. The SEA System™ "bags" are suspended in the water from a specially designed floatation system (see Figure 3). Because water pumped into the bags helps to sustain a relatively constant pressure, the shape of the bag is maintained. Future SEA makes a standard production unit that measures 15 metres in diameter by 11 metres deep, for a total rearing volume of 2,000 cubic metres.

Figure 3. Schematic Drawing of Future SEA Technologies' SEA System (Reproduced with permission from Future SEA Technologies © 2008)

Future SEA has also developed a patented waste trap based on a concentric discharge double-drain concept. Clear water is discharged from the upper portion of the tank through a central drain while solids-laden wastewater is collected from a concentric drain at the bottom of the tank. Based on laboratory testing with plastic pellets comparable in density to fish manure and uneaten feed, Future SEA claims that its waste trap can remove 75 per cent of solids. This technology is conceptual only, and has not been developed or tested at commercial scales.

Future SEA has also developed waste "silos" where waste particulates are further concentrated and stored for up to one week prior to disposal. The silos are emptied into a service vessel with a sealed hold. At the dock, the contents of the vessel are pumped into a sewage pump truck that removes the "sludge" for treatment, composting, or land application in suitable habitats (Future SEA 2007).

System 3c[5] utilizes 40 Future SEA SEA System™ "bags" and operates on a flow-through basis. To complement the oxygen supply from the inlet water, ultra-fine bubble diffusers introduced at a depth of 10 to 20 metres inject liquid oxygen into the tank influent. Solid wastes are collected via Future SEA's patented waste trap, based on a double-drain concept that directs a small fraction of the total flow out a central bottom drain. The remainder of the flow is relatively clear and

[5] The numbering system used in this report is the same as that used by CSAS in order to maintain consistency between reports. In those instances where a numbered system is missing, it is due to the fact that the scenario is not practically achievable.

overflows into the surrounding waters. The particulate waste removal efficiency has not been demonstrated in a system of this scale. Under-drain flows will flow into on-site solids settling and storage basins. The latter consist of eight additional SEA System™ tanks of the same dimensions as the production tanks, and are located in the centre of the production tanks. Each settling /storage tank will receive solids-laden water from five production tanks, and will generate a clarified discharge (overflow) to the surrounding waters.

System 4: Land-based technologies

System 4a uses 76 concrete tanks measuring 19.5 metres in diameter by 5.6 metres deep, with an individual tank rearing volume of 1,665 cubic metres. Constructed on-grade on ocean-side property, it is estimated that the static head from mean tide to the operating level in the tanks will be approximately 10.5 metres. The influent aeration tower adds another 2.4 metres of head, bringing the total static head for this system to about 13 metres. The tanks operate on a flow-through basis with single drain configuration, requiring all process effluent to be treated for solids removal prior to discharge. Solid wastes in this system are collected in an excavated settling basin measuring 555 metres long by 185 metres wide and 2 metres deep. A second basin would be required to enable one basin to be taken off-line for cleaning.

System 4b uses the same number and volume of tanks as system 4a, but in this scenario the tanks are installed below grade to reduce the total pumping head. It is estimated that the static head from mean tide to the operating level in the tanks will be approximately six metres. The influent aeration tower adds another two metres of head, bringing the total static head for this system to about 8 metres. All other technical aspects are similar to those of system 4a.

System 4c uses 48 concrete tanks of similar size and volume to system 4a. All tanks are installed below grade to reduce the total pumping head; it is estimated that the static head from mean tide to the operating level in the tanks will be approximately 6 metres. Liquid oxygen is to be injected into the influent for each tank with a tank inlet pressure greater than 4 psi. The tanks operate on a flow-through basis with a double drain configuration to make solid waste management easier. From each tank, a small fraction of the total flow exits through a central bottom drain, which removes a large proportion of total particulate wastes. The remainder of the flow is relatively clear and overflows from the system for discharge to the receiver. The particulate waste removal efficiency has not been demonstrated in a system of this scale. Under-drain flows are directed to on-site solids settling and storage basins measuring 162 metres long by 54 metres wide and 2 metres deep. A second basin would be required to enable one basin to be taken off-line for cleaning.

System 4d is identical in setup (same number and volume of tanks) to system 4c, except that under-drain flows are clarified using rotary drum filtration, enabling 65 to 70 per cent of total solid wastes to be removed and further concentrated. A solids-laden backwash flow of 400 Lpm is projected from each of the three drum filters. The backwash is treated to improve particle removal and directed to on-site solids settling and storage basins measuring 36 metres long by 12 metres wide and 2 metres deep. A second basin would be required to enable one basin to be taken off-line for cleaning.

System 4e, a land-based, 98 per cent recirculation system based largely on an AquaOptima design, was proposed by the CSAS process. Due to limitations in available data, differing production strategies, initial model design (see Section 1.2), and high preliminary capital cost estimates, the AquaOptima design was not evaluated through this process. Instead, a more moderately priced land-based recirculating aquaculture system was proposed and evaluated, the details of which are presented in Section 4.

4.0 Detailed Production Scenarios

Based on the preliminary financial analysis (see Section 6.1), only two production technologies, net pens and RAS, displayed positive economic potential. Therefore, from this point forward, only these two technologies are considered for more in-depth analyses. The following sections explore the production systems and technical considerations of each in greater detail.

4.1 Conventional Net Pen

This scenario reflects two 12-cage systems (see Figure 1), each with a production capacity of 2,500 t over a two-year cycle. To achieve yearly harvests and equalized revenue streams, the sites are stocked every other year. It is assumed that a single year-class of 75 g smolts are transferred to the marine site in October and grown at ambient temperatures to an average harvest weight of 5.65 kg over a period of approximately 20 months. Sites are located mainly in bays where they are protected from bad weather that can disturb activities and damage cages. The feeding system and storage are on site and under constant staff supervision, either on land or at adjacent sites. Fish receive their feed directly in their cages, leaving a small amount (perhaps 1 per cent) uneaten and lost. Technical and maintenance staff travel to the site by boat to operate feeding systems and perform maintenance. Feed and smolts must also be shipped to the site. Fish are harvested in a single batch when mature. The site lies fallow until the next introduction of smolts.

4.2 Recirculating Aquaculture System (RAS)

The design concept includes the usual equipment found in RAS systems: circular tanks, dual drain solids management systems, biofiltration media, carbon dioxide stripping, mechanical filtration, ultraviolet irradiation, water circulation pumps, oxygenation system, ozone treatment and feeding systems. Oxygen and carbon dioxide regulation for individual tanks has been included.

DFO reviewed closed-containment finfish farms in 2008. Circular tanks were used in several of these farms, and are proposed for the RAS operation within the financial model. The diameter-to-depth ratio is approximately 4:1. The maximum tank diameter is 15.4 m for a 2,500 t farm, with 30 production tanks arranged into five independent production modules with six tanks per module (see Figure 4). The total rearing volume is 21,418 m^3 in the 30 production tanks, with an average stocking density of 50 kg /m^3. Rearing volume depends on the desired water temperature, with more volume required at lower water temperatures. Tank construction is concrete, with an interior surface finish that is compatible with salmon and sea water. The water circulation rate is based on a sufficient supply of oxygen and the adequate removal of carbon dioxide, ammonia, and suspended solids. Approximately 100 litres of makeup water are required per kilogram of fish production, depending on the quantity of water required to remove solid wastes.

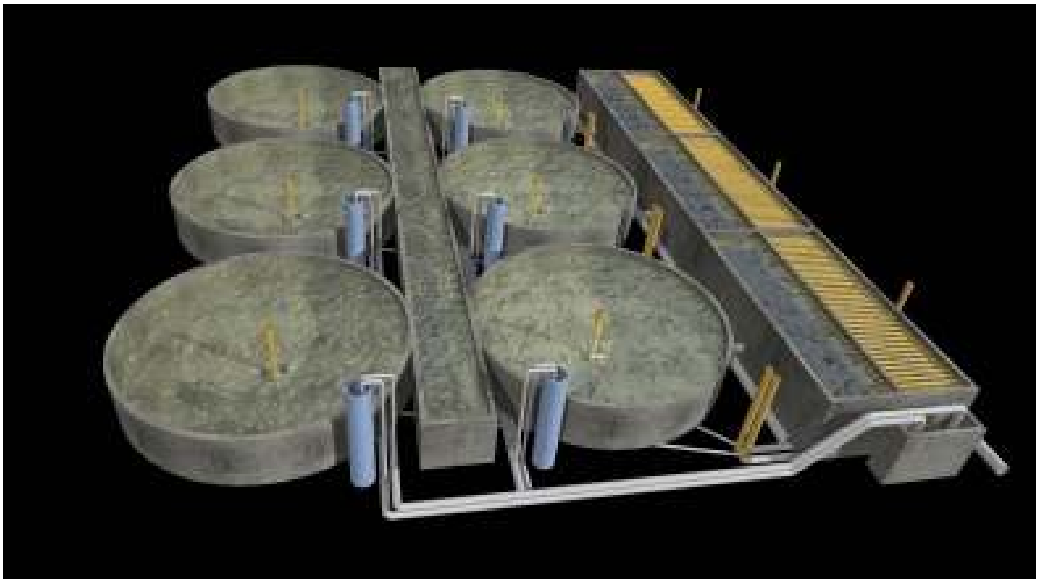

Figure 4. Schematic Drawing for One Fish Production Module

Tank drains are located in the tank centre. A solids collection trap is located around the centre drain and below the tank bottom. This trap is drained intermittently directly to a sludge waste basin via the secondary drain. The preference is for 100 per cent of the water flowing from the tank centre, and for all water to be processed through the water treatment system. The drain pipe is sized to provide a flow rate of approximately 1 litre/sec and low head loss (less than 0.08 metre/30 metres of pipe), with gravity flow into the solid waste settling chamber. The tank water level is regulated in the settling chamber.

The solid waste settling chamber has tube settler media. This solid waste is drained to the solid waste collection basin and backwashed with fish culture water on an intermittent schedule depending on waste accumulation. This settling process is used to collect most of the collectable solid waste that is not removed through the secondary drain. Fish water drains from the tank centre and into the adjacent settling basin, with the least amount of agitation possible to avoid breaking solid waste particles. A screening step is avoided at this location because screens often increase the quantity of small particles, and only remove 50 to 60 per cent of the total solid waste.

Water flows by gravity from the upper level of the tube settler chamber over the trickling biological filter media distributed by low-head spray nozzles. Total head loss through the biological filter is 1.4 metres plus the media depth. Hydraulic loading over the media is adjustable to attain the optimum media wetting and gas exchange. High-efficiency blowers distribute air into the base of the biological filter, which has enough water depth to help provide a surge reservoir for the water flow and to provide for air space between water and media.

