Feasibility of Land-Based Closed-Containment Atlantic Salmon Operations in Nova Scotia

Gardner Pinfold
Consultants Inc.
www.gardnerpinfold.ca

Nova Scotia
1331 Brenton St.
Halifax, NS
Canada, B3J 2K5
Ph: 902-421-1720
Fax: 902-422-5343
mgardner@gardnerpinfold.ca

New Brunswick
46 Weldon Street
Sackville, NB
Canada, E4L 4N4
Ph/Fax: 506-939-2261
gregmacaskill@gardnerpinfold.ca

British Columbia
6150 Baillie Rd.
Sechelt, BC
Canada, V0N 3A7
Ph: 604-740-2703
Fax: 604-885-9450
tpinfold@gardnerpinfold.ca

Submitted to:

Nova Scotia
Department of Fisheries and Aquaculture

Submitted by:

Gardner Pinfold

May 2014

Table of Contents

Summary ..... **i**

1 Introduction **1**
1. Background 1
2. Objectives 1
3. Outline 1

2 Closed containment aquaculture systems **3**
1. Why the interest in land based systems for salmon 3
2. Growth of Atlantic salmon markets and production 7
3. An update on closed containment systems 8

3 Financial feasibility of LBCC Atlantic salmon production **13**
1. System technical description 13
2. Financial analysis 14

4 LBCC considerations and policy implications **22**
1. Life cycle assessment 22
2. Geographic location 23
3. Marketability 26
4. Government policy implications 30

5 Concluding observations **34**

Appendix 1: System elements included in capital cost estimates **35**
Appendix 2: Review of Life Cycle Analysis **38**
Bibliography **44**

List of Tables

Table 1: Examples of land-based aquaculture facilities 9
Table 2: Financial support to the aquaculture sector ($000s) 11
Table 3: Grants and loans for aquaculture facilities 11
Table 4: Base case performance profiles by system scale (100-1,000 t capacity) 17
Table 5: Sensitivity analysis – impact on IRR (1,000 t system) 20

List of Figures

Figure 1: Schematic view of a closed containment aquaculture system 4
Figure 2: Closed containment system grow-out tanks 4
Figure 3: Atlantic salmon net pens 5
Figure 4: Atlantic salmon global output and value, 1980-2012 7
Figure 5: Atlantic salmon global export price trend 8
Figure 6: Unit capital costs ($/kg) 18
Figure 7: To market unit operating costs ($/kg) 19
Figure 8: Unit energy use (kWh/kg) 20

Summary

Overview

Land-based closed containment technology is a well-established method for producing a wide range of saltwater and freshwater fish species. Economics and production parameter control provided the main rationale for the development and adoption of this technology.

The production of Atlantic salmon in land-based closed containment (LBCC) systems is at a relatively early stage of development. Most aspects of technical feasibility have been demonstrated; some issues remain to be fully resolved. Financial feasibility remains to be confirmed by actual performance of commercial scale facilities. The interest in the potential of LBCC technology for Atlantic salmon arises mainly out of concern for threats to the marine environment from conventional marine-based systems.

The findings of this report as they pertain to the feasibility of LBCC systems for Atlantic salmon are based on a financial model adapted to Nova Scotia operating conditions. The model incorporates accepted design parameters and operating assumptions, and uses up-to-date capital and operating costs. Nonetheless, the reader is cautioned that some assumptions have yet to be confirmed in actual commercial operating conditions, particularly in larger scale systems.

- **Technical feasibility**: research projects have confirmed the ability to meet key production parameters needed to grow Atlantic salmon, though production is not routine as it is with other species. Further work is needed to determine optimal stocking density and to resolve issues concerning early maturation of males (resulting in slow growth), mortality and "off-flavour" in fish. Critical biological factors are feed conversion, thermal growth coefficient and mortality. Key technical factors include temperature, stocking density, energy requirements and labour.
- **Financial feasibility**: the analysis concludes systems producing Atlantic salmon with capacities ranging from 250 to 1,000 t are not viable, given the current cost estimates and price assumptions used in this report. Among the key factors affecting financial feasibility are capital cost, stocking density, growth rate, feed conversion, mortality and price.

LBCC systems operate at an economic disadvantage because much of their cost goes toward creating growing conditions occurring naturally within the ocean, including the chemical properties and temperature of ocean water, as well as current and tidal action that provide waste dispersion services. As the findings of this report make clear, two factors are central to the challenge of overcoming any cost disadvantage: economies of scale and market.

Main findings

- **LBCC is a well-established technology**: Several hundred LBCC systems of various designs and scales operate globally, including in North America. The technology is well advanced and constantly improving in terms of its applicability, reliability and efficiency. Industry development is marked by the diversity of species cultured, the growth in the number of companies offering design and construction services, and the increasing number of countries and regions (rural and urban) where land-based systems are located.

- **LBCC systems operate in Nova Scotia**: Within Nova Scotia, companies using LBCC systems produce Arctic char, trout, halibut (juveniles and adults) and Atlantic salmon smolt. And significantly, a company that had successfully produced sea bream and sea bass for several years began converting its facility to Atlantic salmon in early 2013, with a planned initial production of 100 t.
- **Practical experience with LBCC systems producing Atlantic salmon is limited**: Actual experience to date with commercial scale LBCC systems for producing Atlantic salmon provides a limited basis for assessing technical and commercial feasibility. The Freshwater Institute in the U.S. has conducted a grow-out trial, producing Atlantic salmon to market weight. Elsewhere, three commercial scale projects ranging in capacity from 100 to 1,000 t began production in 2012-13. One of these, the ‘Namgis First Nation in BC, produced its first crop in April 2014.
- **Viability of LBCC for Atlantic salmon depends on scale**: Model results indicate that LBCC systems for Atlantic salmon have the potential to be financially viable, provided scale economies are achieved and all performance parameters are met. Systems do not approach commercial viability until capacities exceeding 2,500 t are reached. Systems below this scale are unlikely to achieve commercially viability because of the relatively high unit costs attributable to engineering, building, labour and energy use. Prevailing salmon prices are not high enough to cover capital and operating costs at smaller scales.
- **Life-cycle analysis (LCA) results for LBCC systems**: A review of the limited literature indicates LCA results are project-specific. Modern, well-designed systems with low energy use generated from renewable sources compare favourably with net-pen systems across conventional impact indicators. Nova Scotia continues to rely heavily on non-renewable sources of energy, though through its aggressive renewable energy policy is greatly reducing this dependence.
- **Location of LBCC systems**: With closed containment technology able to achieve recirculation efficiencies exceeding 99%, citing of facilities is not constrained by access to large volumes of water. This means that they do not have to be located in coastal communities or rural areas where water supplies (salt or fresh) are abundant. Depending on the of the LBCC facility, costs could vary substantially, e.g., land, energy and municipal taxes.
- **LBCC salmon may attract a premium price, but sustainability is mainly about market access**: Empirical analysis of the impact of eco-certification of seafood products indicates that it facilitates market access, but does not necessarily provide a basis for a price premium. LBCC operators may be able to carve out a niche market for Atlantic salmon (as operators have done with other species), but competitors can enter the market with the same product or close substitutes, thereby eroding the price premium. On the demand side, tastes and preferences may change.
- **Government support**: The Government of Nova Scotia has provided financial support to aquaculture projects in the past, including ones involving LBCC technology. Some of these projects would have been characterized as developmental – or even experimental – at the time, where both technical and

financial feasibility were uncertain. The risk for government in providing financial support at the developmental stage is that there is little to ground the technology and its eventual commercial expansion in Nova Scotia. The province could be investing in local technology development, but seeing the rewards in terms of economic impact reaped elsewhere.

1

Introduction

1. Background

The Government of Nova Scotia released its *Aquaculture Strategy* in mid-2012. The Strategy sets out Nova Scotia's vision for a sustainable aquaculture industry and the framework of principles and initiatives required to achieve this goal.

The purpose of this study is to implement a key commitment set out in the *Strategy*, namely, to foster innovation and promote the adoption of proven technologies that "…minimize the impact of aquaculture on the marine environment". Investigating the technical and economic feasibility of closed containment salmon aquaculture systems in a Nova Scotia context is one step in meeting this commitment.

2. Objectives

The specific objectives of this study are to:

- Investigate the feasibility (financial and environmental) of land-based closed-containment rearing of Atlantic salmon in rural coastal Nova Scotia, and
- Outline the strategic advantage/disadvantage for Nova Scotia, if any, of land-based closed-containment compared with existing ocean net pen technology.

The study is intended to answer one overriding question:

- Considering industry expectations for financial returns and ability to attract investment, is land-based closed containment Atlantic salmon farming feasible in rural Nova Scotia?

3. Outline

Following this introduction, Chapter 2 gives an overview of closed containment systems, describing the rationale for their initial development in the 1980s, and how the technology has evolved and been adapted for a wide range of species. An overview of the expansion of salmon farming globally is provided to gain insight into the market in which closed containment facilities will be competing. This chapter also focuses on the financial feasibility of closed containment systems, generally, including examples from Nova Scotia.

Chapter 3 examines the financial feasibility of using closed containment to grow out Atlantic salmon. It starts with a technical description of the key features of the system, outlining factors influencing capital and operating costs. The financial model used to conduct the analysis is described, key assumptions and the test of feasibility explained, and results (including sensitivity analysis) presented.

Chapter 4 examines some key considerations surrounding LBCC systems for Atlantic salmon including lifecycle impacts vs. marine-based systems, marketability and the prospect for price premiums, how geographic location might affect viability, and the implications for government with respect to policy, financial support and social license.

2

Closed containment aquaculture systems

1. Why the interest in land based systems for salmon

Elements of a land-based system

Land-based closed-containment aquaculture systems (LBCC), also referred to as recirculating aquaculture systems (RAS), are a relatively recent technological innovation. Prototypes were developed initially in Japan in the 1950s, with experimentation beginning in Europe in the 1970s. The first commercial scale systems emerged in the late 1980s, with facilities in the Netherlands, Denmark and Germany designed for eel production. Since then, innovation and development have continued, with the technology adapted for many other species. The applications of recirculation include broodstock management, hatchery and nursery rearing, grow-out and quarantine holding.

LBCC systems consist of large fish tanks linked by pipes and pumps to various filters. A system may be a closed or partially closed loop, where the effluent water from the system is treated and re-circulated to enable its re-use. The system pumps water through a series of filters to remove waste (solids, ammonia and carbon dioxide), while adding oxygen to maintain water quality at an optimum level for fish health and growth. Figure 1 contains a schematic outline of a LBCC system, intended simply to illustrate the main components (designs vary). Figure 2 shows an array of grow-out tanks.

Such systems have both advantages and disadvantages:

- The main advantages of recirculation technologies are the minimization of water consumption (upwards of 99% re-use in some system designs) and adverse environmental effects, as well as the possibility of controlling essential production parameters such as water temperature, oxygen concentration and the spread of diseases. Systems are scalable in the sense that the modular designs currently available allow gradual increments to capacity to facilitate expansion. Also, systems can be adapted to a wide range of species, and the production cycle can be controlled to supply markets on a year-round basis.
- Major disadvantages of such systems are the high initial capital costs for establishing the system and high-energy costs for circulation, temperature control and oxygenation. The equipment used to move and treat the rearing water requires skilled technicians, whose knowledge ranges from plumbing to computer systems. LBCC requires intensive, constant monitoring of the various parameters of water quality, since facility malfunction can prove costly if not addressed immediately.

For many of the species now produced using land-based systems – sea bass/bream, sturgeon, trout, halibut, barramundi, turbot, Arctic char – economics provided the main impetus behind the adoption of this technology. Central to the economic rationale were relatively high prices for the species in question, coupled with the ability to control production parameters and reduce risk.

Figure 1: Schematic view of a closed containment aquaculture system

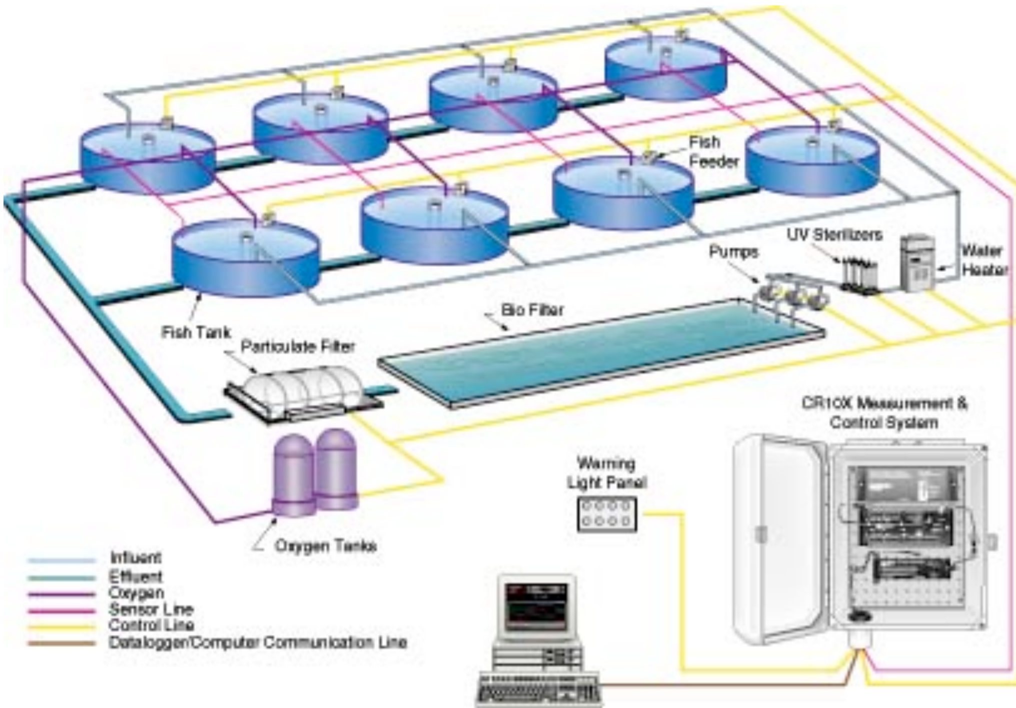


Figure 2: Closed containment system grow-out tanks

The role of environmental considerations

The objectives behind the interest in the potential of LBCC technology for Atlantic salmon are rooted more in environmental considerations than economics. The world is awash in Atlantic salmon, because of the adaptability of the species to hatchery rearing and growth in marine-based systems. And demand continues to increase thanks to global market development and a relatively affordable price. Once a luxury item when only wild-caught supply was available (pre-1980s), Atlantic salmon now competes directly in the same price/market segment with whitefish species such as cod and haddock (more on prices below).

