



THE EVOLUTION OF
LAND BASED ATLANTIC SALMON FARMS



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THE EVOLUTION OF LAND BASED ATLANTIC SALMON FARMS



There have been many conversations about the future of salmon farming, farming technologies and the role that land based facilities could and should play in that future. Some, the NGO community in particular, have been promoting a theory that all salmon farms could be taken out of the ocean and moved to land based tank farms.

To help facilitate the dialogue, the International Salmon Farmers Association has produced this document that reviews available reports from around the world, the current state of knowledge, technology and the challenges that would have

to be overcome before Atlantic salmon could be grown for their entire life cycle in land based facilities. We have also incorporated international industry experience from salmon farmers, who are the experts in land based freshwater farming systems and are successfully using these systems for smolt production and a variety of broodstock programs.

We believe the resulting document: “The Evolution of Land Based Farms for Atlantic Salmon” provides a valuable tool for this discussion.

For our industry, the conversation is about growing healthy, nutritious seafood in an efficient and sustainable manner – both in our oceans and in land based facilities. Both play an important role today and will continue to do so in the future.

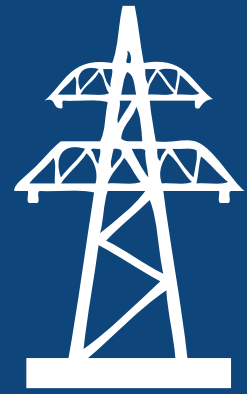
Although land based farming systems continue to evolve, there are still a number of challenges that must be overcome, including the real costs of energy, water and land usage, animal welfare and quality of the final product before all of the world’s commercial production of farmed salmon could move to land.

This report shows that farming Atlantic salmon in their natural environment - the ocean - is the responsible way to farm. Until that changes, we will do what we do best: use the marine and freshwater resources in the most efficient and considered way, in both marine and land based systems, to help feed the world.

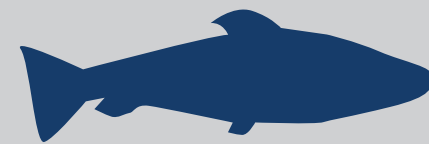
The salmon farming industry understands the value of land based salmon farming as well as its limitations. As such, we will continue to collaborate with researchers, governments and ENGOs to understand the socio-economic and environmental realities of land based fish farming systems, both the opportunities and limitations, to advance the technology and apply it on a case-by-case, species-by-species basis as technology advances.

Trond Davidsen
President ISFA

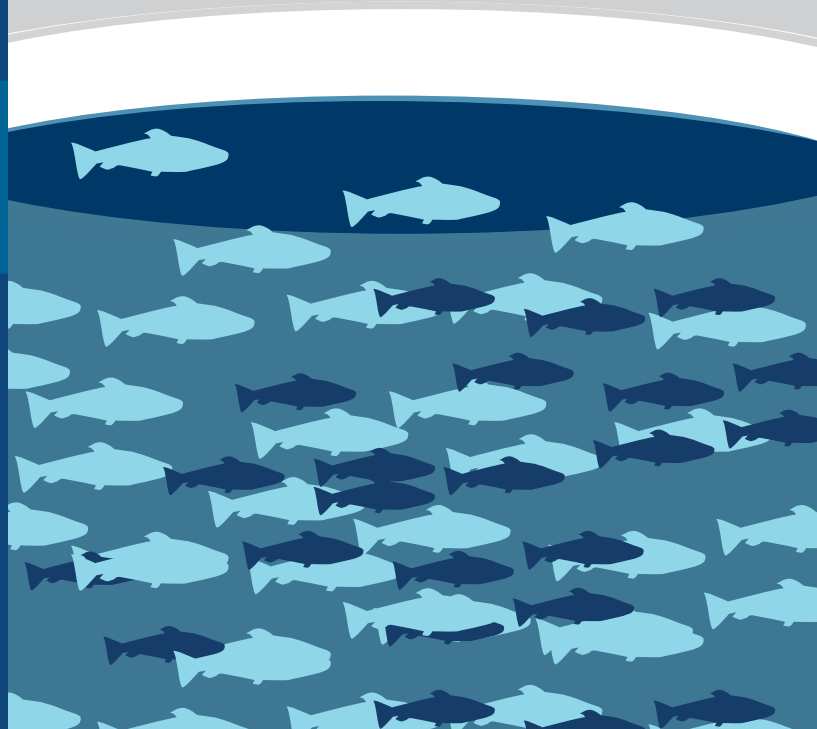
KEY CONSIDERATIONS OF LAND BASED FISH FARMS