Water flows via gravity from the base of the biological filter through a screen filter of approximately 20 μm mesh size to collect any solids not collected in the tube settler as well as solids from the biological filter.

Screen filtering and ultraviolet treatment control pathogens in the incoming makeup water. Ultraviolet and ozone treatment are also used for the recirculated water. Ultraviolet light treatment is most important in treating new water before it enters the facility. Project capital costs and electric demand also include ultraviolet light treatment on recirculated water flow.

Water flows from the screen filter (and ultraviolet) into the pumping sump. Water pumps have high-efficiency electric motors (93 per cent minimum). There is a minimum of two pumps for each module. These pumps are connected to separate water pipe systems that provide important system redundancy. The pipes leave the pumps at an elevation that allows them to be routed to the tanks without a change in elevation. Pipe diameters are sized to minimize head loss due to friction. The circulation water for each tank flows into an oxygen injection system with two units per tank.

Oxygen is supplied with high-efficiency gas separation technology. The rated production efficiency is 3.25 kg O_2 /kWh. Air diffusion hoses are placed in each tank to provide pure oxygen during emergency situations. A liquid oxygen (LOX) tank supply is used to supply emergency oxygen. This tank is also connected to the generated oxygen supply and set to supply LOX automatically if the generated oxygen supply drops below the established minimum pressure. This line will also collect any oxygen gas released from the LOX pressure relief valve.

Effluent management has been included, but not specifically designed, owing to the possibility for site specific requirements. The cost for this process has been included in the model as a cost per ton of fish produced. The waste stream in this production system is 35 m^3 /h.

The system can control water temperatures at the selected value and maintain 100 per cent saturated oxygen concentration. The proposed design is efficient in maintaining heat and including by-product heat recovered in the production process. A boiler is also included for emergency heat requirements. It is expected that cooling may be as important as heating, if not more so; cooling capability is part of the total temperature control planned for the farm. Water replacement is a backup method for cooling.

The production system includes duplicate or backup equipment in all critical areas, including: water pumps, water circulation piping, oxygen supply, carbon dioxide blowers, electrical supply, and three solid waste separation steps.

Production Strategy

The growth plan uses a 75 g smolt to meet the production and harvest plans. Production management implies regular stocking of smolt at one-month intervals. Special smolt production techniques are required to maintain this stocking schedule. The plan is for the stocked smolt to grow for two months before the batch of fish is transferred to larger tanks at an average size of 250 to 300 grams per fish. Then fish grow for three months (reaching 900 to 1,000 grams), and the number of tanks is increased. The last sorting would be at 2,000 to 2,500 g, and from there the fish are grown to market size. There are equipment and procedures in the design for moving fish among the production tanks.

The production plan is for a regular daily harvest after the initial biomass inventory buildup. The first harvest would be 12 months after smolt transfer for temperatures controlled at 15°C.

Land utilization

The total land footprint is estimated at 80,900 m^2 (8.09 hectares) for the operation. The space used by the building, assuming 30 circular tanks of 15.4 m in diameter and a 40 per cent use of space by the tanks (since additional space is required for tank access, storage, office, etc.), is 13,928 m^2. Additional space is required to comply with environmental and building regulations relating to matters like storage, site access, minimum distance to adjacent property, etc.

5.0 Assumptions and Model Design for Net Pen and RAS

This study makes certain assumptions about the parameters and costs of the various operations, and comparisons between technologies are based on these assumptions. These assumptions have been vetted through several subject matter expert committees, and represent realistic inputs and suppositions concerning the operating environments of these production methods. Many of the assumptions are financial in nature, but a number of fundamental biological and technical assumptions were set for the model as well. The assumptions that have the greatest influence on the model's performance are summarized in Table 2 and discussed below.

5.1 Biological

Biological assumptions are fundamental to the analysis because they determine the performance of fish under the given rearing conditions. The three most important assumptions relate to feed conversion ratio, thermal growth coefficient, and mortality.

FCR_b

The biological feed conversion ratio (FCR_b)—the proportion of feed absorbed and converted into flesh—has an important impact on the amount of feed needed, and therefore on total feed costs within the production cycle. A value of 1.27 was considered representative of the current industry norm for net pen production. Due to increased environmental control and the necessary use of higher-quality feeds, a value of 1.05 was used for RAS. It is common practice in many recirculation facilities to use specially formulated feeds that maximize growth, are resistant to quick breakdown, and improve the consistency and durability of the fecal pellet to facilitate solids removal. It is possible that lower values (e.g., 1.0) could be achieved; however, DFO used a slightly more conservative value (1.05) for the purpose of this analysis. The impact of varying FCR_b is examined in the sensitivity analysis section.

TGC

The thermal growth coefficient (TGC) is an important part of the growth formula used in the model, and it relates growth directly to the sum of daily water temperatures over a given period (expressed as day degrees). Its effect on cycle length has important implications on revenue structure, especially for RAS. If a 12-month cycle based on improved TGCs can be achieved, revenues will be consistent with the 2,500 t annual target set as the basis for the analysis. If

Table 2. Biological, Technical and Economic Assumptions Used in Model

Item	Description	Unit	Net pen	Source	RAS	Source
Biological						
Biological feed conversion ratio	Proportion of feed converted into flesh	-	1,27	EC	1,05	DFO
Thermal growth constant	Coefficient of growth used in the growth formula	-	2,7	T&F	2,7	T&F
Mortality over cycle	Total mortality computed for one single cohort	%	~10	CSAS	7,0	EC
Technical						
Temperature	Rearing temperature in tanks or cages	ºC	7.74 - 10.41	CSAS	15	EC
Average biomass density	Average stocking density over cycle	kg/m^3	15	CSAS	50	EC
FTEs						
Management		-	2	EC	4	EC
Maintenance		-	1	EC	-	
Technicians		-	7	EC	14	EC
Energy used						
Grid electricity		kWh/cycle	-		7 260 205	Myers
Diesel generator electricity		kWh/cycle	542 640	CSAS	-	
Gasoline		L/cycle	720	CSAS	-	
Propane		kg/cycle	2 333	CSAS	-	
RAS-specific technical assumptions						
Tank space	Proportion of building occupied by tanks	%	-		40	Myers
Biofilter amonia removal		$kg/m^3/day$	-		0,0375	Myers
Ammonia production		% of feed weight	-		3	Myers
Head required for water circulation		m	-		8	Myers
Media depth		m	-		1	Myers
Gas to liquid ratio		-	-		7	Myers
CO_2 removal rate		% of dissolved CO_2	-		90	Myers
Drum filter screen size		Microns	-		21	Myers
Drum filter backwash time	Proportion of time drum filter backwash operating	%	-		25	Myers
Source water pumping head lift		m	-		100	Myers
Fish oxygen use		kg O_2/kg feed	-		0,46	Myers
Oxygen dissolving efficiency		%	-		90	Myers
CO_2 concentration in water		mg/L	-		14	Myers
Ozone use		g/kg of feed	-		20	Myers
Heating requirements for building		btu/m^2	-		300	Myers
Building air exchanges		Exchanges per hour	-		2	Myers
Number of tanks		-	-		30	Myers
Concrete floor depth		m	-		0,15	Myers
Tank wall thickness		m	-		0,4	Myers
Water turnover rate	Calculated water replacement rate	Minutes/Exchange	-		106	

Item	Description	Unit	Net pen	Source	RAS	Source
Economic						
Revenues	**Obtained from farm gate price, target total weight and loss to HOG weight**					
Market price of fish	Price of fish in Seattle FOB	USD $/lb	2.60	EC	2.60	DFO
Processing labour	Processing services	$/kg	0.40	EC	0.40	EC
Packaging		$/kg	0.16	EC	0.16	EC
Freight		$/kg	0.11	EC	0.11	EC
Sales commission		%	5.0	EC	5.0	EC
Exchange rate		USD/CAD	0.95	BOC	0.95	BOC
Farm Gate Price		$/kg	5.05		5.05	
Loss to HOG weight		%	17	EC	17	EC
Administrative cost	**Administrative costs including administrative staff**	**$/kg live**	**0.21**	**DFO**	**0.21**	**DFO**
Other fixed costs						
Insured value	Value insured in case of cohort mortality	% of costs	70	EC	70	EC
Mortality insurance	Insurance fee related to the value insured	% of insured value	3	EC	3	EC
Maintenance		% of capital	6	EC	1	EC
Waste disposal		$/t live	N/A	EC	50	EC
Other (includes fire insurance)		$/year	13,060	G&P	245,081	Myers
Variable costs						
Labour cost	**Obtained from FTEs and following assumptions**					
Management		$/week	1,200	EC	1,200	EC
Maintenance		$/week	1,150	EC	1,150	EC
Technicians		$/week	800	EC	800	EC
Social benefits		% of wages	35	EC	35	EC
Remote housing		$/year	30,000	EC	N/A	EC
Feed cost	**Obtained from FCR_b, growth, number of fish and feed price**					
Feed price		$/t	1,200	DFO	1,500	DFO
Production-based costs	**Obtained from energy consumption, number of fish and following assumptions**					
Grid electricity		$/kWh	0.07	BCH	0.07	BCH
Diesel generator electricity	Direct price of electricity when produced by a diesel generator	$/kWh	0.25	CEA	0.25	CEA
Gasoline		$/L	1.39	NRCAN	1.39	NRCAN
Propane		$/L	0.77	NRCAN	0.77	NRCAN
Liquid oxygen price	Liquid oxygen price as necessary for RAS backup purpose	$/kg	-		0.25	Myers
Smolt price (vaccinated)		$/fish	2.00	EC	2.00	DFO
Equipment rental		$/fish/month	0.0038	G&P	-	
Diving services		$/fish/month	0.0082	G&P	-	
Financing costs	**Includes loan interests and line of credit interests**					
Loan Interest rate	Initial investment loan interest rate	%	7.0	DFO	7.0	DFO
Line of credit interest rate	First years operating shortfalls line of credit interest rate	%	9.0	DFO	9.0	DFO

Table 2 Legend:

BCH: B.C. Hydro Business Rate – http://www.bchydro.com/youraccount/content/business rates.jsp (access Feb. 15/10)
BOC: Bank of Canada USD-CAD Noon Rate – http://www.bank-banque-canada.ca/en/index.html (accessed Feb. 15/10)
CEA: Canadian Electricity Association – http://www.canelect.ca/en/home.html
CSAS: Canadian Science Advisory Secretariat
DFO: Fisheries and Oceans Canada
EC: Subject Matter Expert Committee
Myers: Myers Consulting, personal communication
NRCAN: National Resources Canada – http://fuelfocus.nrcan.gc.ca/price_map_e.cfm (accessed Feb. 16/10)
T&F: Thorarensen and Farrell, 2010

decreased TGCs are used, then the length of the production cycle is increased to meet the 2,500 t production goal. This would have an impact on total rearing capacity if the intent is to maintain steady monthly harvests. For the purpose of this modelling exercise, and based on the review by Thorarensen & Farrell (2010), TGC values of 2.7 were used for both net pen and RAS production systems.