The conventional approach to marine-based salmon farming is to use open net-pens. A farm site typically consists of a cluster of 10-12 circular or square pens, each consisting of steel or plastic frames anchored to the sea floor from which enclosed nets holding the fish are suspended. A single pen may hold salmon at a typical density ranging from 15-25kg/m^3. Although the term "open net-pen" is used to describe the cage system, the word "open" refers to the flow-through of ocean water. The pens are fully enclosed, and ordinarily covered with mesh at the surface to prevent escapes and also to prevent predation by birds.

Figure 3: Atlantic salmon net pens

The objections to open net-pen salmon farming from environmental organizations, as well as coastal fishing communities, stem from three main risk factors:

- **Nutrient pollution**: organic waste falling to the sea floor under the pen can affect bottom-dwelling organisms.[1] Farms rely on ocean currents to carry waste matter away and limit accumulation. Fallowing of farms sites is required after each production cycle to minimize any harm from deposition. In a LBCC system, waste is removed from the water and may be treated/composted and used as fertilizer.

[1] Royal Society of Canada (2012). *Sustaining Canadian marine biodiversity: An expert panel report on sustaining Canadian marine biodiversity: responding to the challenges posed by climate change, fisheries and aquaculture*. Ottawa: Royal Society of Canada.

- **Disease transmission**: salmon are susceptible to sea lice and to four main diseases, ISA, IHN, furunculosis and bacterial kidney disease. An outbreak at a marine farm risks transmission to wild stocks, particularly where farms are located near estuaries frequented by wild populations.[2] Antibiotics and pesticides used to control disease outbreaks are released into the marine environment with the potential to harm other marine organisms.[3] A disease outbreak in a LBCC system is possible, but because the system is closed, there is little or no risk of transmission to wild stocks or of treatment affecting wild stocks.
- **Effect of escapes on wild fish**: escapes resulting from storms or equipment malfunction can have severe impacts on wild populations of salmon.[4] Due to the location and design of LBCC grow-out systems, there is little or no risk of escapes or harm to wild stocks.

Economists refer to these kinds of incidental effects of production as "externalities", or in this case, as "external costs".[5] They are called external because the producer does not pay for them. To the extent these costs in the form of environmental or ecosystem damage occur, they become costs borne by society. Effectively, this means that the prices paid by consumers understate the full cost of producing salmon.

By their design, LBCC systems greatly reduce or eliminate most of these environmental risks, though in the process, create financial risk by incurring relatively high capital and operating costs in trying to mimic ocean conditions: chemical properties and temperature, as well as currents and tidal action that provide waste dispersion services. Much of the operating cost arises from the electrical energy needed to run the equipment. This can create its own environmental (external) costs (GHG emissions), though the magnitude of these costs depends largely on the source of electricity: they would be relatively high if thermal sources such as coal or oil were used, but relatively low if renewable sources such as hydro or wind were used.

LBCC systems internalize most of the external costs (not the effects of GHG emissions) of achieving comparable naturally occurring ocean conditions, but are not rewarded for it unless they can find a way to charge higher prices that reflect this environmental advantage. The potential for premium pricing this is explored later in this report.

Notwithstanding the advantages LBCC offers from an environmental standpoint, commercial scale adoption of this technology for salmon farming has been slow to develop. Mainly, this has been because conceptual models of production systems have shown that the economics would be challenging: at *prevailing salmon prices*, production levels would be unable to generate the revenues needed to overcome the combined effects of high initial capital costs for establishing the system and high energy costs for operating it.

[2] Royal Society of Canada (2012).
[3] Burridge, L. E., Hamilton, N., Waddy, S. L., Haya, K., Mercer, S. M., Greenhalgh, R., Tauber, R., ... Endris, R. G. (2004). Acute toxicity of emamectin benzoate (SLICE®) in fish feed to American lobster, *Homarus americanus*. *Aquaculture Research, 35,* 8, 713-722.
Burridge, L.E., Haya, K., Waddy, S.L. (2008). The effect of repeated exposure to azamethiphos on survival and spawning in the American lobster (Homarus americanus). *Ecotoxicology and Environmental Safety, 69*, 411-415.
[4] Thorstad, E. B., Fleming, I. A., McGinnity, P., Soto, D., Wennevik, V., & Whoriskey, F. (2008). Incidence and impacts of escaped farmed Atlantic salmon Salmo salar in nature. *NINA Temahefte 36: 110 pp., 36*.
[5] Whitmarsh, D., Palmieri, M.G., Aquaculture in the Coastal Zone: Pressures, Interactions and Externalities, in Holmer, M, et al. (2008). *Aquaculture in the Ecosystem*, Springer.

2. Growth of Atlantic salmon markets and production

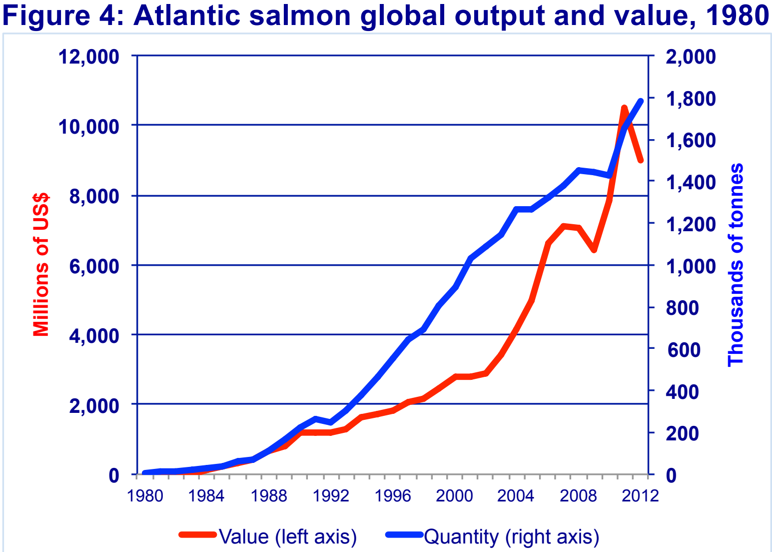
Atlantic salmon prices are one of the key variables affecting the viability of LBCC systems, so it is important to see and understand the long-term trends, and also to see just how volatile prices can be in the short-term. Any LBCC producer will be subject to price movements in the broader salmon market, even if land-based production is able to command a price premium because of the environmental benefits consumers associate with this approach relative to conventional net pen systems.

Research into artificial propagation of salmon (smolt production) began in Canada in the early 1900s, leading eventually to the development of programs to enhance wild stocks in the 1950s. Using sea cages to grow Atlantic salmon to market size began in Norway in the 1960s. From there, salmon aquaculture developed in Scotland, then Ireland, the Faroe Islands, Canada, the U.S., Chile and Australia. With the availability of hatchery-reared smolt using local strains, the first experiments with commercial salmon aquaculture applying Norwegian techniques began in Atlantic Canada in the late 1970s.

Commercial production of Atlantic salmon had become well established by the late 1980s, with some 40 companies operating in New Brunswick and 100 in British Columbia. Norway and Chile were the leading producers, with global output rising to 200,000 t by 1990, and to 1.0 million t by 2000. But production outstripped the capacity of markets to absorb the supply and prices began a decade-long slide. Weakening prices, exacerbated by disease issues, caused a sharp consolidation of the industry during the 1990s.

Industry consolidation coupled with improved market development brought supply and demand into better alignment. There were occasional periods of oversupply, but the basis for a long-term recovery of prices had been established, with growing markets in rapidly expanding economies such as China, Russia and Brazil. During the early 2000s as well, the combined effects of improved farming techniques and increasing scale of farms resulted in steadily declining production costs (though this is being offset by rising feed prices resulting from higher input costs). Global production and value are shown in Figure 4.

Figure 4: Atlantic salmon global output and value, 1980-2012

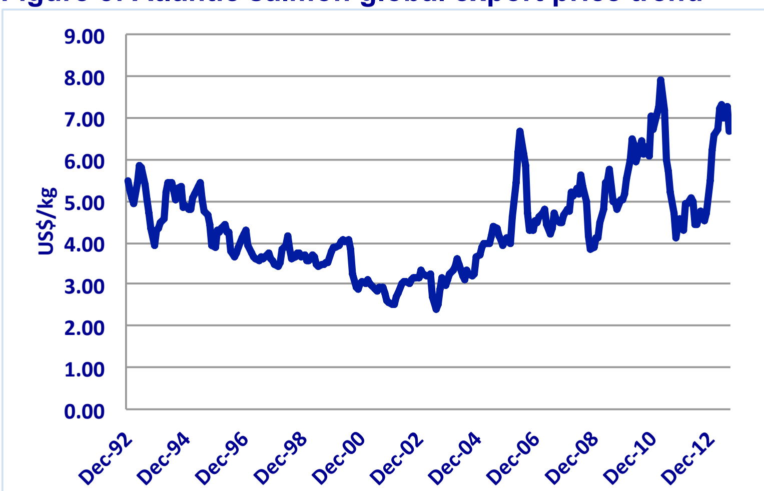


Source: FAO and Marine Harvest

The steady growth in global salmon production stalled at about 1.5 million t in 2008, following a disease outbreak in Chile. This led to a sharp increase in prices, inducing companies elsewhere to increase their stocking of smolt to make up for the global shortfall in supply. This production hit the market in 2010, and by mid-2011, markets were clearly in oversupply with an earlier than anticipated recovery of Chilean production. Prices peaked in May 2011 and then dropped sharply, reaching a low of just over US$4.00/kg in October (Figure 5). Prices fluctuated between US$4.25-5.00/kg through 2012 as supply continued to increase and outstrip demand (reaching an estimated 1.8 million t in 2012).

Prices began to rebound in December 2012, then climbed steadily in early 2013, exceeding US$7.30/kg in July and then dropping to US$6.70/kg in August. This turnaround is due partly to seasonal factors (higher demand/lower supply), but also to an overall drop in Norwegian production and sharply rising feed costs. Some upward pressure on prices may also be attributable to speculative behaviour because in early 2013 there were signs of another disease outbreak in Chile (ISA and sea lice).

Figure 5: Atlantic salmon global export price trend



Source: Marine Harvest

3. An update on closed containment systems

Global perspective

Several hundred LBCC systems of various designs operate globally, including in North America. The technology has advanced and is constantly improving in terms of its applicability, reliability and efficiency. Development of the industry is marked by the diversity of species cultured, the growth in the number of companies offering design and construction services, and the increasing number of countries and regions (rural and urban) where land-based systems are located. Table 1 sets out in summary form the various types of land-based systems, species produced and location.

A characteristic shared by commercial land-based farms is the production of high market-value species. This applies to saltwater species such as sea bream, sea bass and turbot, as well as freshwater species including Arctic char, trout and sturgeon. Many of the facilities listed in Table 1 are relatively small-scale, ranging in capacity (output) from 50-200 t/year. The notable exceptions are an 8-10,000 t turbot farm in Spain (Stolt Sea Farms); a 1,200 t tilapia farm in Poland; and 500-1,000 t barramundi farms in Massachusetts (Australis Aquaculture), the U.K. (Aqua Bella) and Israel (Aqua Maof).

Some projects are worth noting because they involve Atlantic salmon. These are LBCC systems implemented by Shandong Oriental Ocean Sci-Tech Co. in Yantai, China (1,000 t/yr); BDV SAS in Normandy, France; and Langsand Laks AS in Denmark. The Langsand Laks farm has a 1,000 t/year capacity, with first production expected in 2013 (a farm is also planned for the U.S.).[6] Information is not available on the financial performance of these facilities. The owner of the Danish facility (Langsand Laks) notes that the project benefited from government grants totaling US$5.5 million.

Table 1: Examples of land-based aquaculture facilities

Systems/Description	Species	Location/region
Recirculating Tanks		
Tanks can come in a variety of forms. Circular formats have been preferred in many cases because of the self-cleaning properties they provide. Polygon shapes, however, have advantages in being more space efficient. These systems are often modular and scalable, allowing producers to scale-up systems at their own pace and without having to interrupt operations to add greater capacity. Inland recirculating tanks are often located where there is both limited land and water availability, as they can be located in industrial areas and achieve high degrees of water reuse.	Atlantic salmon (*Salmo salar*)	China, Denmark, France, Canada
	Turbot (*Scophthalmus maxima*)	Netherlands (HESY)
	Tilapia (*Oreochromis niloticus)*	El Salvador, Israel (HESY)
	Eel (*Anguilla anuilla*)	Denmark (produces 20% eel consumed by European Market), Croatia and Netherlands (HESY)
	Barramundi (*Lates calcarifer)*	Australia, USA, Russia, The Netherlands, Israel, Denmark, UK
	Jade perch (*Scortum barcoo*)	Australia (Ausyfish)
	Golden perch (*Macquaria ambigua*)	Australia (Ausyfish)
	Murray cod (*Maccullochella peelii peelii*)	Australia (HESY)
	Sleepy cod (*Oxyeleotris lineolatus*)	Australia (Ausyfish)
	Black rockfish (*Seabastes schelegeli*)	Korea (Schipp, 2006)
	Pike perch (*Sander lucioperca*)	Netherlands
	Seabass (*Centropristis Striata*)	Greece (HESY)
	Seabream (*Sparus aurata*)	Greece (HESY)
	Trout (*Onchorhynchus mykiss*)	Chile (HESY)
	African catfish (*Clarias gariepinus*)	Benin (HESY)
	Sturgeon (*Acipenser transmontanus*)	Greece (HESY)
Raceways (recirculating or flow-through)		
Modern raceway systems are made from a variety of materials: concrete, plastic, steel; can be either outdoor or indoor; gravity fed by a stream; partially or fully recirculating.	Trout (*Onchorhynchus mykiss*)	US, Spain, France
	Turbot *(Scophthalmus maxima*)	Spain, (Akvaplan-Niva, Stolt sea Farms) France, Denmark (UNI-Aqva)
	Seabass (*Centropristis striata*)	France
	Channel catfish (*Ictalurus punctatus*)	USA
	Sole (*Solea solea*), Japanese flounder (*Paralichthys olivaceus*)	Spain, Denmark
Flow-through Tanks		
Flow-through tanks come in similar formats as recirculating tanks. These however are more commonly found where reliable water sources are available and used to harvest species that require certain conditions (i.e. trout).	Arctic char (*Salvelinus alpinus*)	Canada (Icy Waters), Iceland.
	Trout (*Oncorhynchus mykiss*)	Europe, N. America, Chile, Latin America

Source: Ecoplan International Inc. (2008) *Global Assessment of Closed System Aquaculture*.

[6] http://tidescanada.org/salmon/aquaculture-innovation-workshops-and-reports/

Canada and Nova Scotia perspective

LBCC is an established technology in Canada and Nova Scotia, though not yet with respect to Atlantic salmon. Canadian and Nova Scotia companies operate several commercial scale closed containment aquaculture systems. In central and western Canada, hatcheries using closed containment technology produce Atlantic and Pacific salmon smolt. Other LBCC systems produce Arctic char and trout.