Considering the high degree of control on water parameters in RAS operations, DFO postulated that increased TGCs may exist within these production systems, thus offering a slightly improved grow-out cycle. However, for the purpose of this modelling exercise, the study relied on more conservative estimates based on published values. Values for production cycle lengths, using a TGC of 2.7, are 12 months for RAS and 20 months for net pens. Based on a controlled growing environment and a constant temperature maintained at 15ºC for RAS—and considering current industry performances in saltwater environments—the cycle length for RAS does not seem overly optimistic when compared with net pens. It has to be noted that a change of one month of the total length of cycle does not have a significant effect on profitability for net pen and does not drastically affect RAS performance either.

Mortality

Mortality over the entire production cycle was estimated at 10 per cent for net pen production based on both the CSAS review (DFO, 2008) and subject matter expert consultation. The model computes a mortality value every 15 days, with greater mortality during early stages of growth, resulting in 10 per cent mortality for the entire production cycle. Mortality for RAS was set at 7 per cent, with 50 per cent occurring in the first two months of production, and the remainder occurring equally in the subsequent production months. The effects of changing mortality rates are examined in the sensitivity analysis section.

5.2 Technical

Temperature

For net pen production, the water temperature values used were those established by the CSAS review (DFO, 2008), and they reflect the average value of water temperatures in B.C. For this modelling exercise, values ranged from 7.74 to 10.41 ºC. For RAS, a constant temperature of 15 ºC was assigned. The effects of changes in water temperature for RAS are examined in the sensitivity analysis section.

Stocking Density

For net pen production, a maximum stocking density of 15 kg /m^3, based on industry standard practices, was used. For RAS, an average biomass of 50 kg /m^3 was chosen, based on subject matter expert consultation. It was postulated that the average biomass could be as high as 80 kg /m^3, but for the purpose of this modelling exercise, a more conservative value was used. A sensitivity analysis of varying stocking density was also performed.

Labour

Labour requirements for net pen production systems were based on industry-established norms and in consultation with subject matter experts. Net pens require the following full-time equivalents (FTEs): two managers, one maintenance staff, and seven technicians. RAS production systems require the following FTEs: four managers and 14 technicians. No dedicated maintenance staff are used, as it is assumed that at least one of the expert management staff will be qualified to manage any technical issues within the operation. A larger number of technicians will also be required due to the more technical nature of RAS production systems. During the days, seven technicians and two managers will be present on site. During the nights, two technicians will be present. To allow for full coverage (24 hours a day, seven days a week), additional FTEs in the form of three technicians and two managers are required for days, with an additional two technicians for nights.

Energy and RAS-specific elements

Energy requirements and RAS-specific inputs are presented in Table 2. These numbers are based on both the CSAS review (DFO, 2008) and subject matter expert review.

Contingency

A cost of 10 per cent for net pen production and 20 per cent for RAS of capital investment sub-total was applied to allow for any unexpected capital expenses for a given project. This contingency was assumed to be higher for RAS due to the higher level of uncertainty related to such ventures.

5.3 Economic

The model incorporates a number of economic assumptions, with some having a greater effect on system profitability due to their significant variability. The key economic assumptions are discussed below.

Exchange Rate

The Canadian–American exchange rate was set at US$0.95 per Canadian dollar based on rates at the time of analysis. A sensitivity analysis using varying exchange rates was performed, and its effect on profitability assessed.

Market Price

Within the model, the market price is user-defined. The free on board (FOB) market price of salmon used in this analysis was set at US$2.60/lb ($5.05 /kg). It was chosen in order to represent an average value that the producer may face over the duration of the project. The average value is different from the day-to-day value in that it has less variability and is more effective in representing the financial potential of a given production scenario. For this analysis, the five-year historical values from 2006–2010 (US$1.87/lb to $US3.87/lb) were used to obtain an average price (US$2.60/lb). Despite the current increase in average price (Urner Barry's COMTELL, 2010), many observers and industry experts expect the price to decline once Chile's production returns to normal over the coming few years.

It has been suggested by subject matter experts (see list on page 7) that there is potential for RAS-produced fish to receive a price premium of approximately $0.33/kg versus net-pen raised fish, due to the perception of more sustainable production practices. The lack of current experience with RAS-produced Atlantic salmon suggests that this is speculative for now; as such, the same market price between the two systems was used. A sensitivity analysis using varying market prices was performed to assess its effect on profitability.

Feed Price

Another important economic consideration is the price of feed. For net pen production, the study used an industry standard of $1,200/t (including transportation). For RAS production systems, a cost of $1,500/t (including transportation) was used. This elevated cost is based on specially formulated feeds that maximize growth, are resistant to quick breakdown, and improve the consistency and durability of the fecal pellet to facilitate solids removal. Depending on the RAS farm location, the feed transportation cost could be lower than for ocean-based farms, but that has not been incorporated into this general model. A sensitivity analysis of varying feed prices was performed to assess the effect on profitability.

Smolt Cost

The analysis used a smolt cost of $2.00 each for both production systems, based on industry norms. It was suggested that smolt costs for RAS systems could be discounted by $0.40/smolt in the absence of vaccination. Currently, however, there is not a free and competitive market for smolts in B.C., as all smolts are produced by vertically integrated companies. Therefore it is unlikely that any potential RAS facility would be able to purchase smolts at discounted prices from existing hatcheries. Even though it is possible that a RAS operation could be vertically integrated in the future (based on a company or industry achieving critical mass), it is speculative or premature at this point to assume such operating conditions for this analysis. A sensitivity analysis of varying smolt costs was performed.

Depreciation

A straight-line depreciation method was used to assess the necessary re-investments and associated cash flows over the project's duration.

The study used straight-line depreciation (instead of capital cost allowance and income tax calculations) in the model to assess the cost of depreciating assets. As a result, tax has not been included as a cost in this analysis. It is therefore important to note that all values shown in this analysis do not include corporate income tax.

5.4 Calculation of the Costs of Production Within the Model

Feed ration is computed in the model from the expected fish growth using a biological feed conversion ratio (FCR_b), a user input price of feed, average weight of the fish at the beginning and end of the period, and the number of fish. (The last three values are set by the model at each period.) A certain amount of feed is also considered lost, since some is either not eaten or is absorbed by fish that die during the period. This loss has been set at 1 per cent for both production systems. The calculation of feed costs uses the following formula (DFO, 2008):

$$\text{Feed cost} = \text{Number of fish} * \Delta\,\text{Weight} * FCR_b * (1+\text{Percentage of loss}) * \text{Feed price}$$

Fish weight is calculated as follows (DFO, 2008):

$$\text{Weight}_t = (\text{Weight}_{t-1}^{1/3} + \text{Temperature}/1000 * \text{Growth constant} * \text{Growth percentage} * \text{Days in Period})^3$$

Production-based costs include energy, diving, smolt purchase, and equipment rental for net pens. They all depend on the total number of fish in culture at any period, with the exception of energy costs, which are based on the CSAS review

(DFO, 2008) and are linked to the total target weight. RAS production-based costs include smolt purchase (which is based on total target weight, initial and harvest fish weight, and mortality) and energy costs, which are computed by the model and based on input from subject matter experts.

Fixed costs (excluding administrative costs) are modeled in different sections for net pens and RAS, and include items such as waste disposal, building insurance, and maintenance. Some may only be applicable to certain production systems (e.g., license costs and site and lease payments for net pens), or are included in a broader "other" category (e.g., telephone and transportation for RAS). Administrative costs include all administrative expenses (i.e., accounting services, advertising and promotion, payroll fees, bank charges, community engagement, entertainment expense, janitorial services, management fees, board meetings, membership or subscription fees, office supplies, payroll taxes, training, transportation and travel) and related staff. Property tax is also included, at a rate of 3 per cent.

Revenues are calculated after removing packaging, processing, freight and sales discount from the FOB market price that has already been converted from American to Canadian currency to obtain a farm gate price. Total fish weight is transformed to head-on gutted (HOG) weight before revenues are calculated. With a market FOB price of US$2.60/lb (C$6.01/kg), the farm gate price calculated after removing the costs listed above is $5.05/kg, resulting in a difference of $0.96/kg between the market price and the farm gate price for this analysis. Out of this difference, $0.67/kg is for harvesting costs, which include processing, packaging and freight.

5.5 Capital Cost Estimates

Based on all the assumptions related to capital investment for net pens and RAS, the capital costs, as well the useful life of the major components, are presented in Table 3. The values used are based on industry norms and have been validated by subject matter experts.

The capital cost estimates for a net pen facility are $5,000,716 (including a 10 per cent contingency of $454,611). Major capital elements include nets ($3,360,000), backshore site and preparation ($350,000), and feeding system ($333,900). Capital costs are $2,000/t of production.

The capital cost estimates for a recirculating aquaculture system are $22,622,885 (including a 20 per cent contingency of $3,770,481). Major capital elements include land ($1,800,000), production tanks ($1,593,392), drum filtration ($1,883,047), biofilter ($2,625,845), piping ($1,207,081), pumps (1,255,364), building ($2,263,341), ultraviolet sterilizer ($2,243,964) and settling media ($1,274,678). Capital costs are $9,049/t of production.

Table 3. Capital Cost Estimates

Conventional Net Pen System **$2,000 /mt**

Capital Component	Description	No. Req'd	Unit Cost	Total Cost	Useful Life*	Depreciation (straight-line)
Backshore site & preparation	Estimate	2	$ 175,000	$ 350,000	**Years**	
Net pen (cage) system	30m x 30m Wavemaster	24	$ 140,000	$ 3,360,000	10	$235,200
Nets & moorings (30% of system cost)					3	$336,000
Back-up generators	100 kW Kohler	1	$ 10,190	$ 10,190	10	$1,019
Fork lift	Yale model GLC050	1	$ 7,015	$ 7,015	10	$702
Feed storage	AKVA	1	$ 50,000	$ 50,000	20	$2,500
Feeding system	AKVA	2	$ 166,950	$ 333,900	10	$33,390
Service & crew boat	Jackson Craft	1	$ 135,000	$ 135,000	20	$6,750
Misc. fish culture equipment		2	$ 150,000	$ 300,000	5	$60,000
> feeders, graders, fish pumps, monitoring systems, etc.						
Subtotal				$ 4,546,105	**Total**	**$675,561**
Contingency (10%)				$ 454,611		
Total Capital Cost Estimate				**$ 5,000,716**		

Recirculating Aquaculture System **$9,049 /mt**

Capital Component	Description	Total Cost	Useful Life*	Depreciation (straight-line)
Land purchase 20 acres (8.09 ha)	At $90,000/acre - Avison Young	$ 1,800,000		
Site preparation		$ 200,000	**Years**	
Production tanks	Concrete at estimated cost of $400/m3 of concrete	$ 1,593,392	20	$79,670
Drum filter	PRAqua	$ 1,883,047	10	$188,305
Biofilter media & basin	LS Enterprises - concrete basin[1]	$ 2,625,845	20	$131,292
Water pipe system	HDPE pipe	$ 1,207,081	20	$60,354
Circulating pumps		$ 1,255,364	10	$125,536
Source water pump	Vertical pumps for salt water use[2]	$ 7,886	5	$1,577
Insulated building	Large wide span galvanized steel framing[3]	$ 2,263,341	20	$113,167
Ventilation heat exchanger		$ 289,708	10	$28,971
Boiler		$ 108,640	10	$10,864
Heat exchangers	Plate and Frame heat exchangers for water[4]	$ 65,421	15	$4,361
Oxygen generator	Large systems Air Liquide[5]	$ 599,151	10	$59,915
Ozone generator	Ozonia[6]	$ 562,681	10	$56,268
UV sterilizer	Ozonia[6]	$ 2,243,964	15	$149,598
Influent drum filter		$ 17,929	10	$1,793
Settling media	LS Enterprises	$ 1,274,678	20	$63,734
Backup generator		$ 177,776	20	$8,889
Fork lift		$ 7,000	10	$700
Feed storage		$ 25,000	20	$1,250
Feeding system	Cablevey feeding system[7]	$ 147,000	10	$14,700
Monitoring system		$ 97,500	5	$19,500
Fish culture equipment		$ 400,000	10	$40,000
Subtotal		$ 18,852,404	**Total**	**$1,160,444**
Contingency (20%)		$ 3,770,481		
Total Capital Cost Estimate		**$ 22,622,885**		

* Useful life for capital components were discussed and reviewed internally by DFO

[1] http://www.biofilters.com
[2] http://www.fpipumps.com/
[3] http://www.apexbuilding.com/about.htm
[4] http://www.muel.com/default.cfm
[5] http://www.ca.airliquide.com
[6] http://www.degremont-technologies.com/dgtech.php?rubrique121
[7] http://www.cablevey.com/

6.0 Results

The study adopted a two-phased approach for the financial analysis. Section 6.1 presents an initial analysis of all closed-containment production systems to determine which systems warranted more in-depth analysis. Section 6.2 presents a refined analysis of net pens (current industry standard and reference case) and RAS production systems. Furthermore, Section 6.3 presents sensitivity analyses for parameters that may vary and have an impact on the profitability of the operations.

6.1 Initial Analysis of All Production Systems

The results of this initial analysis suggest that all technologies except net pens and RAS resulted in a negative ROE, ranging from -2 per cent to -20 per cent. However, many of the systems lacked sufficient information for a complete analysis, so best-guess estimates were used in several of the assumptions. Total investment, third-year income and ROE are summarized in Table 4.

Table 4. Preliminary Results for All Technologies[6]

Technology	Initial investment	Third-year income	ROE
1. Net pen	$5,000,716	$2,641,147	52%
2a. Rigid–no aeration	-	-	-
2b. Rigid–with aeration	$23,284,470	-$2,125,885	-10%
2c. Rigid–pure oxygen	$24,004,470	-$253,079	-2%
3c. Flexible–pure oxygen	$29,332,086	-$2,041,169	-9%
4a. Land-based grade	$72,352,066	-$17,417,907	-20%
4b. Land-based below grade	$67,748,173	-$13,496,265	-19%
4c. Land-based liquid oxygen injection	$19,628,900	-$403,142	-4%
4d. Land-based LOX Mechanical filtration	$18,858,685	-$260,773	-2%
4e. Recirculating aquaculture system	$22,622,885	$381,467	4%

System 2a (rigid wall, flow-through, no aeration) was considered unrealistic due to the required water exchange rate of once every five minutes, and was therefore not modelled. DFO encountered further difficulties in obtaining realistic capital and operating costs for some of the other systems (e.g., flexible and rigid floating systems) due to their early-stage development and associated proprietary rights. To perform the analysis, many costs had to be approximated, resulting in somewhat uncertain results.

[6] The numbering system used in this report is the same as used by CSAS in order to maintain consistency between reports. In those instances where a numbered system is missing, it is due to the fact that the scenario is not practically achievable.

Land-based systems (systems 4a–4d) have been attempted in the past, but have failed to show financial feasibility at the commercial level, mainly because of high capital and operating costs (e.g., 4a and 4b). The initial outcomes of the financial model support these past findings.

6.2 In-Depth Analysis: Conventional Net Pens and RAS

Following the initial financial analysis of all technologies, and the negative profitability of all but two cases, DFO concluded that a more in-depth financial analysis of the current industry standard (net pen) and the most promising closed-containment technology (RAS) was needed. There are two main reasons for this: 1) Based on preliminary analysis, both technologies are sufficiently advanced that reliable biological and economic data are available to perform a robust analysis; and 2) Both technologies resulted in a positive profitability based on the initial financial analysis.

6.2.1 Third-Year Income

Based on initial capital expenses of $5.0 million and $22.6 million respectively for net pen and RAS, the analysis showed a significant advantage for net pens in terms of income before tax (see Table 5). Because the same price and total yearly production were used for both systems, revenues were identical. Total feed costs were also equivalent for both technologies despite the fact that different feed costs and biological feed conversion ratios (FCRs) were assigned to each system. The higher value for FCR in net pen production is offset by its lower feed price, while the efficiency of RAS is offset by the use of higher-quality, more expensive feed.

Differences resulted mainly from:

- **Labour costs.** These are almost double for RAS versus net pens, an important difference between the two technologies.

- **Energy costs.** Because of the more considerable pumping and heating requirements of RAS, energy costs are significantly lower for net pens.

- **Depreciation.** Capital investments for RAS and net pens ($22.6 million and $5 million respectively) mean depreciation costs must be considered. These costs are about $500,000 greater for RAS, and thus have an effect on income. Also, interest charges on the initial loan are nearly five times greater for RAS than for net pens.

Table 5. Revenue, Income and Financial Ratios During Third Year of Operation

Item	Net pen	RAS
Revenue		
Sales	$10,478,750	$10,478,750
Cost of goods sold		
Fixed costs		
Mortality insurance	$141,228	$141,625
Maintenance	$300,043	$188,524
Waste disposal	N/A	$125,000
Others	$13,060	$245,081
Production-based costs		
Energy	$70,109	$508,214
Smolts	$969,865	$951,565
Others	$118,816	-
Feed costs	$4,065,039	$3,952,294
Labour	$672,330	$1,123,200
Total	$6,350,490	$7,235,504
Gross profit	$4,128,260	$3,243,246
General expenses		
Depreciation	$675,561	$1,160,444
Admin costs	$525,000	$525,000
Operating income	$2,927,700	$1,557,802
Other expenses		
Loan interest	$218,239	$987,297
Line of credit interest	$68,315	$189,039
Income	**$2,641,147**	**$381,467**
Capital investment	$5,000,716	$22,622,885
Private investment (as capital)	$1,700,243	$7,691,781
Private investment (as working capital)	$3,341,109	$1,911,846
Total equity	$5,041,352	$9,603,627
ROE	52%	4%
ROI	53%	2%

ROE is lower than ROI for net pens due to the fact that equity in ROE is calculated using both private capital and the line of credit. Normally, the ROE would be greater than the ROI, however the larger line of credit necessary to cover operational shortfalls during the first two years of operations for net pens affects the calculation in this case. ROI, on the other hand, is calculated from capital investment only.

Feed cost is another potential source of difference between net pens and RAS. An improved FCR_b for RAS would have normally permitted savings on feed costs due to total feed consumption differences (3,388 t for net pen and 2,635 t for RAS). However, the higher price of feed for RAS (see sections 5.1 and 5.3) compared to net pens resulted in equal feed costs for both technologies.

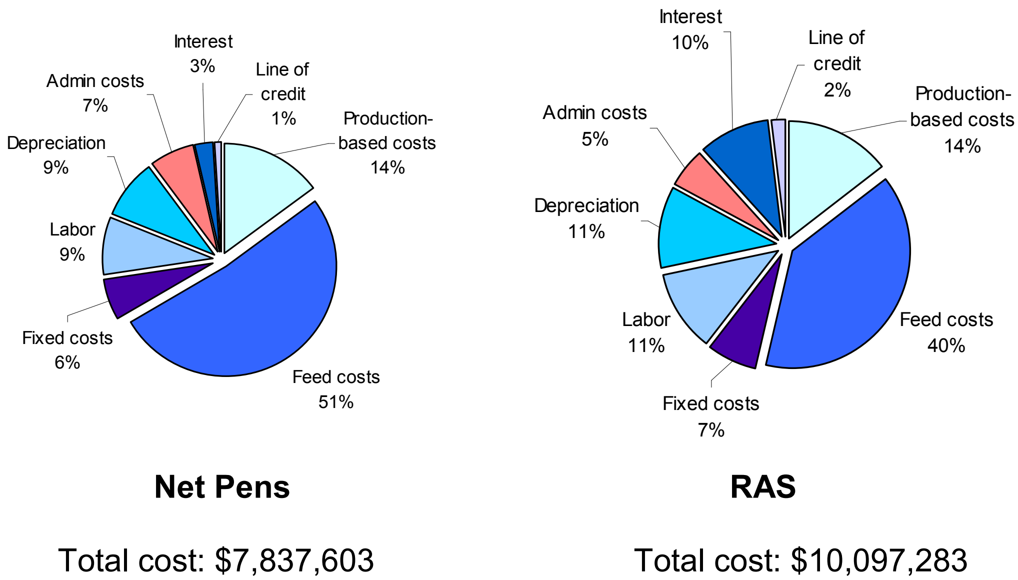

Figure 5. Conventional Net Pen and RAS Cost Breakdown

An analysis of the importance of each cost category relative to total costs shows that the proportion of costs allocated to feed is approximately 51 per cent for net pens, which points to that technology's capacity to keep the proportion of total costs related to non-feed expenses lower than RAS can (see Figure 5). That is, a larger proportion of the costs are directly related to growth and fish production.