Within Nova Scotia, companies using LBCC systems produce Arctic char, trout, halibut (juveniles and adults) and Atlantic salmon smolt. One company (Sustainable Blue) that had produced sea bream and sea bass for several years began converting its facility to Atlantic salmon in early 2013, with a planned initial production of 100 t growing eventually to 375-500 t. First production of 3.5-4.0 kg salmon had been expected in May of 2014, but an electrical malfunction in March caused a system failure resulting in the loss of 12,000 fish.[7]

In early 2013, the 'Namgis First Nation on Vancouver Island in British Columbia completed construction of Canada's first Atlantic salmon LBCC facility (described as a pilot project to test production parameters). The capital cost of the facility, initially estimated at $7.5 million, incurred overruns and reached about $9.7 million. It is designed with an annual production capacity of 470 t (live weight), though additional modules are planned, which would bring the eventual capacity to between 2,000 and 3,000 t.

Financial feasibility

Aquaculture development in North America and Europe has relied on considerable financial support from governments, particularly during its formative stages, but also during periods of expansion and diversification. This applies to conventional marine-based operations as well as emerging closed containment systems.

Forms of support fall into three main categories: direct payments to companies (grants), cost reducing transfers (loans) and general services (research and resource management), though the distinction is not always made in reported data. Table 2 provides an overview for several countries, including Canada. The European Union subsidizes aquaculture through the European Fisheries Fund (EFF), and EU member states may also provide support under certain circumstances. In the aggregate, support in most countries accounts for 5% or less of the total value of production, though in some cases it reaches 6-7%. The support by Canada has tended to be in the $45 million range, with most of this provided in the general services category.

Identifying and comparing the level of subsidization in the form of direct payments and cost reducing measures on a national basis is problematic because of data limitations, including definitional differences. Canadian data may be obtained from three sources: Statistics Canada (Aquaculture Statistics); DFO (annual reporting under the Aquaculture Innovation and Market Access Program); and provincial governments. There is overlap in these sources, since subsidies provided by the provinces and under the former AIMAP should show up in the annual Aquaculture Statistics reports. Since the latter are compiled from an industry survey, it is not certain that the data are comprehensive; also, in some years, data are not reported due to confidentiality restrictions.

[7] http://www.novanewsnow.com/Business/2014-03-18

Table 2: Financial support to the aquaculture sector ($000s)

	Support			Value of production	Support as % of value
	EFF	National	Total		
Canada		43,650	43,650	809,000	0.05
Denmark	319	9,155	9,474	163,000	0.06
France	3,488	9,513	13,001	970,000	0.01
Ireland		3,171	3,171	148,000	0.02
Norway		28,024	28,024	4,000,000	0.01
Spain	9,354	31,710	41,064	550,000	0.07
Sweden	149	1,493	1,642	34,000	0.05
U.K.		2,670	2,670	84,000	0.03
U.S.		11,419	11,419	860,000	0.01
EU	40,125		40,125	1,300,000	0.03

Source: OECD Review of Fisheries Statistics, 2012; EC Government subsidies to the fisheries and aquaculture sector, 2012; EC Evaluation of the European Fisheries Fund (2007-2013).

Allowing for these limitations, the Canadian data indicate that since 2006, the aquaculture industry has received direct subsidies (grants) ranging between $1.6 and 2.5 million annually. Though there are confidentiality limitations, it would appear from the reports that companies in each province received at least some support.[8]

To gain insight into the details of financial support – companies, species and technology – it is necessary to examine projects funded under the previous federal program, AIMAP, and also to explore funding announcements made by the provinces. Both these sources indicate funding commitments; it is not clear when the funds may have been drawn down (or if). Table 3 lists projects funded within the past five years, with a focus on salmon and closed containment. AIMAP committed a maximum of $4.5 million annually under a defined contribution arrangement.[9] Provincial funding includes grants and loans; commitments vary according to applications. Federal funding was also available to support applied research projects under the Aquaculture Collaborative Research and Development Program (ACRDP).

Table 3: Grants and loans for aquaculture facilities

AIMAP Projects	Species	Technology	Amount
▪ 2012: Broodstock conditioning/holding	▪ Halibut	▪ LBCC	$400,000
▪ 2012: Integrated hatchery facility	▪ Arctic Char	▪ LBCC	$330,000
▪ 2012: Increasing production capacity	▪ Halibut	▪ LBCC	$300,000
▪ 2012: Developing production capacity	▪ Tilapia/Coho	▪ RAS raceway	$415,000
▪ 2011: Smolt production facility	▪ Atl. salmon	▪ LBCC	$500,000
▪ 2011: 'Namgis (grow-out) facility	▪ Atl. salmon	▪ LBCC	$800,000
▪ 2010: Optimized tank farming	▪ Halibut	▪ LBCC	$1,200,000
Provincial funding			
▪ 1999: NS – Hatchery and grow-out	▪ Halibut	▪ LBCC	$2,190,000
▪ 2006: NL – Hatchery and grow-out	▪ Atl. salmon	▪ Net pen	$10,000,000
▪ 2009: NS – Grow-out facility	▪ Bass/bream	▪ LBCC	$1,450,000
▪ 2012: NS – Hatchery and grow-out	▪ Atl. Salmon	▪ LBCC/Net pen	$25,000,000
▪ 2013: NS – Canaqua Seafoods	▪ Halibut	▪ LBCC	$1,000,000

http://www.dfo-mpo.gc.ca/aquaculture/sustainable-durable/index-eng.htm;
http://www.gov.ns.ca/econ/news/
http://www.releases.gov.nl.ca/releases/2008/fishaq/0424n07.htm

[8] See Statistics Canada, *Aquaculture Statistics*, Cat. No. 23-222-X, Table 3 Value Added Account.
[9] Though the program has terminated, details are available at: http://www.dfo-mpo.gc.ca/aquaculture/sustainable-durable/index-eng.htm

Experience indicates that LBCC systems are, or can be, feasible. Many of those producing high valued species in Europe and North America have operated successfully for several years. Though the history of these facilities in Nova Scotia is not as long, there are examples of successful companies (excluding salmon and trout hatcheries):

- Scotia Halibut (producing juveniles for on-growing)
- Can Aqua Seafoods (halibut and Arctic char grow-out)
- Millbrook First Nation (Arctic char grow-out)
- Sustainable Blue (sea bream and sea bass; converting to Atlantic salmon)

It is important to note that continued operation for years demonstrates technical feasibility. Whether it also demonstrates financial feasibility depends on the extent of any reliance on external funding (e.g., from governments or other sources not expecting a return on investment), *and* whether that funding represents the difference between positive and negative returns. This second condition is important because there may be very good reasons for government assistance – for example, to provide capital because conventional lenders find these projects too risky.

To a greater or lesser degree, all the LBCC projects listed above have received government support. In view of the challenges securing capital from conventional sources, it is most unlikely that they would have been established without this support (in the form of grants and loans). To what extent this has made a difference to their feasibility is not clear since financial statements are not a matter of public record.

The final point to note is that the experience with LBCC systems for Atlantic salmon is too limited to comment meaningfully on financial feasibility. Information of any kind is not available for the facilities in China and France. The facilities in Denmark and British Columbia are operating but have not yet produced their first crop:

- **Langsand Laks (Denmark)**: this 1,000 t facility secured US$5.5 million in government grants to support its development (capital cost in the US$12-13 million range). In its first year of operation (2013) it apparently experienced a problem with early maturation (grilsing) and is taking steps to resolve this.
- **'Namgis (British Columbia)**: this 470 t facility with an initial capital cost estimate of $7.5 million, secured $6.5 million in philanthropic funding and government grants. Cost overruns have brought the final capital cost to the $9.7 million range. The facility produced its first crop in April 2014.

3

Financial feasibility of LBCC Atlantic salmon production

1. System technical description

System design and components

There are many design and construction options as LBCC technology continues to develop around the world. Relatively few recent facilities have been purpose-built for commercial production of Atlantic salmon therefore the best way to design and construct LBCC systems has yet to emerge for commercial scales in the future. The approach here is to take a combination of information sources and examine a general system design to evaluate financial feasibility.

Before proceeding with the feasibility analysis, anyone wishing to obtain more background on LBCC system design and operation could refer to 2010 reports by Fisheries and Oceans Canada and Wright and Arianpoo.[10] These descriptions provide excellent detail on production parameters and design options. Additional information from some existing LBCC systems provides alternative options for system design and construction that are discussed in the sensitivity analysis.

The objective is to produce 5.65kg market fish with some additional smaller fish harvested to thin stocks and optimize growth of the main cohort. Although there is flexibility in stocking plans, the system is intended to be stocked monthly and therefore produce a harvest monthly. This is the most efficient production that maximizes fish growth and profitability. The design relies on 10 to 30-tank arrays to accommodate the needs of fish at sequential growth phases, although other tank arrays are possible. Tank sizes can be varied to accommodate smaller changes in production capacity, but for larger changes in scale (e.g. 1,000 t to 2,500 t) the design is considered modular, though with some economies of scale.

The production cycle time is driven by temperature settings ranging from 13^0 to 16^0 C. Higher temperatures produce market salmon in about 12 months, and each degree drop adds one month to the production cycle. The initial number of smolts is set to meet the biomass density and harvest objectives at the end of the production cycle, allowing for mortality and stock thinning as needed. The density is targeted for $50kg/m^3$, although higher densities may be possible. Higher densities are subject to concerns about fish quality and challenges in managing the system to maintain optimal growth. System design and component selection supports both freshwater and saltwater production; the merits of each are discussed later.

[10] Boulet, D. et al, *Feasibility Study of Closed Containment Options for the British Columbia Aquaculture Industry*, Fisheries and Oceans Canada, September 2010; Wright, A. and Arianpoo, N. *Technologies for Viable Salmon Aquaculture, An Examination of Land-Based Closed Containment Aquaculture*, May, 2010.

System scale

How system scale affects project viability forms a key element of the analysis because of the economies of scale evident with the technology. As the analysis shows, there is a trade-off between the size of the capital commitment and the viability of the system; smaller capacity systems may be more affordable, but they tend to be less viable than larger systems with higher capital costs.

Four scales are assessed, ranging from 250 t to 1,000 t (the largest scale yet attempted for Atlantic salmon). Conceptual analysis suggests that designs beyond 1,000 t are more robust, but are more challenging to finance and unlikely to represent practical options in Nova Scotia at this time.[11]

2. Financial analysis

Approach

Pre-operating and capital construction

It is first important to recognize that capital costs in the analysis are simply fixed estimates according to each scale of production examined, and do not vary according to adjustments in design variables and operating settings. For instance there is no option to specify more or less automation of system operations that would change the capital costs. A high level of automated feeding, monitoring, and water quality controls is assumed, especially at the larger scales (corresponding to minimal labour inputs). Another example of fixed capital costs relates to adjustments in targeted biomass density and other operational decisions. Setting the stocking density higher does not reduce the capital cost of tanks in the analysis. The capital costs are simply set to estimates at each scale that accommodate a range of features an owner/operator would likely choose for high performance and low operating costs in the long run.

Specifically, capital costs include the system elements set out in Appendix 1 (with suppliers indicated). Technology options are listed within each the main elements. The relative contribution to operating costs associated with specific components is shown. The main differences in system costs arise from pre-construction costs such as land, site works for power and water, design and engineering, and buildings to enclose the system and provide office/work space. These sources of cost account for most of the scale economies (they decline as a proportion of total cost). Unit costs of equipment (cost per unit of throughput) also decline, up to a limit, as capacity increases.

The pre-construction costs do not include licensing and permit fees, however these tend to be less onerous for LBCC than for sea-cage applications. More involved site works such as road construction are not included. Some locations/systems may be able to use geothermal resources and these are not included specifically, but would presumably be adopted based on a value proposition that fits within this financial feasibility assessment.

---

[11] The smallest capacity considered commercially viable given current technology and costs is 2,500 t (see Appendix 3 of this report for financial results). This size formed the basis for the detailed conceptual analysis conducted by Fisheries and Oceans Canada in 2010. The analysis concluded that this facility would generate a modest return on investment (2%). (See Boulet, D. et al, *Feasibility Study of Closed Containment Options for the British Columbia Aquaculture Industry.*)

Numerous variations in system element selection are possible, and this list is mainly intended to show the elements included in the capital costs. Some selections would not be finalized until the site and production plans are known.

Three other components to capital costs not already mentioned are taxes, contingency funds, and working capital that are included in the capital costs. Taxes are set to Nova Scotia rates and apply to all of the above system elements. Contingency funds are incorporated at 20% keeping in mind that sensitivity analysis assessing higher overall capital costs will also capture the possibility of cost overruns. Working capital is the funding required to cover the shortfall in cash that accrues before the first harvest (revenues). The most significant working capital requirement will be for feed costs and, although feed companies at one time made arrangements with operators to incorporate financing into their feed purchases, this is no longer common practice.

Debt financing is handled in many ways and is often unique to each company; it is beyond the scope of this analysis to look at the range of possibilities so we make assumptions about the source of financing. Equity investment is set to 50% of capital across all system scales, and the share of capital costs covered by loans from commercial lenders is 25%, and 25% from federal and provincial governments. Payments on the entire debt are set to begin at the start of the pre-construction period, which is not necessarily required since contractors will likely be paid as construction milestones are reached, and working capital is not required until the first year of operation. The capital/debt burden is therefore somewhat over-stated, but this provides a more conservative assessment and/or allowance for delays in operation that involve carrying debts longer than expected until first revenues are produced.

Operations

Operating parameters are set for a wide array of system inputs. These are described here to emphasize that all operating parameters are considered in the analysis, and to indicate what values are used for the key parameters in the base case.

Maintenance and capital additions are set to 1% of capital cost per year, while depreciation is set to 5% per year over the expected system life of twenty years. The system life is likely longer, but this coincides with the period of analysis.

A range of system inputs is required once the construction is complete, including smolt stocking ($2.25 per smolt) from an independent supplier. The average feed price used in the model reflects the dominance of feed in the later grow-out phases where feed prices are lower than for feed used in the early stages. Feed prices are lower for large-scale systems due to favourable bulk pricing and freight costs. The average prices per tonne of feed are: $1,875 (250 and 500 t systems), $1,800 (750 t), and $1,775 (1,000 t). Mortality over the growth cycle is set at 4%. Mortality insurance is set to cover 70% of the annual operating expenditures, and the insurance premium is 3% of this value.

A set of fish production settings includes the target fish weight at 5.65kg, with 10% of the weight removed for a head off and gutted (HOG) finished product. The growth constant (2.4), feed conversion rate (1.08), and growth percentage (0.3%) are used in calculating monthly fish growth. Temperature can be set from 13-16 degrees; 15^0 C is used for the base case. Effluent disposal costs are set to $50 per t of fish.

Building costs include air exchanges per hour, heat requirements (btu/m^3), and the percentage of the building floor space that will be occupied by the production tanks. The costs of gasoline, diesel, propane, and electricity are inputs to the model.