6.2.2 Net Present Value and Investment

The net present value of a project gives an idea of the monetary return investors can expect from each technology. At an exchange rate of US$0.95 and a market price of US$2.60/lb FOB, the NPV is C$19,255,055 for net pens and - C$3,777,934 for RAS (see Table 6). With an initial investment of approximately $5.0 million (one-third equity, two-thirds loan), net pens achieve a better performance than RAS.

A project's internal rate of return reflects the discount rate that equates the present value of future cash flows from the venture to the cost of the venture—that is, the net present value of cash flows (NPV) is zero. Therefore, the internal rate of return (IRR) reflects the expected return on the investment generated by the venture. For net pens, the expected rate of return is 40.3 per cent. For RAS, it is 3.4 per cent—lower than what investors might require for this kind of venture.

Table 6. Net Present Value and Internal Rate of Return Comparisons

	Net pen	RAS
Capital investment	$5,000,716	$22,622,885
Operating shortfall	$9,800,218	$5,680,291
Private investment (as capital)	$1,700,243	$7,691,781
Private investment (as working capital)	$3,341,109	$1,911,846
Total equity	$5,041,352	$9,603,627
NPV (7%)	$19,737,471	-$3,777,934
IRR	40.6%	3.4%

Lower yearly incomes for RAS translate into insufficient cash flows to compensate for the investment required. This is the result of higher labour costs, higher energy costs and higher capital investments.

6.3 Sensitivity Analysis

DFO performed a sensitivity analysis on the results to assess the impact of biological FCR, technical parameters (rearing density) and economic parameters (market price, exchange rate feed cost, smolt cost, interest rate, etc.) on net pen and RAS production scenarios in order to identify which parameters were likely to be uncertain. Uncertain parameters would have an impact on the financial feasibility if they vary beyond the assumptions made in the model.

6.3.1 Common factors

The first factors to be analysed were those that potentially affect the two technologies' profits. The factors evaluated were the U.S.–Canada exchange rate, the market price of salmon, the biological FCR, the price of feed, the price of smolts, and the contingency on capital expense.

A. Exchange rate

The analysis showed that common variations in exchange rate have an important impact on profitability, with values of third-year income ranging from a little above $4.0 million to around $1.5 million for net pens when the U.S.–Canada exchange rate varies from $0.85 to $1.05 (see Figure 6). The third-year income varies between $2.0 and -$1.0 million for RAS at the same exchange rate values.

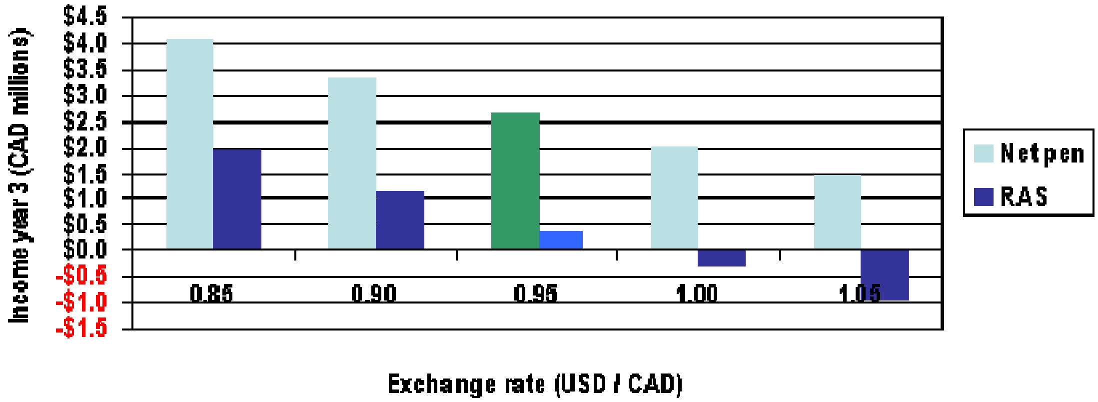

Figure 6. Sensitivity of Third-Year Income to Exchange Rate

B. Market Price

DFO observed the same impact for the market price of fish, with values from $0.8 to $4.5 million for net pens and from -$1.8 to $2.4 million for RAS when the market price goes from US$2.20 to US$3.00 per pound (see Figure 6).

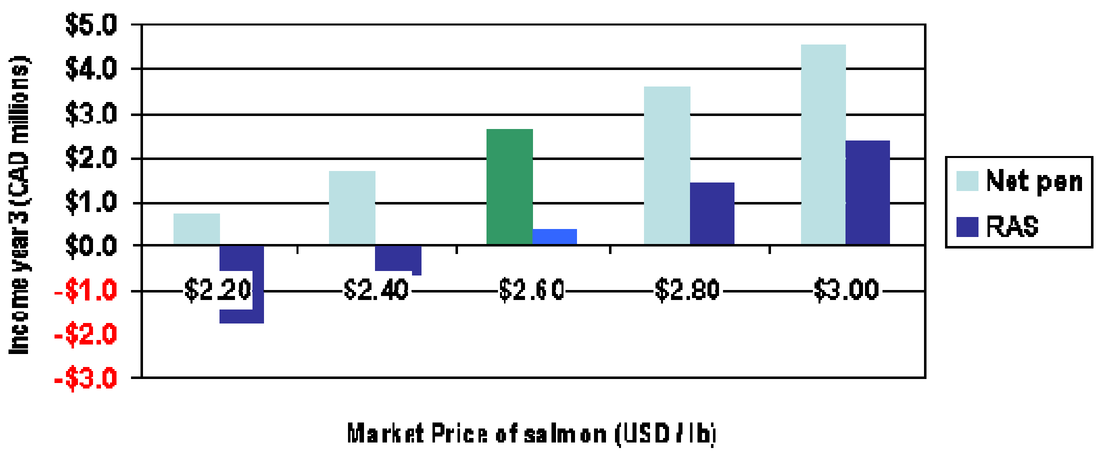

Figure 7. Sensitivity of Third-Year Income to Market Price

C. Biological Feed Conversion Ratio

This biological parameter shows a strong potential to influence income, with a more noticeable effect on RAS production scenarios (see Figure 8). Iterations were performed for RAS at ratios of 1.00, 1.05 and 1.10, resulting in third-year incomes of $727,960, $381,467 and $34,973 respectively. The same analysis was also performed for net pen scenarios, assessing the effect of FCR_b with values of 1.20, 1.27 and 1.30, and resulting in third-year incomes of $2,882,333, $2,641,147 and $2,537,781.

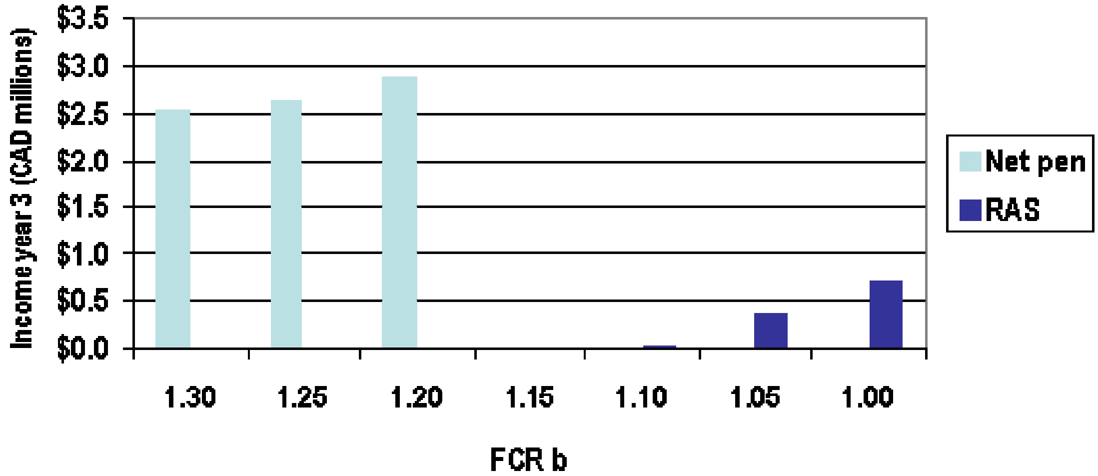

Figure 8. Effect of Varying FCR_b on Both Technologies

D. Feed Price

The analysis of feed price variation (see Figure 9) showed an advantage for net pens when using different values for feed price. For values ranging from $1,200–$1,500/t, net pens always displayed a healthy and positive income (from higher than $2.5 million to around $1.5 million). For RAS, values between $1,400–$1,600/t showed decreasing profitability to a point approaching zero income (from nearly $700,000 down to around $60,000). This sensitivity analysis demonstrates a capacity for net pens to reach higher returns with increasing feed prices.

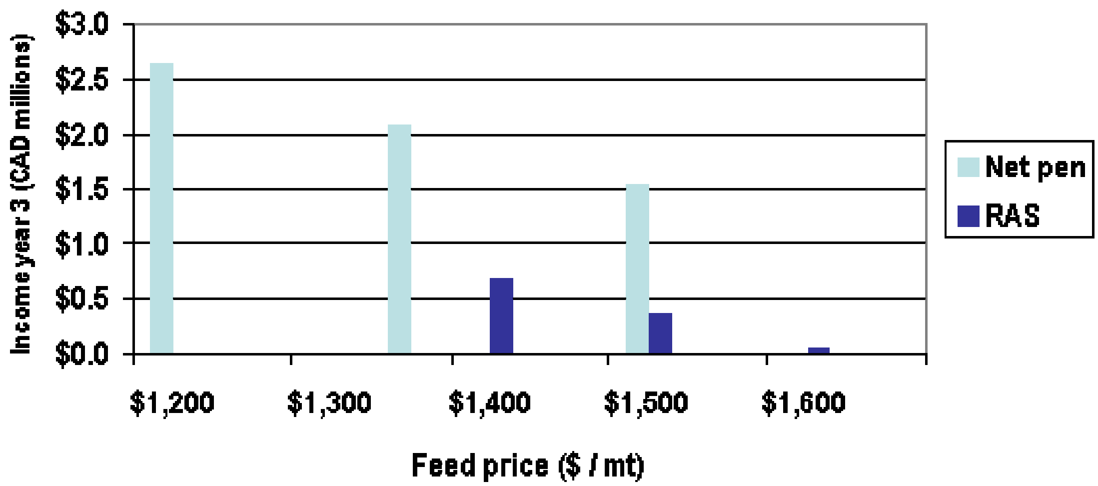

Figure 9. Effect of Feed Price on Both Technologies

E. Smolt Price

Smolt price does not have as important an effect on profitability for either of the technologies. Income decreases from $0.5 million to $0.26 million for RAS when smolt price increases from $1.80 to $2.20 per fish (see Figure 10.). The effect is similar on net pens, with income ranging from $2.7 million to $2.5 million. The overall effect is somewhat greater on RAS, as the third-year income is closer to zero than for net pens.