A number of key water quality parameters may be set including the source water pumping lift (m), oxygen use, liquid oxygen price (only for backup), ozone use, CO_2 concentration, drum filter screen size (microns), filter backwash time, and oxygen dissolving efficiency. Finally, the biomass density can be set although it does not tie back to capital cost estimates, only to tank size which influences lighting requirements and associated energy costs. To be clear, setting a higher density does not allow the capital cost of tanks to be held constant while production (system capacity) is increased to generate more revenue per m^3 of tank space. The rationale is that operators should set their density based on the ability to maintain desirable water quality and fish growth, and the capital cost estimates accommodate a range of tank sizes that will meet these needs.

The last set of operational inputs pertains to farm gate revenue. The estimated northeastern U.S. (Boston) FOB market (wholesale) prices for 5.65kg whole fresh salmon are entered in U.S. dollars. The farm gate price is based on the volume weighted average monthly export price (eastern Canada to U.S. northeast) for the three years, 2010-2012 (US$5.72/kg). The exchange rate is then specified along with a number of costs that must be backed out of the export price to establish a farm gate price. These costs include processing, packaging, freight, and sales commission. The first three are expressed in $/kg of fish, and sales commission is a percentage of the market price.

Results

The financial analysis indicates that none of the four system scales examined produces a positive overall return on investment, and only the 1,000 t system results in even a positive return on equity (a modest 1.7%). The systems are evaluated using a suite of indicators to reflect costs, financial ratios and economic impacts. The main indicators are summarized for comparison across all system scales in Table 4. Some additional information on system design and inputs is shown for reference to appreciate key factors with each system (e.g. % equity, exchange rate).

The key cost indicators are: required funds (construction and working capital including taxes and contingency), unit capital costs, feed price, electricity price and unit energy use (kWh/kg of fish), and “to market” unit costs of fish production (including processing, packaging, shipping, and sales commission).

Local economic benefits are simply economic outputs (expenditures) of system construction and operation and exports based on 90% of product being exported from the province. Economic input-output analysis (not conducted as part of this study) would be required to determine the provincial GDP (added value), salaries, jobs, and tax revenues associated with direct, indirect and induced spinoffs from the LBCC start-up.

Twenty-year balance sheet and cash flow information is available within the spreadsheet model, and a set of key financials is presented in the summary table. The payback period (years), internal rate of return (IRR – the percentage return earned by the project after all capital and operating costs are covered), and five financial ratios are shown for year 5 of operations. Year five is simply a year by which ratios have stabilized after the effects of first and possibly second year of operating without revenue depending on the temperature setting which determines the time to first harvest. The return on equity, net cash flow, debt to equity ration, and profit margin are shown.

Table 4: Base case performance profiles by system scale (100-1,000 t capacity)

Capacity (t)	250	500	750	1,000
Financing				
Funds required ($M)[1]	$8.2	$12.3	$15.1	$17.2
Unit cap costs ($/kg)	$22.0	$17.0	$14.0	$12.0
% Equity	50%	50%	50%	50%
Operating				
Feed price ($/t)[2]	$1,850	$1,800	$1,775	$1,750
Electricity price ($/kWh)[3]	$0.11	$0.11	$0.11	$0.11
Unit energy use (kWh /kg)	4.65	4.56	4.04	3.13
Temperature (deg C)	15	15	15	15
To market costs ($/kg of fish)[4]	$5.00	$4.00	$3.54	$3.31
Revenues				
Target fish weight (kg)[5]	$5.65	$5.65	$5.65	$5.65
Market price ($/kg)[6]	$5.72	$5.72	$5.72	$5.72
Market revenues ($millions)	$1.35	$2.70	$4.05	$5.41
Exchange rate ($1 U.S. =)	$1.05	$1.05	$1.05	$1.05
Local economic benefits				
Pre-operating and construction	$6,215,000	$9,605,000	$11,865,000	$13,560,000
On-site employee incomes	$396,000	$396,000	$396,000	$396,000
Operating expenditures	$2,029,919	$2,913,080	$3,661,384	$4,340,112
Provincial exports	$1,216,215	$2,432,430	$3,648,645	$4,864,860
Plant financials				
Payback period (yrs)	>20	>20	>20	>20
IRR	Negative	Negative	Negative	Negative
Year 5 return on equity	-27.0%	-14.0%	-5.4%	1.7%
Year 5 net cash flow ($M)	($1.1)	($0.9)	($0.4)	$0.2
Year 5 debt:equity	63%	63%	63%	62%
Year 5 profit margin[7]	-83%	-32%	-10%	3%

Notes: This Model is intended to provide general guidance and a tool for analysis only and is not intended to provide financial advice or to be used as the basis for investment decisions.
1. Includes design, construction, 20% contingency, taxes, and working capital.
2. Feed price reflects weighted average for feed used over production cycle where most feed is consumed at lower prices in the final grow-out stages. Source: feed/aquaculture companies.
3. Current price in Nova Scotia. Source: NSPI and NS aquaculture companies.
4. Includes processing, packaging, shipping, marketing and sales commission.
5. Target is for larger size class than average (e.g. 10-12lb rather than 8-10lb), and market price selected should therefore be higher than the average FOB fresh whole Northeast U.S. farmed prices.
6. Based on three-year average monthly price of Canadian exports to the U.S. Source: Statistics Canada/U.S. NOAA
7. Profit margin represents revenue relative to costs in year 5, and does not suggest capital investments are paid off by that year.

Quite often the payback period and IRR provide the simplest assessment of performance for the full investment in the project. Payback periods under five years could attract private investment, and more readily under three years. Over five years payback could still attract private investors, but with new or developing technologies the risks would have to be well-understood or some public support would be needed to make the project move forward. Similarly for IRR, but typical investment thresholds for investments of this kind are high (likely in the 25-30% range), given the technical and financial risks

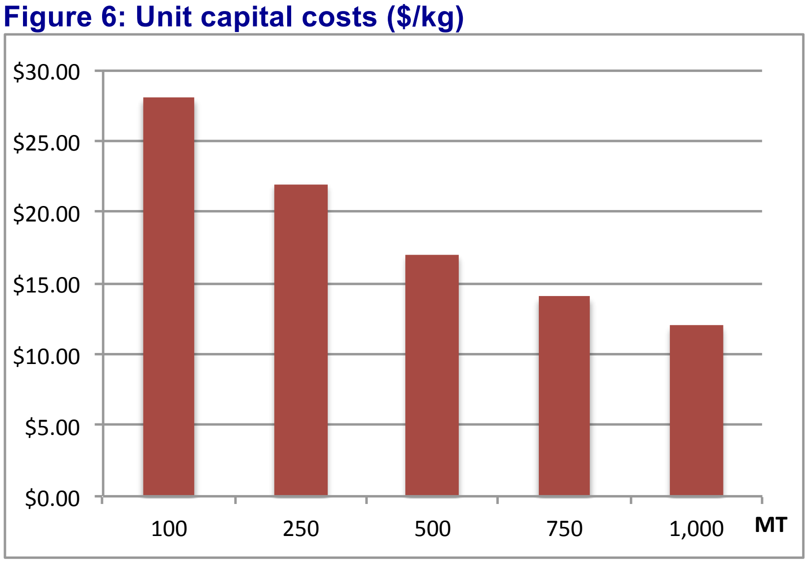
Effects of scale

The significance of scale is the first critical point to appreciate since it has the greatest influence over financial performance. Although there is no one aspect of increasing scale that drives efficiencies and economies, there are a number of things that together contribute to scale advantages in terms of lower unit capital costs (Figure 6), unit operating costs (Figure 7), and improved environmental performance (Figure 8).

Design and engineering, land acquisition, water and power installation, and building construction costs do not rise proportionally with scale. Larger systems can make these costs much less significant in the overall financial performance. However, the tanks, piping, and filtering components are essentially modular and increasing system size does little to minimize these costs. One exception is the oxygenation equipment, which can be setup to accommodate a range of scales, and therefore larger systems will take better advantage of this.

The largest drop in unit capital costs is from the 100 t to 500 t systems (400% increase in scale), resulting in roughly a 40% drop in unit costs. Up to 1,000 t, the gains are more moderate: an 18% drop between 500 and 750 t, and 14% between 750 and 1,000 t. Conceptual designs also indicate a substantial drop between 1,000 and 2,500 t (see Appendix 3).

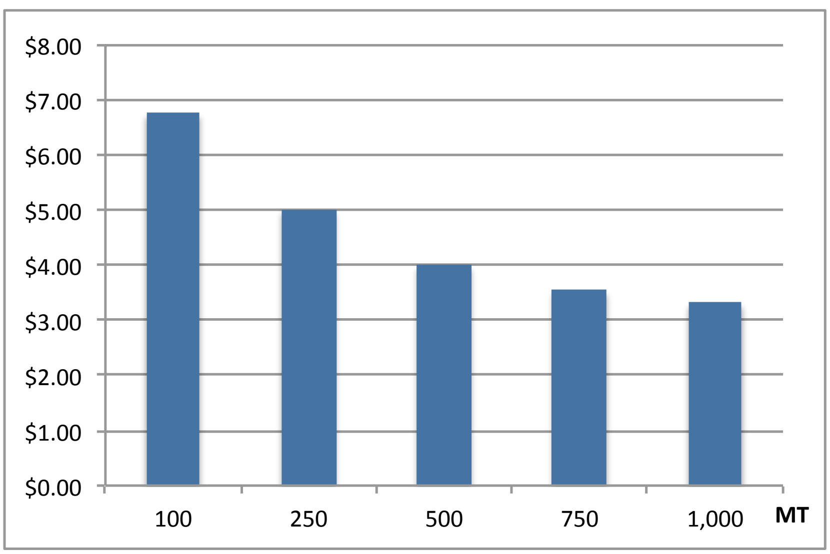
Figure 6: Unit capital costs ($/kg)



“To market” unit operating costs also decline with scale. These costs include processing, packaging, shipping, and marketing that often occur beyond the farm gate, but are required to earn the market value of fish in the analysis.

- The unit operating costs improve with scale mainly due to relatively fixed labour and overhead requirements. Managing more fish is not more difficult for staff since most tasks are organized on a tank basis or by growth phase rather than according to volume of fish. Labour is minimized, especially at larger scales, with the use of automated feed systems etc.
- Some favourable feed pricing occurs at greater scales due to bulk purchasing and transport efficiencies. At very large scales integration of feed manufacturing on-site or in close proximity begins to make sense.
- Similarly, some post-farm costs such as processing, packaging, shipping, and sales commissions may improve slightly with larger scale operations.
- Pumping efficiency improves with scale and this reduces energy use and costs.
- Office related costs, marketing costs, and a host of essentially fixed business costs all contribute to smaller unit operating costs at larger scales. Again large drops occur between 100-500 t, and more moderate drops from 500-1,000 t.

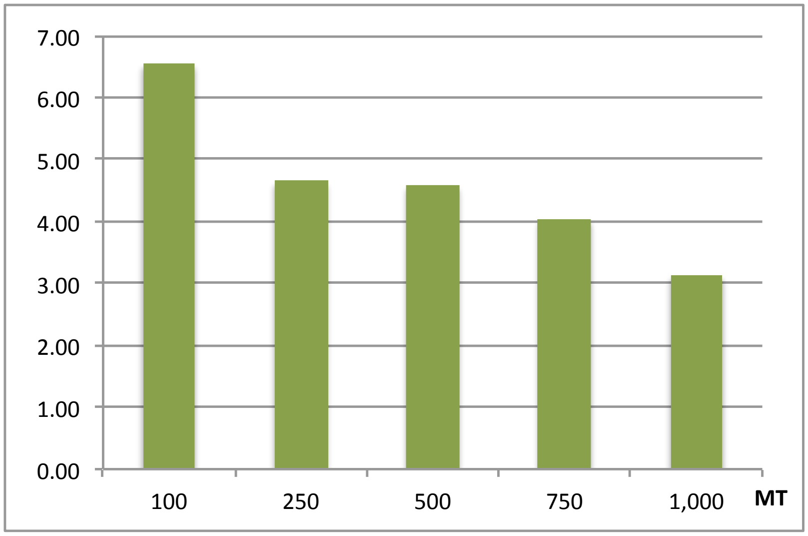
Figure 7: To market unit operating costs ($/kg)



Some aspects of environmental performance will improve with scale including unit energy use expressed in kWh per kg of fish produced. These advantages are related to initial acquisition of water to fill tanks and bring them up to operating temperature, lighting, building heating, and small gains in pumping and filtering efficiencies.

There are no scale advantages in terms of the energy footprint of feed, except if the system is located near a feed producer (flexibility of LBCC location) or the scale moves beyond those shown here and it makes sense to integrate a feed manufacturing process with the facility. The unit energy use starts to level off beyond the 1,000 t scale, but is not likely to be much better than the 3.0 kWh/kg achieved at this scale.

Figure 8: Unit energy use (kWh/kg)



Sensitivity analysis

Sensitivity analysis is a means of assessing the uncertainty regarding key variables affecting financial feasibility. By increasing or decreasing fixed or variable costs we can determine the impact on financial indicators, and identify those project inputs (e.g., feed costs) or outputs (e.g., prices) requiring greater risk management. The changes in key variables reflect historical experience or ranges that could be plausible given uncertainty of projecting into the future. Keep in mind these changes assume that the higher or lower values remain on average for the twenty-year period of analysis, and they do not just represent fluctuations and cyclical changes that are already assumed. They are meant to go beyond inflationary changes; they are real increases or decreases in today's terms.

In light of the negative IRR at all scale levels, there would appear to be little point in assessing the sensitivity of results to negative changes in key variables – this would only drive results to even higher negative values. For this reason, we assess the sensitivity of results to positive changes only – either a 20% change in factors affecting revenues (price and mortality) and a 20% decrease in values affecting costs (capital, feed, labour and electricity). Essentially, this sensitivity analysis asks, "What positive changes in key variables would produce more favourable results?". Results are shown in Table 5.

Table 5: Sensitivity analysis – impact on IRR (1,000 t system)

Variable	Base value	Adjusted value	Adjusted IRR
Exchange ($CAD=)	$0.95 US	- 20% ($0.76 US)	4.1%
Price (3-yr avg.)	$5.72/kg	+25% ($7.15/kg)	3.6%
Capital ($million)	$17.0	- 20% ($13.6)	Negative
Feed price	$1,750/t	- 20% ($1,400/t)	Negative
Smolt cost	$2.25	- 20% ($1.80 ea)	Negative
Electricity price	$0.11/kWh	- 20% ($0.088/kWh)	Negative
Labour & admin	$30k salary	- 20% ($24k)	Negative
Mortality	4%	- 50% (2%)	Negative
Cumulative			22.6%

Concluding observations

The Table 5 results are instructive, indicating just how substantial a shift would be required from the base case assumptions to achieve a minimally acceptable rate of return. Individual adjustments in price, capital cost and exchange rate turn negative returns to mildly positive, but nonetheless too low to be attractive to investors and lenders. It would take the simultaneous shift of all the values as indicated for the result to approach an acceptable rate of return.

The Table 5 results also indicate that price, exchange rate and capital costs represent critical drivers of viability. If a niche market could be developed that was prepared to pay, say, 25% more than the average price for the past three years, then this would contribute greatly to enhancing LBCC viability (more on this in the next chapter). Similarly, if system capital costs decline as technology is refined, then this would also enhance viability. These are both factors that industry can influence through marketing and research and development. A return to a stronger U.S. dollar – a factor over which industry has no control – would also improve viability.

4

LBCC considerations and policy implications

1. Life cycle assessment

What life cycle assessment means

Life cycle assessment (LCA) is an international standardized method (ISO 14044:2006) for quantifying the global and regional environmental impacts of a product or process. It encompasses the assessment of all actions and industrial processes required to produce, distribute and use a product. In the case of Atlantic salmon, this includes the material and energy demands arising from inputs into the construction and operation of production systems (including waste), production of feed, transportation of inputs and outputs (feed and salmon), and consumption of the product.

Central to LCA is the specification of local and global environmental indicators by which impacts can be measured and compared. These indicators could include:

- **Global warming potential (GWP)**, expressed in kg CO_2 (equivalent), measuring the impact of the greenhouse effect of emissions of such gases as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
- **Cumulative energy demand (CED)**, expressed in MJ, measuring energy from all sources used in the system (fuel oil, coal, gasoline).
- **Net primary product use (NPP)**, expressed in kg of carbon (C), measuring the use of biotic resources as inputs into the system (fish meal and oil in salmon feed).
- **Eutrophication potential (EUT),** expressed in kg PO_4 (equivalent), measuring the ecosystem impact of macronutrients such as phosphorus and nitrogen.
- **Acidification potential (ACD)**, expressed in kg SO_2 (equivalent), measuring the ecosystem impact of acidifying compounds such as sulphur dioxide (SO_2), ammonia (NH_3), nitrite (NO_2), nitrogen oxides (NO_x).
- **Human and marine toxicity potential (HTP/MTP)**, expressed in kg 1,4-DB (equivalent), measuring the impact of dichlorobenzene or equivalent volatile chemical compounds entering land and marine environments.
- **Surface use (SU),** expressed in m2, measuring the land or marine area used in the system life cycle.
- **Abiotic depletion (ABD)**, expressed in Sb (equivalent), measuring the impact of extracting of scarce minerals and fossil fuels in comparison to the reference case (Antinomy).

LCA is a data-intensive exercise, conducted systematically. First, it requires the analyst to delimit the boundaries of the system or systems under consideration, and specify what is referred to as the functional unit – the basis for comparing systems – in the case of salmon the functional unit is 1 t of production. This first step also sets out the scope of the analysis: whether a mid-point approach is taken, whereby impact is measured in terms of its potential impact on the environment using selected indicators (above); or whether an end-point approach is taken, whereby the analysis is carried through to quantifying actual damage to the environment.

The second step requires compiling the life cycle data inventory – all the information (primary or secondary data) needed to quantify all the relevant inputs and outputs associated with the production of salmon (expressed on a per tonne basis). The final step is to classify and characterize the results. Classification means grouping the results of the life cycle inventory into categories (e.g., infrastructure inputs such as concrete and steel; operational inputs such as feed and electricity – all on a per tonne basis), while characterization refers to the expression of potential impact on the environment in terms of the selected indicators (e.g., global warming in kg CO_2/t, acidification in kg SO_2/t).

Findings for Atlantic salmon production systems

There are examples of LCA applied to Atlantic salmon production, though most of these focus on conventional net-pen systems. This should not be surprising since the adaptation of LBCC technology for Atlantic salmon is fairly recent, with few systems actually in commercial production. The literature on LCA for other species produced with LBCC systems (Arctic char, sea bass and trout), while limited, is growing, and serves as a useful proxy in this discussion. The results of our review are presented in Appendix 2.

LCA results can vary widely within particular types of salmon production systems (LBCC or net-pen), depending on the specific characteristics a facility – design, performance and location. Analysts should be careful to highlight such characteristics to provide guidance to those wishing to generalize from study results.

2. Geographic location

Key factors

With closed containment technology able to achieve recirculation efficiencies exceeding 99%[12], citing of facilities is not constrained by access to large volumes of water. This means that they do not have to be located in coastal communities or rural areas where water supplies are abundant. They could locate closer to markets, for example, *if* proximity conferred an economic advantage *and all location criteria could be met*.

Economic advantage: The question of economic advantage is an empirical one, meaning that it can be determined only by examining for each potential site each of the factors in the cost equation that is likely to vary with location. These factors include:

[12] The recirculation percentage applies to each cycle of the water through the system. So, a LBCC that recirculates 99.8% of its water effectively loses 0.2% during each cycle. If a full cycle takes one hour, then during a 24-hour period, the system would have to make up 4.8% of its volume. A farm operating with 1,000m^3 of water would have to draw 4.8m^3 each day. This is the equivalent demand of five average households in Canada.

- **Transportation**: lower transportation costs would provide one of the main reasons for locating close to markets, but the trade-off is between lower shipping costs for product and possibly higher costs for feed. Transportation between Nova Scotia and major centres in eastern North America (Montreal, Toronto, Boston, New York) can reduce effective farm-gate salmon prices by $0.30-0.40/kg (by ±5-7%). But these savings could be at least partially offset by higher feed costs; this depends on the source of feed. If shipped from the west coast (Ewos), the cost may be less than paid for this feed by east coast producers (there may be a volume-distance trade-off); if shipped from the east coast (Skretting), the cost is likely to be higher than paid by local producers because of the additional distance. The distance may add $0.10/kg to the feed price (±5%).
- **Distribution**: production facilities in major markets could eliminate the need for local distributors, though this may depend on whether product is mass-marketed or niche-marketed. Seafood is ordinarily sold through distributors in urban markets. This is because distributors handle many products and serve as a one-stop source, thereby reducing search and local transportation costs. But this service comes at a price (usually based on a percentage of the sales value (10-15%). If the urban fish farm markets to niche outlets, it could avoid paying this distribution margin, but the trade-off is incurring its own administration and distribution costs.
- **Cost of land**: land costs in rural/coastal Nova Scotia vary depending on location specifics, but in more remote areas of less interest for cottage owners, prices in the $10-$35,000/ha range can be found. A recent report by commercial real estate firm CB Richard Ellis indicates that the cost of serviced industrial land in large urban centres (Vancouver, Toronto, Calgary, Edmonton, Montreal) continues to rise, with prices exceeding $1.0 million/ha.[13] If a 1,000 t farm requires a minimum of two hectares, this would add as much as $3 million to the capital cost, thereby weakening the economics considerably (increasing capital costs by ±25%).

  Of course, a LBCC facility needn't locate within the urban boundary in order to reduce transportation costs. Both Toronto and Montreal (and other large centres in central Canada) are only short distances from rural communities where land is considerably less expensive and other location criteria can be met. For example, a LBCC tilapia farm (450 t capacity) developed a few km to the west of London, Ontario is expected to produce its first crop later in 2013. It is housed in a re-purposed 7,000 m^2 building that had been used for mushroom composting. This $5 million project received a $1.4 million repayable loan from the federal government and a $415,000 grant under AIMAP.
- **Electricity:** electricity represents the major input cost (after feed). The Hydro Québec comparison of national electricity rates indicates that Nova Scotia has among the highest rates in Canada.[14] A 1,000 t LBCC farm would fall into the General Service Large Power category (at 3kWh/kg, consuming over 3 million kWh) and would pay $0.0900/kWh for energy in Nova Scotia. The respective rates in Montreal and Toronto would be $.0476/kWh and $0.1060/kWh. In Boston and New York they would be $0.1014 and $0.1155/kWh, respectively. So, apart from Montréal, there would be nothing to be gained from an electrical energy perspective by locating in major urban centres.

[13] http://www.canada.com/calgaryherald/news/calgarybusiness/story.html?id=f6653d9a-16ef-4cf3-92eb-896a4ec2d84d
[14] http://www.hydroquebec.com/publications/en/comparison_prices/pdf/comp_2012_en.pdf

- **Property taxes**: property taxes in rural Nova Scotia range from $1.80 to $2.70 per $100 of assessment. By contrast, the industrial rate in Toronto is $3.20/$100 of assessed value[15], and in Montreal, $3.32/$100 of assessed value.[16] For a $12 million facility, the property tax in rural Nova Scotia could be as low as $216,000 compared with $400,000 in Toronto or Montreal.
- **Labour costs:** these would be higher in urban areas, given the competing job opportunities in other industries.
- **Provincial tax rates**: Nova Scotia taxes are among the highest in Canada. A worker at a farm in Nova Scotia with taxable income of $30,000 would pay $2,650 in provincial tax.[17] With the same taxable income in Ontario, the provincial tax would be: $1,515. In Québec, the provincial tax would be $4,800.

Location criteria: a 1,000 t LBCC farm requires just over two hectares of land. Within an urban setting, the most suitable location would be an industrial zone (or rural area outside the city). The proximity to other businesses that may be sensitive to noise or aesthetic considerations may be a constraint. An advantage of an urban location would be the proximity to major roads, transport, airports and markets.

- **Water supply:** while the enclosed nature of LBCC provides isolation from the environment, a key risk to systems is that the quantity and quality of the water supply to the system will be inadequate. During site selection, LBCC developers must consider existing and potential water supply issues including housing and industry development and the potential effects of climate change.
- **Water quality**: municipal suppliers provide a consistent supply of high quality water but often disinfect water with chemicals that can kill stock and the beneficial bacteria in biofilter systems. Groundwater obtained from bores offers a more predictable source of water but is often deoxygenated and can contain elevated levels of harmful metals, particularly iron. Though the need for make-up water is minimal with modern LBCC designs, water quality could require added treatment by the facility to ensure it meets specifications.
- **Effluent disposal:** best practice environmental management requires evaluation of all effluent disposal options including land irrigation, hydroponics and disposal through the mains sewer system.
- **Aesthetic values**: building design and site maintenance should consider the aesthetic values of the area and the planning requirements of the zone in which the facility is located.

Concluding observations

It is not clear that locating in proximity to major urban centres would confer a significant, if any, economic benefit on a LBCC facility. The greatest benefit from proximity to markets would arise from reduced transportation costs, with greater product freshness as a bonus. These revenue gains could be offset to some extent by higher feed costs. Beyond any net gain from transportation, other factors including land costs, energy and

[15] http://www.toronto.ca/taxes/property_tax/tax_rates.htm
[16] http://ville.montreal.qc.ca/portal/page?_pageid=44,14111603&_dad=portal&_schema=PORTAL
[17] http://www.cra-arc.gc.ca/tx/ndvdls/fq/txrts-eng.html

municipal taxes could contribute to significantly higher capital and operating costs. Land costs would be less in rural areas outside the cities, but still more expensive than in much of rural Nova Scotia.

3. Marketability

What marketability means

In the absence of actual production and pricing data, evidence of any enhanced marketability of LBCC Atlantic salmon is not available. Nonetheless, the experience with LBCC production of other species, as well as with eco-labeling, does provide some insight into how markets may respond to an alternative to ocean net-pen salmon.

Two dimensions of marketability are explored here: market access and premium pricing.

- **Market access** simply refers to the ability to place products in major retail chains or restaurants; access in some markets (notably the EU, U.S. and Canada) is becoming increasingly difficult for seafood that does not carry an eco-label (e.g., MSC) certifying that the species is the product of a sustainably managed fishery. Aquaculture had lagged the capture fisheries in the creation of independent certifying bodies and standards, but today has several certifying bodies.
- **Premium pricing** refers to the ability of a product to attract a premium price by virtue of its sustainable management/production credentials, which could include third-party certification. The price premium would be measured against prices for the same or comparable species that lack sustainable certification.

Marketability is mainly about access

The evidence indicates that the main advantage gained through eco-certification is market access. The Marine Stewardship Council (MSC) is the leading certifier. Since its inception in 1997, MSC has certified 200 capture fisheries worldwide (including 24 in Canada), with another 103 in assessment as of April 2013.[18] Over 18,000 products display the MSC eco-label.

Environmental NGOs provided the initial impetus for eco-certification, and continue to influence its growth and development. Working with commercial partners – the fishing industry and retail grocery chains – NGOs (including MSC) have been successful in building awareness of the unsustainability of fishing practices and the need for effective fisheries management.

While NGOs continue to advance the sustainability agenda, evidence indicates that it is corporate rather than consumer demand that is behind the drive to obtain seafood products from sustainable sources.[19] This is an important difference. Corporate demand arises from two considerations: the possibility of short-term gain in market share

[18] http://www.msc.org/business-support

[19] Roheim, C.A., and Sutinen, J. (2006) *Trade and Marketplace Measures to Promote Sustainable Fishing Practices*, ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 3, International Centre for Trade and Sustainable Development and the High Seas Task Force, Geneva, Switzerland.

by retailers cloaking themselves in a "green" mantle to attract consumers; and, the very real need to support sustainable practices to ensure the long-term supply of fish to meet customer needs. Corporate demand does not necessarily provide a basis for a price premium, but displaying corporate social responsibility (CSR) does contribute to profitability.

Seen in this light, corporate demand is really about access – large retail chains becoming the gatekeepers for access to the market. In recent years, several major retail chains (e.g., Whole Foods, Walmart, Safeway) have positioned themselves squarely within the sustainable seafood camp. They have done this through public commitments to carry wild-caught products only if they are third-party eco-certified (e.g., MSC) or have an equivalent rating from a recognized organization such as Monterey Bay Aquarium or Blue Ocean Institute.

Standards are also being applied to farmed fish, though, as noted above, an equivalent to MSC and generally accepted standards have yet to emerge. Several third-party certification schemes currently exist with others entering the field, though opinion varies about their value to businesses and consumers as reliable guides to sustainable practices. In its review of these schemes, the Coastal Alliance for Aquaculture Reform (CARR) notes that not all certifications have the same degree of credibility, offer valid assurances of sustainability, or require the same rigour for standards development and implementation.[20]

Setting aside the relative merits of the various certification schemes, the underlying issues are whether they are an effective means for businesses and consumers to assess sustainability practices; whether and how this information helps inform purchasing decisions; and, most importantly for this study, whether consumers are willing to pay more for a product that is sustainably produced (whether wild-caught or farmed).