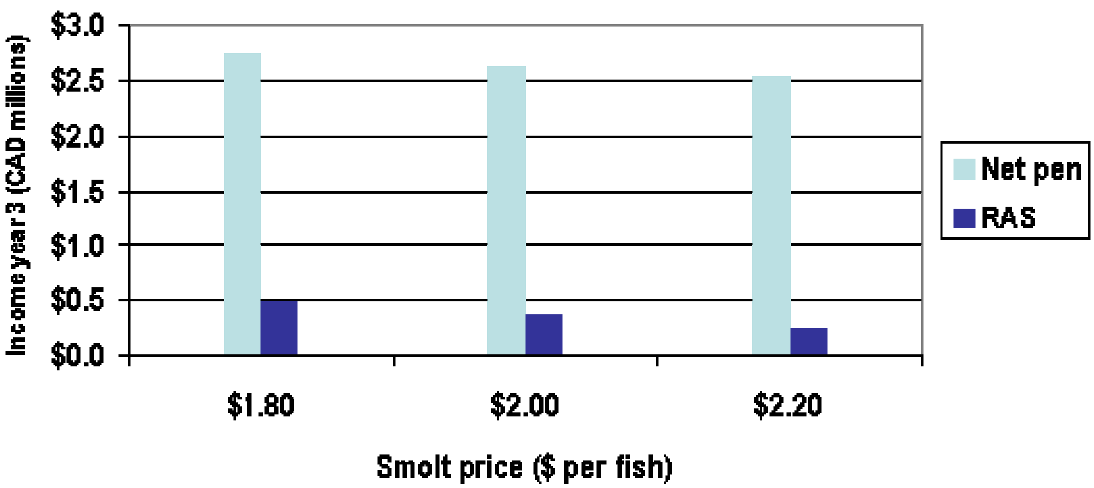

Figure 10. Effect of Smolt Price on Both Technologies

F. Contingency

A variation may be applied to the value of contingency on capital expenses, since this value is subject to uncertainty. As shown in Figure 11, this value does not have a significant effect on RAS profitability. The effect of this parameter on net pen production is also marginal.

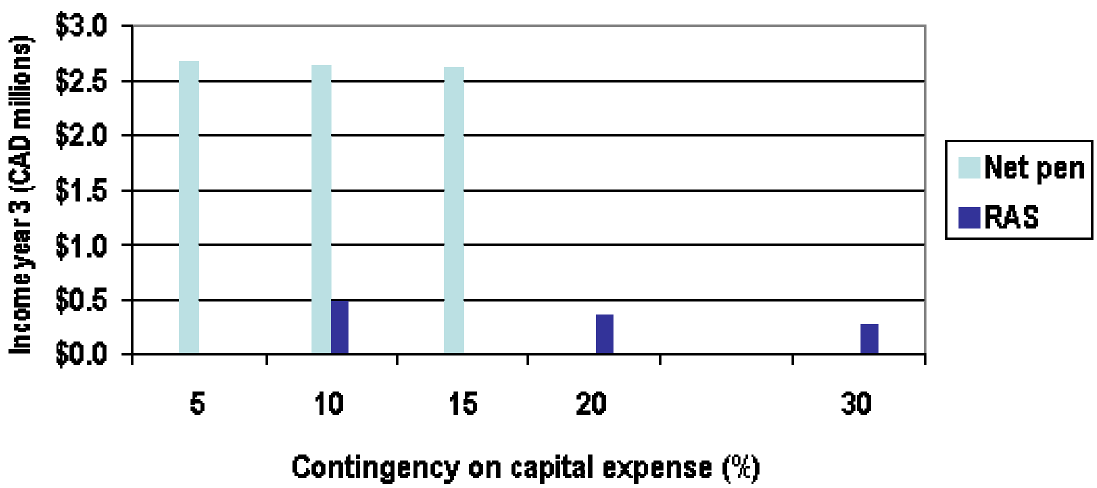

Figure 11. Effect of Capital Cost Contingency on Third-Year Income

6.3.2 RAS-Specific Factors

Having assessed the impact of common factors that could influence the profitability of net pens and RAS, DFO then performed a more specific analysis of the effects of parameters that would influence only RAS. This differential analysis is necessary because of the higher level of knowledge associated with net pen production. The values of certain production factors are well known (based on experience and historical values), and not likely to vary considerably, as they may for RAS production systems. Such factors include the interest rate on initial loan, stocking density, water temperature, number of FTEs and mortality over the cycle.

A. Loan Interest Rate

Figure 12 shows the effect of a higher interest rate on the initial loan for a RAS operation. The intent of such an analysis is to assess the effect of possible higher rates for RAS due to perceived elevated risk. Such a difference is not expected for net pens. The difference in profit between scenarios is significant when the interest rate differs from that used in the base case scenario (7 per cent). Income ranges from $0.4 million to around $30,000 for RAS when the interest rate rises from 7 per cent to 9 per cent.

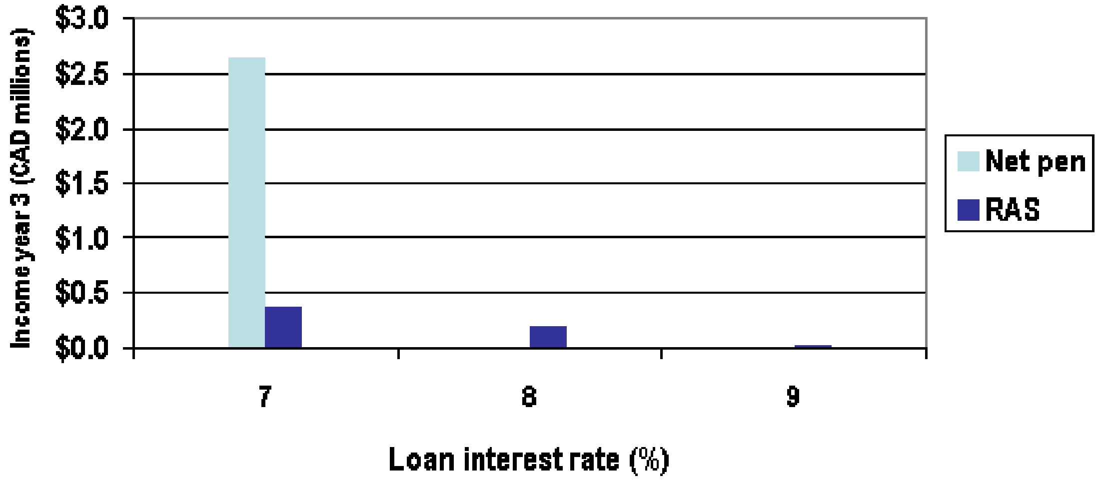

Figure 12. Effect of Loan Interest Rate on RAS

B. Stocking Density

The profitability of RAS hinges on the producer's ability to achieve a high stocking density. When average stocking density decreases from 50 kg /m^3 to 30 kg /m^3, RAS income decreases from around $0.4 million to -$100,000 or so (see Figure 13). Decreased stocking density also changes capital, energy and labour requirements within the model.

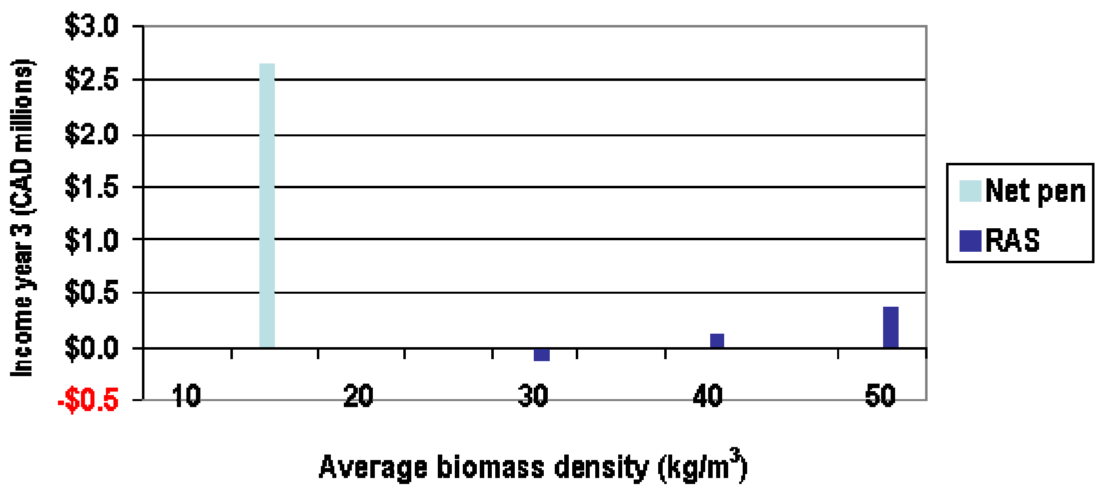

Figure 13. Effect of Stocking Density on RAS

C. Water Temperature

Figure 14 shows the effects of water temperature variations. The sensitivity analysis demonstrates that water temperature as a single factor can compromise profitability considerably, with results ranging from -$209,847 to $381,467 with temperatures ranges between 11ºC and 15ºC.

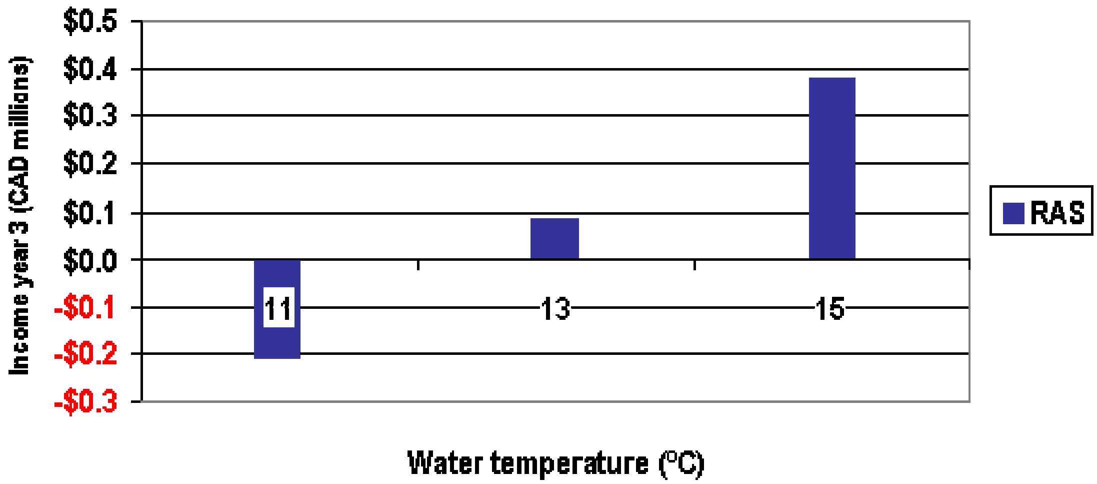

Figure 14. Effect of Water Temperature on RAS

D. Number of FTEs

As Figure 15 shows, the number of full-time equivalents (FTEs) has only a slight effect on RAS profitability. When ranging from 16 to 20, the lower and upper limits of third-year income are $241,583 and $521,351 respectively.