Limited evidence of a price premium

A review of the literature indicates there is some direct evidence that eco-certification labels provide a basis for a price premium for seafood products, but that almost all studies on the subject have been based on consumer surveys (hypothetical demand), rather than actual spending data, due in large part to the challenge of obtaining sufficient price data from retailers. Among the findings:

- U.K. retailers are achieving a price premium of 14%, and achieving higher sales, for products bearing the MSC eco-label, compared with their non-labelled equivalents. The products in question are derived from Alaska Pollock. This finding, reported in a peer-reviewed journal, represents statistically rigorous evidence that U.K. consumers value the environmental attributes of MSC-labelled products and are prepared to pay a premium for them. What the study did not address was whether the higher price at the retail level is reflected in higher producer prices that would compensate harvesters for the costs they incur in meeting the certification standard.[21]

---

[20] Coastal Alliance for Aquaculture Reform, 2011, A Resource Guide to Farmed Salmon Certifications

[21] Roheim, C., F. Asche and J. Insignares. 2011. *The Elusive Price Premium for Ecolabeled Products: Evidence from Seafood in the UK Market,* Journal of Agricultural Economics, forthcoming.

- Consumers in the U.S. and Norway showed a preference for eco-labelled seafood when presented with choices of eco-labelled and non-eco-labelled products of the same species, but only as long as the price premiums are not large.[22] Another study found that consumers consider overfishing so important that they consider changing the species they buy, but are unwilling to switch to a less favoured species solely because it has an eco-label. One German company learned this the hard way when they switched from uncertified cod and haddock to higher cost certified hoki and tried to pass on the cost in the form of a 10% price increase, assuming that consumers (in environmentally conscious Germany) would be willing to pay a price premium for sustainable seafood products. They weren't. The company's market share dropped by 50%.[23] The consensus within the seafood industry is that a critical mass of species/products carrying the MSC logo (or that of another well-respected certifier) is needed in order to attract the attention of consumers. This is critical to obtaining consumers' attention, interest and willingness to buy.[24]
- To work around the absence of direct information on market impacts of eco-labeling, one study (in 2009) took an indirect approach and looked at the price premiums for organic foods and suggested that these premiums could be indicative of the upper bound on eco-labelled seafood. The authors argued this was a relevant comparison because consumers are familiar with the organic concept (pro environment and health) and the products, and organic produce is widely available (whereas eco-labeled seafood is just beginning to enter the market). Organic foods comprised about 2.5% of retail food sales in the U.S. in 2006, up from just 1.9% in 1997. Across the full range of dairy products and crops covered in 11 studies reviewed, price premiums tended to range from 20 to 100%, with premiums exceeding 200% in the case of organic eggs.[25]
- Another study examined the market for wood products, trying to determine whether those with an eco-label attracted a price premium, and if so, what this might imply for eco-labelled seafood. The results indicate that even after 20 years of forest products eco-certification there is "…little to document the existence of actual price premiums…although there is some evidence of consumers' willingness to pay a price premium, the evidence is not overwhelming". Some argue the lack of development of a market for eco-certified wood products is due to poor advertising and limited consumer education.[26] So, better market strategies are needed in order to provide the basis for a price premium. This conclusion would also apply to seafood where there are strong indications of limited consumer awareness of eco-labels on the one hand, and confusion over a proliferation of labels on the other.

[22] Johnston et al. (2001) *Measuring Consumer Preference for Ecolabeled seafood: An International Comparison*, Journal of Agricultural and Resource Economics 26(1): 20-39
[23] Goodman and Porritt, 2006, as reported in Roheim and Sutinen, *op cit.*
[24] Roheim and Sutinen, *op.cit.*
[25] Roheim, C.A. and D'Silva, R. 2009, Illustration of U.S. Organic Agricultural Produce Price Premiums: Implications for Ecolabeled Seafood Price Premiums, URI Sustainable Seafood Initiative.
[26] Seara, T and Roheim, C.A. 2009, The market for certified wood products: What can the seafood sector learn from the applied research? URI Sustainable Seafood Initiative.

To conclude, the need for producers to demonstrate seafood sustainability is driven primarily by considerations of market access. Whether CSR or long-term profitability – or both – provide the impetus, the result is the same: corporations, because of their size and power, have become the gatekeepers to the market. There is as yet limited evidence that consumer demand plays a sufficiently large role that it would be reflected in a willingness to pay a price premium for sustainably caught or farmed seafood. Such premiums may exist for some species in some markets, but empirical evidence is scant.

The need for consumer awareness

A lack of consumer awareness may be part of the reason for the absence of price premiums. Few consumers seem to be aware of eco-labels and what they represent. This is due to poor marketing; the thrust of NGO efforts have been aimed mainly at trying to influence business (retailers and restaurants), not consumers. But even if consumers were aware, there is still the question of whether this would translate into a willingness to pay for perceived environmental (and health) benefits.

Some researchers have suggested that the market for organic products serves as a useful analog for sustainable seafood. Consumers are willing to pay a premium for organic products because of perceived health attributes, and also because organic methods are relatively benign from an environmental perspective. An understanding that organic farmers need to be compensated for generally higher production costs contributes to willingness to pay (and the higher prices do trickle down to producers).

While there is certainly some merit in the organic example, it is not clear that the analogy holds completely. One obvious shortcoming lies in consumer awareness: it is currently much higher with organic products than eco-labelled seafood. But this is a shortcoming that can be overcome over time with consumer education.

The more significant issue arises from the difference in the source of demand for the products: organic is consumer driven, while certified seafood is largely corporate driven. Organic produce sits side by side with its non-organic equivalents. The consumer has the choice of paying more for products that meet organic standards (free from pesticides, herbicides, growth hormones, theraputants, etc.), or paying less and accepting the health and environmental risks associated with non-organic production practices. But the many of the same retail outlets that offer consumers a choice between organic and non-organic produce, are gradually constraining the seafood choice to products that are eco-certified. Consequently, there is no basis for a visible price premium since the consumer has no option. In and of itself, the absence of a price difference is not a bad thing; the key is that prices should be high enough to reward seafood producers for incurring the higher costs of meeting eco-label standards.

A niche market for LBCC salmon?

A final point concerns the prospect of earning a premium price in niche markets. Conceptually, a niche market is defined as one prepared to pay a premium for a product that is somehow differentiated from conventional commodity supply. A niche market turns a price taker (many competitors – commodity product) into a price maker (few competitors – differentiated product). Atlantic salmon mass-produced with ocean net-pens is a perfect example of a commodity product where producers are price takers.

The question is whether Atlantic salmon farmed with LBCC systems could carve out a niche market through product differentiation.

Product differentiation should not be problematic for LBCC salmon since the case would be made that the product is grown in an environmentally friendly system that promotes fast growth and efficient feed conversion, eliminates the need for antibiotics and pesticides, prevents escapes and the risk of disease transmission to wild populations, and avoids waste disposal in the marine environment. The target market would be the same as for organic produce: retail stores and restaurants whose customers include health-conscious and environmentally aware consumers.

A major challenge with niche markets is that they can be influenced by both supply and demand changes that undermine the price premium. On the supply side, competitors can enter the market with the same product or close substitutes, thereby eroding the price premium. On the demand side, tastes and preferences may change.

4. Government policy implications

Background

In 2012, the Government of Nova Scotia issued its Aquaculture Strategy "Creating Sustainable Wealth in Rural and Coastal Nova Scotia". The Minister, in his introductory message, stated that the Strategy "…demonstrates our commitment to ensuring aquaculture development is done in a sustainable way".

In its section addressing support for productivity and innovation, the *Strategy* states that government will:

> **Foster innovation and promote the adoption of proven technologies that increase productivity, reduce business costs and minimize the impact of aquaculture on the marine environment.**

Investigating the technical and economic feasibility of closed containment aquaculture systems in a Nova Scotia context represents a first step in meeting this commitment.

In our review of the experience in Nova Scotia and elsewhere in Europe and North America, this report confirms the technical and financial feasibility of LBCC systems that produce high-valued species such as eel, turbot, barramundi, Arctic char, halibut, sea bream and sea bass (the latter four in Nova Scotia). These systems have evolved over the past 30 years and continue to improve in terms of cost efficiency, environmental impact and their capacity to be adapted to new species.

Firm evidence of the financial feasibility of commercial scale LBCC systems for Atlantic salmon is not as robust. The research conducted by the Freshwater Institute in the U.S. provides strong technical evidence that Atlantic salmon can be successfully cultured in a LBCC system, though issues such as early maturation and off-flavour were reported. But this research does not confirm financial feasibility in a commercial context.

A conceptual study modeling a 3,300 t LBCC system based on the research findings does indicate commercial feasibility.[27]

Regrettably, investment in commercial scale Atlantic salmon LBCC systems is relatively recent; too recent to demonstrate feasibility. A Danish project (1,000 t) is expected to produce its first market size fish in late 2013. Government grants approaching 50% of capital costs would certainly help support its on-going viability; whether it would have been financially feasible without this support is not clear. An earlier Chinese project (1,000 t) produced its first salmon in 2011; financial projections anticipated unit production costs consistent with modest profitability, but little is known about actual performance in terms of fish quality or financial return.

Canadian initiatives with LBCC production of Atlantic salmon are also at an early stage. The 470 t facility developed by the 'Namgis First Nation produced its first salmon in April 2014. This is a pilot project intended to demonstrate feasibility at a commercial scale. Much of the capital was provided by outside interests including NGOs and government. The Sustainable Blue LBCC farm in Nova Scotia that had produced sea bream and sea bass successfully is being converted to Atlantic salmon.

Policy support

Policy or regulatory support for LBCC, particularly as it pertains to Atlantic salmon, would flow from a demonstration that this approach to farming is technically feasible and environmentally sustainable – capable of making a positive contribution to rural social and economic objectives, including community stability. A review of the limited LCA literature suggests that well-designed and managed LBCC systems should find support amongst environmentalists and not face social license concerns.

This policy support may be found in Nova Scotia's JobsHere and Aquaculture Strategies. One of the thrusts of JobsHere is to help workers in traditional industries learn new skills and technologies, specifically with a view to strengthening rural and coastal communities. The Aquaculture strategy ties this into opportunities in aquaculture, whether in finfish farms, value-added processing, or land-based aquaculture.

Nova Scotia currently benefits from land-based aquaculture activities, including both hatcheries and grow-out facilities. They provide employment and income in precisely the locations targeted by these Strategies – rural and coastal communities (the facilities in Advocate, Millbrook, Clarks Harbour, Woods Harbour and Centre Burlington underscore this point). And further, LBCC facilities, if well designed and operated, respond to a growing market demand for seafood that is produced sustainably – without damaging the environment. This not only allows LBCC-produced fish access to markets that is denied to seafood that does not meet certification standards, but it can result in a price premium in certain circumstances.

In our view, LBCC technology for Atlantic salmon falls squarely within Nova Scotia Government economic development and environmental sustainability policy objectives. For this reason, it is worthy of support. What form that support might take goes to the question of the financial feasibility of Atlantic salmon LBCC systems.

[27] In their 2012 report, *Concept design and cost for a commercial scale land based salmon farm*, the Conservation Fund (Freshwater Institute) estimated a capital cost of just over $30 million for a 3,300 t farm.

Government financial support

LBCC systems designed to grow Atlantic salmon are at an early stage of development. While the technical viability of these systems has been demonstrated at a pilot scale, their financial viability at a commercial scale awaits confirmation. Experience indicates that much depends on the density at which salmon can be grown and avoiding the problem of grilsing. Results from two commercial operations could come as early as 2014 as the 'Namgis and Danish projects begin to harvest their first Atlantic salmon crops. Of course, a first crop does not necessarily provide a definitive test of financial viability, since operating adjustments are likely to be needed to optimize system performance.

A Nova Scotia company (Sustainable Blue) began in early 2013 to convert its established LBCC facility from producing sea bass to Atlantic salmon. The company is confident that minimum stocking densities of 50kg/m3 can be achieved. This venture has generated considerable interest, given the company's success with other species. Also, shifting production to what is essentially a commodity will provide valuable guidance on whether LBCC farmed Atlantic salmon can be positioned as a niche product (and command a price premium) because of its "organic" characteristics.

Beyond these projects, various models point to the financial feasibility of LBCC Atlantic salmon farming. These results are based on estimates of capital (equipment and construction) and operating costs (cost overruns are not unheard of), as well as specified operating parameters that are believed to be achievable at commercial scale including stocking density, growth rate, feed conversion and mortality. These models indicate financial feasibility is possible provided scale economies are achieved – this generally refers to systems at or above 2,500 t.[28]

The Government of Nova Scotia has provided financial support to aquaculture projects in the past, including ones involving LBCC technology. Some of these projects would have been characterized as developmental – or even experimental – at the time, where both technical and financial feasibility were uncertain. By comparison, current LBCC systems for Atlantic salmon would be considered more advanced technologically, though some uncertainty about financially feasibility remains, particularly with respect to smaller capacity systems.

From a policy standpoint, then, if government wishes to support LBCC Atlantic salmon it must decide whether it wishes to engage at the current developmental stage, and/or only when financial feasibility has been demonstrated. A second question concerns the form and extent of any assistance: loan, grant or tax credit.

- The risk for government in providing financial support at the developmental stage is that there is little to ground the technology and its eventual commercial expansion in Nova Scotia. The province could be investing in local technology development, but seeing the rewards in terms of economic impact reaped

[28] The model results in Chapter 3 show a modest return on investment at 1,000 t, with a more attractive result at 2,500 t. By contrast, in his 2010 report, *Technologies for viable aquaculture: An examination of land-based closed containment aquaculture*, Andrew Wright contends that facilities at a scale of 100 t with capital costs of $1.3 million could be feasible on the west coast. This cost estimate seems low, particularly for the east coast (harsher climate) and it is not clear that it contains all the relevant cost items (e.g., engineering and construction management).

elsewhere. The Freshwater Institute in the U.S. has demonstrated that it is possible to grow salmon to market size in freshwater systems. While saltwater may be a preferred medium, the ability to use freshwater means that systems can be located close to markets in urban centres and away from the coasts (LBCC proponents argue that even saltwater systems could be located inland because water chemistry can be modified to meet conditions optimal for salmon).

- Once financial feasibility is established, the rationale for government support may be found in reducing the daunting challenge the aquaculture industry faces in securing capital, and also in helping to offset risk. In the past, federal funding has been available through the Aquaculture Innovation and Market Access Program, while the province has provided loans and grants. The rationale for these forms of assistance – access to capital and reducing risk – is as strong, or possibly stronger, for LBCC systems for Atlantic salmon. This is because of the size of the required investment – upwards of $12 million for a 1,000 t farm, the minimum scale considered financially viable.

5

Concluding observations

Overview

Land-based closed containment technology is a well-established method for producing a wide range of saltwater and freshwater fish species including sea bass, sea bream, Coho salmon, sturgeon, trout, halibut, barramundi, turbot and Arctic char. Economics provided the main impetus behind the adoption of this technology. Central to the economic rationale were relatively high prices for the species in question, coupled with LBCC systems' ability to control production parameters and reduce risk.

The production of Atlantic salmon in LBCC systems is at a relatively early stage of development. Technical feasibility has been demonstrated, though some issues remain to be fully resolved. Financial feasibility remains to be confirmed by actual performance of commercial scale facilities. The general impetus behind the interest in the potential of LBCC technology for Atlantic salmon arises mainly out of concern for threats to the marine environment from conventional marine-based systems.

- **Technical feasibility**: research projects have confirmed the ability to meet key production parameters needed to grow Atlantic salmon, though production is not routine as it is with other species. Further work is needed to determine optimal density and to resolve issues concerning early maturation of males (resulting in slow growth) and "off-flavour" in fish.
- **Financial feasibility**: the analysis concludes systems producing Atlantic salmon with capacities ranging from 250 to 1,000 t are not viable given the cost and price assumptions set out in this report. Conceptual models point to financial feasibility at certain production capacities, financial feasibility cannot be confirmed until demonstrated under actual operating conditions through a few growth cycles. Among the key factors affecting financial feasibility are density, growth rate, feed conversion, mortality and price.

LBCC systems operate at an economic disadvantage because much of their cost goes toward creating growing conditions occurring naturally within the ocean, including the chemical properties and temperature of ocean water, as well as current and tidal action that provide waste dispersion services. As the findings of this report make clear, two factors are central to the challenge of overcoming any cost disadvantage: economies of scale and market.

The findings of this report as they pertain to the feasibility of LBCC systems for Atlantic salmon are based on a financial model adapted to Nova Scotia operating conditions. The model incorporates accepted design parameters and operating assumptions, and uses up-to-date capital and operating costs. Nonetheless, the reader is cautioned that some assumptions have yet to be confirmed in actual commercial operating conditions, particularly in larger scale systems.

Main findings

- **LBCC is a well-established technology**: Several hundred LBCC systems of various designs and scales operate globally, including in North America. The technology is well advanced and constantly improving in terms of its applicability, reliability and efficiency. Industry development is marked by the diversity of species cultured, the growth in the number of companies offering design and construction services, and the increasing number of countries and regions (rural and urban) where land-based systems are located.
- **LBCC systems operate in Nova Scotia**: Within Nova Scotia, companies using LBCC systems produce Arctic char, trout, halibut (juveniles and adults) and Atlantic salmon smolt. And significantly, a company that had successfully produced sea bream and sea bass for several years began converting its facility to Atlantic salmon in early 2013, with a planned initial production of 100 t.
- **Practical experience with LBCC systems producing Atlantic salmon is limited**: Actual experience to date with commercial scale LBCC systems for producing Atlantic salmon provides a limited basis for assessing technical and commercial feasibility. The Freshwater Institute in the U.S. has conducted a grow-out trial, producing Atlantic salmon to market weight. Elsewhere, three commercial scale projects ranging in capacity from 100 to 1,000 t began production in 2012-13, with results expected in 2014.
- **Viability of LBCC for Atlantic salmon depends on scale**: Model results indicate that LBCC systems for Atlantic salmon have the potential to be financially viable, provided scale economies are achieved and all performance parameters are met. Systems do not approach commercial viability until capacities exceeding 2,500 t are reached. Systems below this scale are unlikely to achieve commercially viability because of the relatively high unit costs attributable to engineering, building, labour and energy use. Prevailing salmon prices are not high enough to cover capital and operating costs at smaller scales.
- **Life-cycle analysis (LCA) results for LBCC systems**: A review of the limited literature indicates LCA results are project-specific. Modern, well-designed systems with low energy use generated from renewable sources compare favourably with net-pen systems across conventional impact indicators. Nova Scotia continues to rely heavily on non-renewable sources of energy, though through its aggressive renewable energy policy is greatly reducing this dependence.
- **Locating LBCC systems close to markets may not confer an advantage**: With closed containment technology able to achieve recirculation efficiencies exceeding 99%, citing of facilities is not constrained by access to large volumes of water. This means that they do not have to be located in coastal communities or rural areas where water supplies (salt or fresh) are abundant. A review of relative cost factors and technical location criteria indicates that it is not clear that locating a facility in proximity to major urban centres would confer a significant, if any, economic benefit. Beyond any net gain from transportation (product vs. feed), other factors including land costs, energy and municipal taxes could contribute to significantly higher capital and operating costs.

- **LBCC salmon may attract a premium price, but sustainability is mainly about market access**: Empirical analysis of the impact of eco-certification of seafood products indicates that it facilitates market access, but does not necessarily provide a basis for a price premium. LBCC operators may be able to carve out a niche market for Atlantic salmon (as operators have done with other species), but competitors can enter the market with the same product or close substitutes, thereby eroding the price premium. On the demand side, tastes and preferences may change.
- **Government support**: The Government of Nova Scotia has provided financial support to aquaculture projects in the past, including ones involving LBCC technology. Some of these projects would have been characterized as developmental – or even experimental – at the time, where both technical and financial feasibility were uncertain. The risk for government in providing financial support at the developmental stage is that there is little to ground the technology and its eventual commercial expansion in Nova Scotia. The province could be investing in local technology development, but seeing the rewards in terms of economic impact reaped elsewhere.

Appendix 1: System elements included in capital cost estimates

Technology Component	Mechanical / Husbandry Risk	%Capital Expense	Operating Costs	Type/Manufacturer
Pre-construction				
Land	Zero	*10%*	Zero	Rural (see location discussion)
Site works (power & water)	Zero	*1%*	Zero	Major works not included (e.g. roads)
Design & engineering	Zero	*3%*	Zero	Various
Building with office	Zero	*14%*	Zero	Insulated / various options
Containment				
Tanks	Zero	*6%*	Zero	Octaform
Raceways	Zero	*<1%*	Zero	Estimate
Fluid Mechanics				
Pumps	Low / Zero Redundant pumps	*7%*	High	31 HP, AOC
Blowers	Low Redundant blowers	*<1%*	High	Aquatic Eco-Systems
Oxygenation				
On-site oxygen generation	Low / Zero Redundant generators	*8%*	Low	Energy Efficient O2 generator, PRAqua
Oxygen injection cones	Low / Zero	*1%*	Zero	PRAqua
Low head oxygenators	Low / Zero	*1%*	Zero	PRAqua
H_20 Sterilization				
UV	Low / Zero	*1%*	Low/Zero	PRAqua
Ozone generation	Low	*1%*	Low / Zero	Azco Industries
Ammonia Removal Bio-filters				
Filter	Low	*<1%*	Low	Floating bead, PRAqua
Rotating contactors	Low	*<1%*	Low	PRAqua
Fluidized bed	Low	*<1%*	Low / Moderate	PRAqua
CO_2 Removal				
Packed degassing columns	Low / Zero	*5%*	Low / Moderate	PRAqua
Unpacked degassing columns	Low / Zero	*5%*	Low / Moderate	PRAqua
Solids Removal				
Separators	Low / Zero	*1%*	Zero	AquaOptima
Drum filters and settling basins	Low: dual redundant filters used	*1%*	Low	21 or 54 micron filter screen, PRAqua
Biofilter media	Low / Zero	*4%*	Very low	Kaldnes
Settling tanks	Low / Zero	*2%*	Zero	Octaform
Misc.				
Robotic feed systems	Low	*1%*	Low	AKVA
Feed storage	Low	*<1%*	Low	AKVA
Fork Lift	Low	*<1%*	Low	Yale model GLC050
Computer control and H2O quality monitoring	Low	*3%*	Low / Zero	Feeders, graders, fish pumps, monitoring systems, JLH
Water piping / valves	Low / Zero	*Moderate*	Zero	Zero
Boiler and heat exchanger	Low	*1%*	Moderate	Raypack, SEC Heat Exchangers
Back-up power generators	Low / Zero with Redundancy	*<1%*	Zero	1200KW generator
Contingency	None	*20%*	None	Estimate for all capital

Adapted from: Wright and Arianpoo (2010); Gary Myers (2013)

Appendix 2: Review of Life Cycle Analysis

Ayer and Tyedmers (2009)[29]:

This paper reports on the results of a LCA quantifying and comparing the potential environmental impacts of culturing salmonids (Atlantic salmon) in a conventional net-pen system with alternative systems including LBCC for Arctic char. The net-pen system used in the assessment is based on a typical British Columbia farm, while the LBCC system is the Millbrook Arctic char facility in Truro.

Confining our attention to conventional net-pen and LBCC, the main findings with respect to life cycle inventory are:

- Material inputs/t of output for system infrastructure were much higher for LBCC than net-pen, despite substantially higher culture density with LBCC.
- Feed requirements were higher for LBCC than net-pen because of substantially higher mortality during grow-out with LBCC.
- Energy requirements (on-site) were much higher with LBCC than net-pen mainly because of the electrical demand to drive water pumps, oxygen and ozone generators, CO_2 strippers and monitoring systems.
- Direct emissions to water were substantially higher with the net-pen system than LBCC, with emissions from the latter discharged into the municipal sewage system.

In terms of life cycle impacts, the main finding is:

- The LBCC system contributed to substantially higher life cycle contributions in six of the seven environmental impact categories selected for analysis (ABD, GWP, HTP, MTP, ACD, CED). Eutrophication potential was the exception because of the treatment nutrients in wastewater rather than deposition into the marine environment.

In determining the contributing factors to the potential environmental impacts, the findings are:

- In the net-pen system, the salmon feed production accounted for over 85% of the impacts in five of the seven impact categories.
- In the LBCC system, the production of electricity required to operate the system accounted for over 80% of the impacts in all seven categories, with feed production a distant second. The authors note that this result is heavily influenced by heavily reliance on coal to generate electricity in Nova Scotia.

The authors draw three main conclusions from their assessment:

- The LBCC system had the poorest environmental performance by a considerable margin, resulting mostly from the substantially higher energy use. This affects primarily acidification, global warming and abiotic depletion.

[29] Ayer, N.W., Tyedmers, P.H., 2009. Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture in Canada. J Cleaner Prod. 17, 362-373.

- A shift in production mode from conventional net-pen farming to LBCC will result in a substantial increase in material inputs and energy use for every tonne of fish produced.
- The implementation of LBCC salmon farming would appear to represent a classic case of environmental problem shifting because they use industrial energy-driven technological services to simulate natural conditions to rear the fish.
- While a shift to LBCC technologies may reduce proximate environmental impacts typically associated with salmon farming, they may contribute to several other environmental impacts of global concern.

Consultant's comment: Ayer and Tyedmers make a valuable contribution to the literature by setting out a practical framework for the conduct of LCA as it applies to Atlantic salmon farming. This work will serve as a useful template for future assessments.

Our concern with the findings as they pertain to LBCC is that they flow from the experience of a single facility; one that was poorly designed and managed at the time the data for the assessment were compiled. The life cycle inventory indicates the LBCC system was operating at about 37% capacity, with mortalities of 30% (compared with 9% for net-pen).

A reader not informed about the particular circumstances of this facility could make the mistake of generalizing these results to all LBCC systems. Not surprisingly, this low capacity utilization and high mortality level would result in the extremely high energy inputs (22,600 kWh/t) reported (Table 2). The current operator indicates the system functions at full capacity (about 125 t), with mortalities <1%.[30] Energy usage was not available at the time of the discussion, but even adjusting the kWh/t reported in the paper to the current production would reduce the energy inputs to 8,350 kWh/t. It would also reduce the feed impact from the 1,448 kg/t reported to less than 1,100 kg/t (indicated by the operator).

Martins et al (2010)[31]

This paper summarizes the most recent developments within RAS that have contributed to the environmental sustainability of the European aquaculture sector (this paper does not address Atlantic salmon). The life cycle analysis shows that feed, fish production and waste and energy are the main components explaining the ecological impact of RAS. Ongoing developments in RAS show two trends focusing on 1) technical improvements within the recirculating loop and 2) the recycling of nutrients through integrated farming. More specifically:

[30] Dr. Jeremy Lee, pers com, March 21, 2013.
[31] Martins, C.I.M. et al. 2010. New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Journal of Aquaculture Engineering, Vol. 43, Issue 3, 83-93

- Within the recirculating loop: the introduction of denitrification reactors, sludge thickening technologies and the use of ozone result in reduced water use, decrease in waste discharge and lower energy use. In addition, discharged waste is more concentrated, facilitating re-use as fertilizer. Ozone improves microscreen filter performance and water quality, but in marine systems ozone by-products (e.g., bromate) can be toxic and impair fish health.
- The recycling of nutrients through integrated farming (e.g., though the use of natural or constructed wetlands), though practiced for many years in Europe, is still very much in the experimental stage. The authors note that all processes managed in RAS reactors also occur in ponds (e.g., sedimentation, denitrification, phosphate precipitation, anaerobic decomposition), and that by compartmentalizing some of these processes in ponds the total production capacity of the system is increased.

The paper concludes by setting out priorities for research to improve energy efficiency and operating costs. This is becoming increasingly important as the industry faces pressure to improve system closure to reduce water use. The main priorities would appear to lie in technology for: handling solid wastes, particularly fine solids removal, taking into consideration tank design, solids removal system, hydraulic conditions and use of ozone; removing nitrogen, including improved feed performance and denitrification systems using internal RAS sludge as a carbon source; controlling phosphate levels.

Consultant's comment: this paper provides a useful summary of technical developments in closed containment systems and how these influence life cycle impacts. It does not address Atlantic salmon, and does not compare LBCC and net-pen systems.

Wright (2011)[32]

This paper squarely addresses the criticism that LBCC systems are not desirable because of their relatively large GHG footprint. The author assesses GHG emissions by modeling LBCC and net-pen systems in British Columbia from feed supply to final harvest and processing (not the full life cycle). The main conclusions are:

- Total GHG emissions from open net-pens are 5 to 10 times higher than they would be for a modern LBCC system based in British Columbia.
- The main reason for the lower GHG emissions in this analysis is the use of electricity generated from hydro sources (low fossil fuel use).

The systems modeled for this analysis produce 2,000 t:

- An open net-pen farm in the Broughton Archipelago (an isolated region north of Vancouver Island). Fuel is consumed by: feed delivery tug/barge (from Vancouver through Johnston Strait to the farm site); on-site to run diesel generators; by boats used to change out crews and deliver supplies; and harvest vessels that deliver to a processing pant in Port Hardy on Vancouver Island.

[32] Wright, A.S., Salmon Aquaculture GHG Emissions: A preliminary comparison of land-based closed containment and open ocean net-pen aquaculture. SOS Marine Conservation Foundation, 2011.

- A LBCC assumed to be located near a processing plant in the Port Hardy area. Fuel is consumed by: trucks delivering feed from Vancouver (via ferry and road); farm is based on modern design using <3 kWh/kg; trucks to deliver harvest fish to the adjacent processing plant.