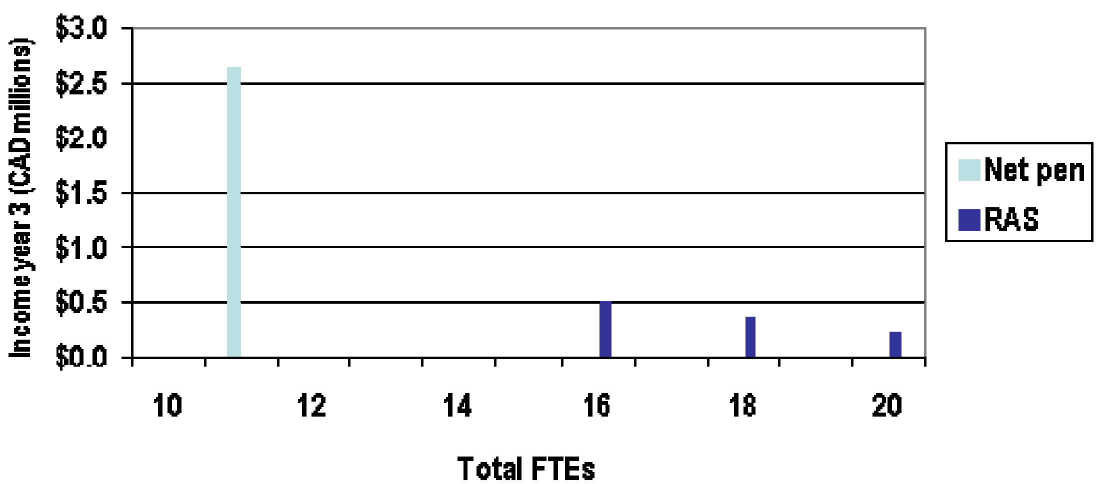

Figure 15. Effect of the Number of FTEs on RAS

E. Mortality

Figure 16 shows the effects of varying mortality. The sensitivity analysis demonstrates that mortality slightly affects profitability, with results ranging from around $500,000 to $250,000 when overall mortality values range from 4 to 10 per cent of total inventory.

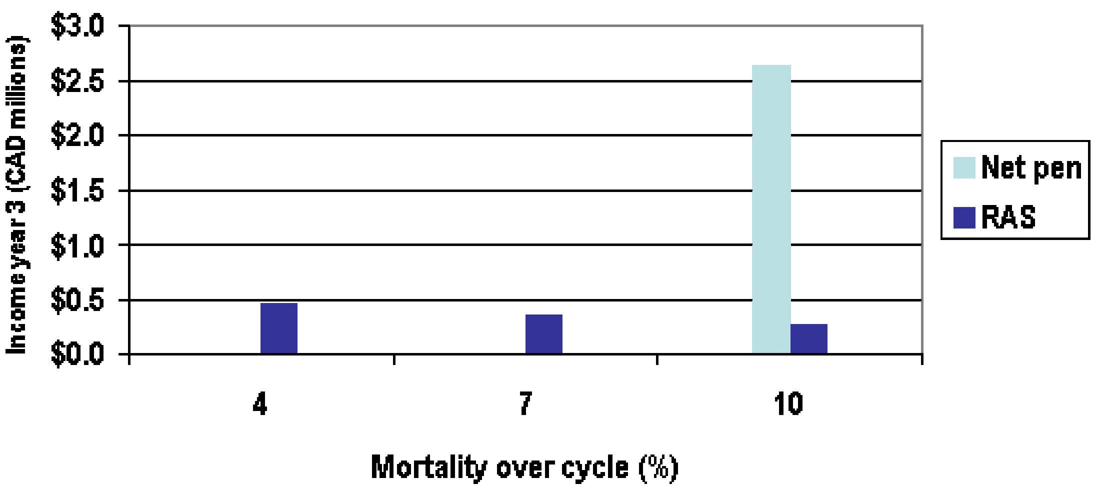

Figure 16. Effect of Mortality on RAS

6.3.3 Effect of Multiple Changes on System Profitability

Following the analyses of single element sensitivities for net pens and RAS, DFO performed a more complex examination of the consequences of variation in the different assumptions (i.e., multi-element analysis), using a combination of factors to assess the extent to which profitability varies for each production scenario. While a multi-element analysis is not as powerful as a simulation-based risk analysis (which allows users to vary the different assumptions and parameters simultaneously), it does provide a good idea of what the worst- and best-case scenarios may look like.

This approach examined the best- and worst-case scenarios for each production technology by examining those elements that are largely within the control of the operator. The analysis excluded external elements, such as exchange rate and the market price of salmon. This exclusion is intended to provide a better comparison between production scenarios where important elements affecting the profitability of the operation are within an operator's control.

Elements varied for this analysis include: temperature, stocking density, FTEs, FCR_b, price of feed, cost of smolts, amount of contingency funding, loan interest rate, and mortality. In determining the worst-case scenario, all sensitivity analyses discussed above were set to their lowest values. The best-case scenario had all elements set to the highest or best values. The default scenario remains the one used in the previous section.

Table 7 shows that under the worst-case scenario, net pens remain profitable, with a third-year income of $1.2 million, a ROI and ROE of 25 per cent, and a gross profit of 27 per cent. Under a best-case scenario, net pens produce a third-year income of $3 million, a ROI and ROE of 60 per cent, and a gross profit of 43 per cent. For comparison, under the worst-case scenario, RAS results in a third-year loss of $2.2 million, a ROI of -10 per cent, a ROE of -23 per cent and a gross profit of 18 per cent. If operating in a best-case scenario, RAS produces a third-year income of $1.5 million, a ROI of 7 per cent, a ROE of 16 per cent, and a gross profit of 38 per cent.

Table 7. Best- and Worst-case Sensitivity Analyses for Net Pen and RAS Production Systems

Technology	Scenario	Third-year income	ROI	ROE	Gross profit
Net pen	Worst case	$1,239,114	25%	25%	27%
	Default	$2,641,147	53%	52%	39%
	Best case	$3,019,723	60%	60%	43%
RAS	Worst case	-$2,248,630	-10%	-23%	18%
	Default	$381,467	2%	4%	31%
	Best case	$1,575,343	7%	16%	38%

The third-year income results (see Figure 17) show a wide total variability for both production techniques, but with greater variance for RAS.

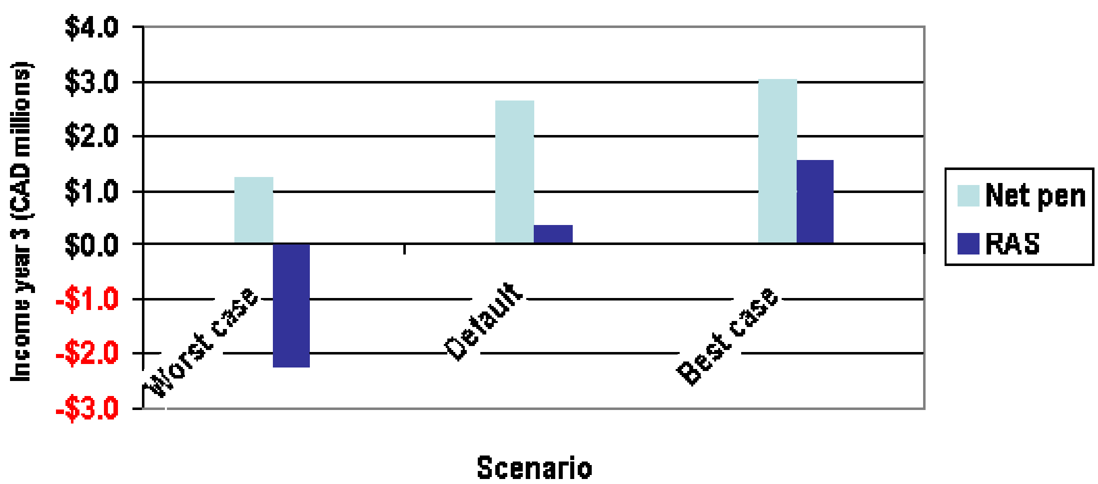

Figure 17. Effect of Multiple Variations on Key Assumptions

6.4 Sensitivity Analyses Summary

In order to compare the results of the sensitivity analyses, DFO used profit margin (the income for a specific year as a proportion of revenues) to qualitatively evaluate the financial risk of net pens and RAS. A lower threshold of 2.5 per cent was established as a minimum acceptable profit margin, which also accounts for income taxes that are not included in the analysis. Profit margins higher than 10 per cent are considered more secure from a business management perspective.

As demonstrated in Table 8, net pens remain an attractive investment option under nearly all variations, with profit margins remaining over 10 per cent for all scenarios except market price. This shows an overall manageable risk for this technology. The profit margin comparisons for RAS show that this technology is riskier from a financial perspective, as variation in production parameters rapidly decreases profitability and profit margin. The only exceptions are market price and exchange rate—two parameters largely beyond the operator's control.

The results presented in this financial analysis demonstrate a positive net income ($2.6 million and $381,467) and internal rates of return (~40.3 per cent and ~3.4 per cent) for net pens and RAS, respectively. But despite having efficiencies in FCR_b, temperature stability and improved environmental control, the presence of higher capital costs, energy costs and labour requirements significantly affected the overall profitability of RAS production scenarios. The financing of initial capital costs, and the resulting depreciation costs, also have a significant effect on system profitability. RAS technology does not show increased performance in terms of operating costs where advantages were expected (i.e., feed and improved FCR_b).

The sensitivity of RAS operations to exchange rate and the market price of fish show that the profit one could expect from RAS ventures is vulnerable to market conditions that are beyond an operator's control. The U.S.-Canadian exchange rate tends to vary significantly, and as the currencies approach par, RAS systems cease to be profitable while net pen operations maintain profitability, albeit at reduced levels. The market price of fish also has a significant impact on income for both RAS and net pen operations. As the price of salmon drops below approximately US$2.50/lb, RAS systems cease to be profitable, while net pens maintain profitability.