The analysis works through the GHG emissions (tonnes CO_2) for each of the system components. GHG emissions attributable to the respective systems:

- Open ocean net-pen farm: CO_2: 8,054 t or 970 t (4,027 kg CO_2/t or 485 kg CO_2/t of fish), depending on whether methane is included. Methane is produced anaerobically in the marine environment from the solid waste-stream.
- LBCC: CO_2: 766 t (or 383 kg CO_2/t of fish).

Consultant's comment: The author states in his conclusions that this study was conducted as a response to "existing peer-reviewed analysis in the context of British Columbia operations". This is presumably the paper by Ayer and Tyedmers (though he does not refer to that paper specifically). In contrast with Ayer and Tyedmers, Wright comes to the conclusion that LBCC is *less* energy-intensive than net-pen systems, and consequently produces far less CO_2 (the LBCC system in Ayer and Tyedmers produces 28,200 kg of CO_2 per tonne of fish, vs 383 kg/t of CO_2 in Wright's system). This does not mean Ayer and Tyedmers were in error in their analysis, but that the LBCC system they used as the basis for the life cycle data fell well below current standards in terms of its energy efficiency. In other words, their analysis and conclusions are unique to that particular operation at that particular time and in that place.

The modern LBCC system Wright uses as the basis for his analysis is considerably more efficient, utilizing <3 kWh/kg, compared with the 22.6 kWh/kg reported in Ayer and Tyedmers. Since energy use is the main contributing factor (over 80%) for most of the impact categories (not just global warming) in the Ayer and Tyedmers assessment, were they to conduct their analysis again basing it on a modern LBCC system, the results would be far less negative. They would still not conform to the Wright results if the LBCC facility were located in Nova Scotia because of the negative impact of coal-fired electrical generation (vs. hydro in British Columbia).

Appendix 3: Minimum scale for viability

Base case and sensitivity at 2,500 t

As mentioned in the report, 2,500 t is currently considered the scale at which LBCC salmon systems begin to become financially viable. Though showing a positive IRR of 5.3% under the given assumptions, this would not be high enough to attract debt financing from conventional lenders, given the risk factors. The following shows the base case results for 2,500 t alongside those for 1,000 t as shown in the report.

Table A3-1: Base case performance profiles by system scale (1,000 vs 2,500 t)

Capacity (t)	1,000	2,500
Financing		
Funds required ($M)[1]	$17.2	$28.0
Unit cap costs ($/kg)	$12.0	$7.6
% Equity	50%	50%
Operating		
Feed price ($/t)[2]	$1,750	$1,750
Electricity price ($/kWh)[3]	$0.11	$0.11
Unit energy use (kWh /kg)	3.13	2.39
Temperature (deg C)	15	15
To market costs ($/kg of fish)[4]	$3.31	$3.10
Revenues		
Target fish weight (kg)[5]	$5.65	$5.65
Market price ($/kg)[6]	$5.72	$5.72
Market revenues ($millions)	$5.41	$13.51
Exchange rate ($1 U.S. =)	$1.05	$1.05
Local economic benefits ($000)		
Pre-operating and construction	$13,560,000	$21,470,000
On-site employee incomes	$396,000	$462,000
Operating expenditures	$4,340,112	$9,181,025
Provincial exports	$4,864,860	$12,162,150
Plant financials		
Payback period (yrs)	>20	12
IRR	Negative	5.3%
Year 5 return on equity	1.7%	20.2%
Year 5 net cash flow ($M)	$0.2	$2.9
Year 5 debt:equity	62%	63%
Year 5 profit margin[7]	3%	21%

Notes: This Model is intended to provide general guidance and a tool for analysis only and is not intended to provide financial advice or to be used as the basis for investment decisions.
1. Includes design, construction, 20% contingency, taxes, and working capital.
2. Feed price reflects weighted average for feed used over production cycle where most feed is consumed at lower prices in the final grow-out stages. Source: feed/aquaculture companies.
3. Current price in Nova Scotia. Source: NSPI and NS aquaculture companies.
4. Includes processing, packaging, shipping, marketing and sales commission.
5. Target is for larger size class than average (e.g. 10-12lb rather than 8-10lb), and market price selected should therefore be higher than the average FOB fresh whole Northeast U.S. farmed prices.
6. Based on three-year average monthly price of Canadian exports to the U.S. Source: Statistics Canada/U.S. NOAA
7. Profit margin represents revenue relative to costs in year 5, and does not suggest capital investments are paid off by that year.

The sensitivity analysis below only addresses positive potential scenarios for key variables since the base case at 2,500 t is considered the starting point for viability.

Table A3-2: Sensitivity analysis – impact on IRR (2,500 mt system)

Variable	Base value	Adjusted value	Adjusted IRR
Exchange ($CAD=)	$0.95 US	- 20% ($0.76 US)	15.5%
Price (3-yr avg.)	$5.72/kg	+25% ($7.15/kg)	15.0%
Capital ($million)	$28.0	- 20% ($22.4)	8.9%
Feed price	$1,750/t	- 20% ($1,400/t)	8.7%
Smolt cost	$2.25	- 20% ($1.80 ea)	6.2%
Electricity price	$0.11/kWh	- 20% ($0.088/kWh)	5.8%
Labour & admin	$30k salary	- 20% ($24k)	5.8%
Mortality	4%	- 50% (2%)	5.5%
Cumulative			36.5%

The base case IRR is 5.3%, and the top three most influential positive scenarios considered here would be: a 20% reduction in the exchange rate (15.5% IRR), a 25% increase in market prices for salmon (15.0% IRR), and a 20% reduction in capital requirements (8.9% IRR).

Bibliography

Ayer, N.W., Tyedmers, P.H., 2009. Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture in Canada. J Cleaner Prod. 17, 362-373.

Badiola, M, Mendiola, D, and Bostock, J., 2012, *Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges.* Aquaculture Engineering 51 (2012) 26-35.

Boulet, D., Struthers, A., Gilbert E., 2010, *Feasibility Study of Closed-Containment Options for the British Columbia Aquaculture Industry*. Innovation & Sector Strategies Aquaculture Management Directorate Fisheries & Oceans Canada. http://www.dfo-mpo.gc.ca/aquaculture/lib-bib/nasapi-inpasa/BC-aquaculture-CB-eng.htm

Bourret, V., et al., 2011, *Temporal change in genetic integrity suggest loss of local adaptation in wild Atlantic salmon (Salmo salar) population following introgression by farmed escapes*. Heredity (2011) 106,500-510.

Burridge, L. E., Hamilton, N., Waddy, S. L., Haya, K., Mercer, S. M., Greenhalgh, R., Tauber, R., ... Endris, R. G. (2004). Acute toxicity of emamectin benzoate (SLICE®) in fish feed to American lobster, *Homarus americanus*. *Aquaculture Research, 35,* 8, 713-722.

Burridge, L.E., Haya, K., Waddy, S.L. (2008). The effect of repeated exposure to azamethiphos on survival and spawning in the American lobster (Homarus americanus). *Ecotoxicology and Environmental Safety, 69*, 411-415.

Coastal Alliance for Aquaculture Reform, 2011, *A Resource Guide to Farmed Salmon Certifications.*

Coastal Alliance for Aquaculture Reform, *Better than the Rest? A Resource Guide to Farmed Salmon Certifications.*

Dalsgaard, J. et al., 2012, *Farming different species RAS in Nordic countries: Current status and future perspectives.* Aquacult. Eng. (2012), http://dx.doi.org/10.1016/j.aquaeng.2012.11.008

Demont, J., 2012, Inland fish farm may signal new wave. Chronicle Herald, August 6, 2012. http://thechronicleherald.ca/novascotia/124757-inland-fish-farm-may-signal-new-wave

Dunning, R.D., et al. 1998, *The Economics of Recirculating Tank Systems: A Spreadsheet for Individual Analysis*. Southern Regional Aquaculture Center Publication No. 456.

Fisheries and Oceans Canada, 2008, *Assessing Potential Technologies for Closed-Containment Saltwater Salmon Aquaculture*.

Food and Agriculture Organization of the United Nations, *Cultured Aquatic Species Information* Programme. Salmo salar (Linnaeus, 1755). Fisheries and Aquaculture Department.

Ford, J.S. et al., 2012, *Proposed Local Ecological Impact Categories and Indicators for Life Cycle Assessment of Aquaculture, A Salmon Aquaculture Case Study*. Journal of Industrial Ecology.

Goodman and Porritt, 2006, as reported in Roheim and Sutinen, *op cit.*

Government of Newfoundland and Labrador, 2008, *Update on Cooke aquaculture Operations in Newfoundland and Labrador.* News Release. http://www.releases.gov.nl.ca/releases/2008/fishaq/0424n07.htm.

Irwin, K., *Sweet Spring Salmon/AquaSeed Corporation: Reconciling Sustainability with Profitability*.

Jackson, A., *Fish in – Fish Out (FIFO) Ratios explained*. International Fishmeal and Fish Oil Organisation.

Jenner, A., 2010, *Recirculating aquaculture systems: The future of fish farming?* The Christian Science Monitor – CSMonitor.com.

Johnston et al. (2001) *Measuring Consumer Preference for Ecolabeled seafood: An International Comparison*, Journal of Agricultural and Resource Economics 26(1): 20-39.

Marine Harvest, 2012, *Salmon Farming Industry Handbook 2012*.

Marine Stewardship Council, 2001, *New study shows UK supermarkets secure price premium for MSC labelled seafood products*. http://www.msc.org/cook-eat-enjoy/news/newsitem/new-study-shows-uk-supermarkets-secure-price-premium-for-msc-labelled-seafood-products.

Martins, C.I.M. et al., 2010, *New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability*. Aquacultural Engineering, November 2010, Volume 43, Issue 3, Pages 83-93.

McGivern, S.M., and Gilbert, T., 2009, *Farmed U.S. Freshwater Coho Salmon Oncorhynchus kisutch*. Seafood Watch.

Morris, M.R.J. et al., *Prevalence and recurrence of escaped farmed Atlantic salmon (Salmo salar) in eastern North American rivers*. Can. J. Fish. Aquat. Sci. 65: 2807-2826 (2008).

Nickum, J. G., *The Miller Hutterite Colony is ramping up production of freshwater coho at a novel new recirc facility in high plains Montana*. High Plains Coho. Aquaculture North America. September/October 2011.

Nova Scotia Economic and Rural Development and Tourism, 2008, *Rural Aquaculture Start-up Will Introduce Mediterranean sea bass.* News Release. http://www.gov.ns.ca/econ/news/nr_view.asp?id=20080623004..

Nova Scotia Economic Development and Tourism, *2010, Province Invests in Rural Aquaculture Company February 4, 2010*. News Release. http://novascotia.ca/news/smr/2010-02-04-aquaculture.asp

Nova Scotia Economic Development and Tourism, 1999, *Halibut Farm to Create 70 Jobs.* News Release.*http://novascotia.ca/news/release/?id=19990623002*

Province of Nova Scotia, *Aquaculture Strategy*, Creating Sustainable Wealth in Rural and Coastal Nova Scotia.

Roheim, C., F. Asche and J. Insignares. 2011. *The Elusive Price Premium for Ecolabeled Products: Evidence from Seafood in the UK Market,* Journal of Agricultural Economics, forthcoming.

Roheim, C.A. and D'Silva, R. 2009, Illustration of U.S. Organic Agricultural Produce Price Premiums: Implications for Ecolabeled Seafood Price Premiums, URI Sustainable Seafood Initiative.

Roheim, C.A., and Sutinen, J. (2006) *Trade and Marketplace Measures to Promote Sustainable Fishing Practices*, ICTSD Natural Resources, International Trade and Sustainable Development Series Issue Paper No. 3, International Centre for Trade and Sustainable Development and the High Seas Task Force, Geneva, Switzerland.

Royal Society of Canada (2012). *Sustaining Canadian marine biodiversity: An expert panel report on sustaining Canadian marine biodiversity: responding to the challenges posed by climate change, fisheries and aquaculture*. Ottawa: Royal Society of Canada.

Seafood Source, 2009, *Cooke to farm cod in Newfoundland*. http://www.seafoodsource.com/newsarticledetail.aspx?id=2716

Seara, T and Roheim, C.A. 2009, The market for certified wood products: What can the seafood sector learn from the applied research? URI Sustainable Seafood Initiative.

Storey, A., 2012, A Third Option: *Using Innovative Canadian Technology to Unlock Further Growth in Canadian Aquaculture Output.* Submitted to standing Committee on Fisheries and Oceans Closed Containment Salmon Aquaculture.

Summerfelt, S., 2012, *Development in Land-Based Closed-Containment System for Fish Production.* Salmon Containment Workshop Halifax, October 13, 2012.

Summerfelt, S., 2012, *Myths Regarding Land-Based Closed-Containment System for Salmon Production.* Salmon Containment Workshop Halifax, October 13, 2012.

Summerfelt, S, et al, *Atlantic Salmon Growout Trials in Freshwater Closed-containment Systems at the Conservation Fund's Freshwater Institute*.

The Coastal Alliance for Aquaculture Reform, *Aquaculture, closed containment technologies and energy consumption.*

The Digby County Courier, 2012, *Province gives millions to Cooke Aquaculture.* http://www.digbycourier.ca/Business/2012-06-22/article-3015075/Province-gives-millions-to-Cooke-Aquaculture/1

The Fish Site, 2009, *Ecolabelling of Fisheries Products: Assessment of its Benefits*. http://www.thefishsite.com/articles/721/ecolabelling-of-fisheries-products-assessment-of-its-benefits.

Thorstad, E. B., Fleming, I. A., McGinnity, P., Soto, D., Wennevik, V., & Whoriskey, F. (2008). Incidence and impacts of escaped farmed Atlantic salmon Salmo salar in nature. *NINA Temahefte 36: 110 pp., 36*.

Vinci, B, *Concept Design and Cost for a Commercial Scale Land Based Salmon Farm*. The Conservation Fund.

Weston, R., 2013, *Closed Containment Salmon Aquaculture*. Report of the Standing Committee on Fisheries and Oceans. 41st Parliament, First Session.

Whitmarsh, D., Palmieri, M.G., Aquaculture in the Coastal Zone: Pressures, Interactions and Externalities, in Holmer, M, et al. (2008). *Aquaculture in the Ecosystem*, Springer.

Wright, A.S., 2011, Salmon Aquaculture GHG Emissions: A preliminary comparison of land-based closed containment and open ocean net-pen aquaculture. SOS Marine Conservation Foundation, 2011.

Wright, A.S., and Arianpoo, N. 2010. *Technologies for Viable Salmon Aquaculture.* An Examination of Land-Based Closed Containment Aquaculture, Draft.

Zaccagna, R, 2012. *Cooke Aquaculture says Nova Scotia expansion makes sense.* http://thechronicleherald.ca/business/109242-cooke-aquaculture-says-nova-scotia-expansion-makes-sense