Sensitivity analyses also showed that FCR_b and feed price have a significant impact on the profitability of both net pens and RAS, with the potential for RAS systems to achieve higher returns with lower feed prices. However, this would not be enough to change the scope of overall results. It should be noted that for all criteria evaluated, the sensitivity analysis showed a higher risk for RAS compared to net pen technologies. This may explain why net pens have historically had the capacity to successfully resist variation in market and production conditions. The relative vulnerability of RAS makes participation in such an undertaking riskier. A combination of two or more factors at values less optimistic than projected could have a significant impact on profitability for RAS.

Table 8. Sensitivity Analyses and Profit Margin Comparisons

Item	Unit	Third-year income /Profit margin								
Net pen										
Exchange rate	USD/CAD	0.85	*$4,077,996*	*39%*	0.95	*$2,641,147*	*25%*	1.05	*$1,458,043*	*14%*
Market price FOB	USD/lb	3	*$4,517,310*	*43%*	2.6	*$2,641,147*	*25%*	2.2	*$725,904*	*6.9%*
FCR b	-	1.2	*$2,882,333*	*28%*	1.27	*$2,641,147*	*25%*	1.3	*$2,537,781*	*24%*
Feed price	$/mt	1200	*$2,641,147*	*25%*	1350	*$2,091,428*	*20%*	1500	*$1,537,097*	*15%*
Smolt price	$ per fish	1.8	*$2,748,978*	*26%*	2	*$2,641,147*	*25%*	2.2	*$2,533,140*	*24%*
Contigency on capital cost	%	5	*$2,667,771*	*25%*	10	*$2,641,147*	*25%*	15	*$2,614,522*	*25%*
RAS										
Exchange rate	USD/CAD	0.85	*$1,946,961*	*19%*	0.95	*$381,467*	*3.6%*	1.05	*-$920,024*	*-8.8%*
Market price FOB	USD/lb	3	*$2,391,694*	*23%*	2.6	*$381,467*	*3.6%*	2.2	*-$1,720,942*	*-16%*
FCR b	-	1	*$727,960*	*6.9%*	1.05	*$381,467*	*3.6%*	1.1	*$34,973*	0.3%
Feed price	$/mt	1400	*$693,775*	*6.6%*	1500	*$381,467*	*3.6%*	1600	*$69,158*	*0.7%*
Smolt price	$ per fish	1.8	*$499,975*	*4.8%*	2	*$381,467*	*3.6%*	2.2	*$262,958*	*2.5%*
Loan interest rate	%	7	*$381,467*	3.6%	8	$207,199	2.0%	9	$31,115	0.3%
Average biomass density	kg/m3	50	*$381,467*	*3.6%*	40	*$137,542*	*1.3%*	30	*-$106,871*	*-1.0%*
Water temperature	ºC	15	*$381,467*	*3.6%*	13	*$86,754*	*0.8%*	11	*-$209,847*	*-2.0%*
Contigency on capital cost	%	10	*$493,285*	*4.7%*	20	*$381,467*	*3.6%*	30	*$269,648*	*2.6%*
Total FTEs	-	16	*$521,351*	*5.0%*	18	*$381,467*	*3.6%*	20	*$241,583*	*2.3%*
Mortality over cycle	%	4	*$478,482*	*4.6%*	7	*$381,467*	*3.6%*	10	*$277,988*	*2.7%*

Profit margin:
- **Higher than 10%** (green)
- **Between 2.5% and 10%** (yellow)
- **Lower than 2.5%** (red)
- **Default value of assumption** (grey)

7.0 Conclusions and Next Steps

It is important to note that the financial analyses contained in this report represent hypothetical ventures for different production technologies, albeit based on currently accepted industry practices. DFO cautions readers against using these data to support future investment decisions, as this document is not intended to be a business plan. Business plans are unique to each individual or project, and must be undertaken as exercises beyond the scope of this financial analysis.

Based on the assessment of 10 proposed salmon-rearing technologies, only two (net pens and RAS) showed potential for financial feasibility, warranting a more in-depth financial and sensitivity analysis. The results of this subsequent analysis have shown that while both technologies are profitable on a pro-forma basis, with returns significantly higher for net pen, RAS technologies are projected to be considerably more sensitive to market forces (e.g., exchange rate and market price) beyond the operator’s control, and may likely prove non-profitable within a range of variability that has actually been experienced by the Canadian salmon aquaculture industry in the past. These sensitivities are due largely to the high initial capital investment and subsequent costs associated with it.

As with most developing or emerging technologies, once wider uptake within the sector is achieved, capital and operating costs may be expected to decrease. Should closed-containment technologies achieve a critical mass of production, economies of scale may be expected; capital items may cost less, and increased expertise could help to reduce operating costs. The costs used for net pens in this analysis are based on several decades of expertise and an industry that has achieved critical mass—factors that convey a certain advantage during analysis. It is possible that similar gains could be experienced for RAS-based production systems in future; however, the scope and timeframe of these gains are beyond the current analysis. It is also possible that certain intangible costs (e.g., environmental and social license) may further affect the profitability of operations.

In summary, the analysis showed that RAS technology is marginally viable from a financial perspective, but that it presents a higher level of risk compared to net-pen systems. However, this potential warrants further assessment, and assumptions should be validated in real-life scenarios. Potential next steps could include a pilot scale or demonstration system capable of producing salmon at commercially viable levels (e.g., one module scalable to financially feasible levels) to demonstrate the technical and financial feasibility of closed-containment rearing of salmon under real world conditions. Life-cycle analysis of such a demonstration facility should also be undertaken and compared with that of net pen production. Life cycle analysis quantifies and compares potential environmental impacts between systems, and is used to compare local ecological impacts to impacts of more global concern, such as climate change, non-renewable resource depletion and ocean acidification.

The outcomes of such further analyses would be needed to determine next steps and guide government policy direction as it relates to closed-containment for salmon aquaculture.

Appendix

Technical specifications for preliminary technologies evaluated											
System	Rearing density (kg/m^3)	Oxygen absorption or transfer efficiency (per cent)	Inlet oxygen concentration (mg/L)	Flow rate (Lpm)	Exchange rate (minutes)	Flow to bottom drain (Lpm)	Estimate bottom drain particulate waste removal (per cent)	Storage tanks solids-laden water inflow (Lpm)	Storage tanks or settling basin overflow rate ($m^3/m^2/day$)	Storage tanks or settling basin solids retention efficiency (per cent)	System total retention efficiency (per cent)
2a	25	-	-	548,000	5	-	-	-	-	-	-
2b	40	-	-	54,000	46	3,000	70	18,000	~82	72-78	50-55
2c	65	90	-	33,000	76	3,000	70	12,000	~55	79-83	55-58
3c	64	90	-	25,000	80	1,770	70	8,850	~72	74-80	52-56
4a	40	-	-	90,000	18	-	-	-	48	45-65	-
4b	40	-	-	90,000	18	-	-	-	48	45-65	-
4c	63	90	22	21,000	79	3,000	50	-	12	80-87	40-44
4d	63	90	22	21,000	79	3,000	50	-	12	90-94	38-46

Glossary

Aeration tower:

A structure or device, often in the form of a tower, used to increase the oxygen in the incoming water supply.

Biofilter:

A unit within RAS that functions to reduce water exchanges by converting ammonia to nitrate. Ammonia (NH_4^+ and NH_3) originates from the brachial excretion of the gills of aquatic animals and from the decomposition of organic matter. As ammonia-N is highly toxic, this is converted to a less toxic form of nitrite (by *Nitrosomonas* sp.) and then to an even less toxic form of nitrate (by *Nitrobacter* sp.).

Biofiltration media (or biological filter media):

The substrate found in the biofilter upon which the biofiltration reaction (ammonia to nitrate) takes place. The biofiltration media has a high surface area to volume ratio, allowing for a more compact footprint for the biofilter. Many commercially ready media types are available, and range in variety from sand to small plastic units.

Biological feed conversion ratio (FCR_b):

The proportion of feed eaten that is converted into flesh.

Biomass density:

The total fish weight (expressed in kilograms) in one cubic metre of water at a given time.

Carbon dioxide stripping:

The process of removing CO_2 (which is toxic at high concentrations) from the culture water, often with the use of counter-current air blowers.

Drum filter (or rotary drum filtration):

A solids filtration element involving a rotating drum with screens (between 10–90 µm).

Farm gate price:

The net value of a product when it leaves the farm, after marketing costs has been subtracted. It does not include costs for shipping, handling, storage, marketing, and profit margins of the companies further down the supply chain.

Free on board (FOB):

Indicates who pays loading and transportation costs, and/or the point at which the responsibility of the goods transfers from shipper to buyer. "FOB shipping point" or "FOB origin" indicates the buyer pays shipping cost, and takes responsibility for the goods when the goods leave the seller's premises. "FOB destination" designates the seller will pay shipping costs, and remain responsible for the goods until the buyer takes possession.

Head (or static head):

The vertical distance from the low point to the high point in the system. It is important to know static head in determining pump sizes.

Income:

The net benefits before tax occurring each year. It is calculated as follows in the analysis:

Income = Farm gate revenues - operating costs (fixed, labour, production-based, feed costs) - administrative costs - straight-line depreciation of assets - interest charges (loan and line of credit)

Influent:

The incoming water.

Makeup water:

New water put into the system to compensate for the water lost during treatment (e.g., evaporation, drainage, spillage, etc.).

Net present value:

By calculating the net present value of cash flows (NPV) of a project, one discounts (brings back to present value) a series of future net cash flows that will result from an investment. The advantage of this approach is that it gives a global idea of the value of a project. That is, any cost or revenue occurring during the project is summed to calculate its worth in the current period (considering inflation, for instance).

$$NPV = \sum [Flows_t /(1+ i)^t] - C$$

$Flows_t$: The net increase /decrease in cash occurring at one period ($)
i: The discount rate chosen to calculate NPV, or the time value of money (per cent)
t: The period at which the flows are discounted (years)
C: The initial cost of the project

Return on equity (ROE):

Equal to a fiscal year's income divided by total equity, expressed as a percentage:

$$ROE = \text{Income before tax} / \text{total equity}$$

Where in this case,

$$\text{Total equity} = \text{Initial private investment on capital and line of credit}$$

Return on investment (ROI):

Equal to a fiscal year's income divided by capital investment, expressed as a percentage:

$$ROI = \text{Income before tax} / \text{capital investment}$$

Smolt:

A young salmon. At the smolt stage, salmon become physiologically adapted to saltwater.

Tube settler:

Often the primary step in the mechanical filtration process. Tube settlers are comprised of multiple tubular channels sloped at an angle of about 60^o, which allow enhanced settling characteristics and accumulation of solids within a settling basin.

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