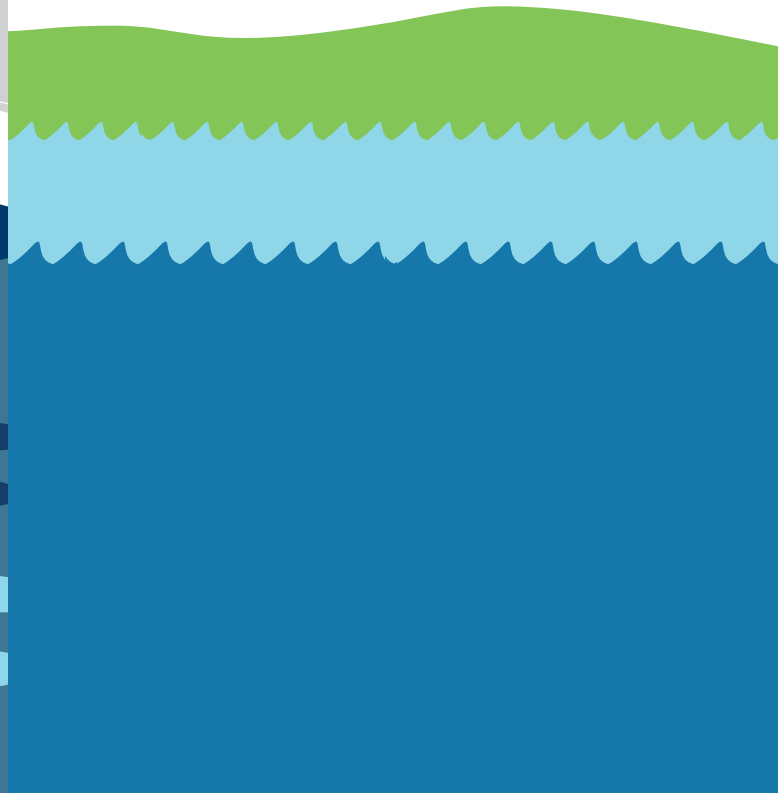
ENERGY



FISH WELFARE



WATER & LAND USE



SOCIO-ECONOMIC REALITIES



EXECUTIVE SUMMARY



Salmon farmers around the world are the experts in land based freshwater farming systems. They have been using and evolving land based systems for more than 40 years, advancing the technology in an environmentally, socially and economically sustainable way. Literally billions of young fish have been hatched and raised on land. To date, the salmon farming industry successfully operates land based facilities for smolt production and a variety of broodstock programs. Experiments to grow salmon for their entire lives in freshwater land systems as well as ambitious projects addressing the question of recirculating saltwater have also been pursued for niche market, small-scale commercial production facilities.

Although land based farming systems continue to evolve, there are still a number of challenges that must be overcome, especially if, as some would advocate, we were to consider moving all post smolt marine based salmon farms onto land. These challenges include the real costs of energy, water and land usage, and considerations around animal welfare, not to mention the quality and acceptance of the product (and its inevitably high retail price) by the final consumer.

The salmon aquaculture industry continues to invest in technological improvements to land based salmon farming systems, recognizing that it is a proven technology and that it has a valuable role to play in the freshwater part of the life cycle of the salmon. However, the evidence provided to date strongly recommends that, at this time, land based fish farming systems are best suited to the early grow out phase of Atlantic salmon and not the best alternative for the commercial production of the entire grow-out of the species to meet the global food demands.

“The importance of aquaculture as an industry in the world, its growing weight in food security and growth potential are a reality” -

***Fernando Garcia,
General Manager of the Mexican-based
aquaculture company Sea Farmers***

INTRODUCTION

Land based freshwater fish farming is a genuinely good option for the production of egg to plate output for a number of species including tilapia and trout. Economics and production control have been the main rationale for the development and adoption of this technology in most species. Globally, the Atlantic salmon farming industry has used this rationale in adopting recirculating aquaculture systems (RAS) in the early (freshwater) life stages of salmon (Gardner Pinfold, 2014).

Extending the use of land based recirculation to provide an environment for the growth of salmon to market size is a different challenge. As of 2007, over 40 trials with an initial capital investment estimated at more than \$283 million, had been conducted on closed containment technology for the production of adult Atlantic salmon around the world (Canadian Science Advisory Secretariat, 2008). Trials and experiments with full grow-out of Atlantic salmon on land continue today with varying success rates that have been shown to be scale dependent (Appendix A). As a result, the technology is advancing at varying levels around the world. This is due to differences in regulatory support, access to resources and financial investment, including coastal land, water and energy.

So how, with the wild fish stocks being harvested to capacity, a growing human population and with it a global demand for seafood (FAO, 2014), do we provide good food to a growing population from our marine resources? Is it through using a tiny proportion, 0.0008% (ISFA, 2015) of the planet’s ocean space to sustainably farm fish or is it by putting extra pressure on limited space and resources such as water, energy and coastal land?



To help answer those questions, this report references twelve papers (Appendix B) and information from Canada, Ireland, Norway, Scotland, and the United States to summarize the evolution of land based salmon farming. By providing a factual summary of the history and current knowledge, with an eye to the future, this paper provides an overview on how land based fish farming operations began and how they are contributing to world food needs.

“Clearly, [land based fish farming] has earned a place as a key technology for juvenile fish across a wide range of species. It enables salmon farmers with their smolt production.”

Josh Goldman, Australis

EGG TO HARVEST



EGGS

Farmed salmon start their lives in fresh water and then move to salt water just as they do in nature. Salmon start out as eggs, which are collected from adult salmon broodstock, and placed in a freshwater hatchery.



ALEVIN

After three months, the baby salmon, known as ‘alevins’ hatch. Alevins feed off their attached yolk sacs for about a month.



FRY

When the alevins have used their yolk sacs, they are ready to eat on their own. They are now called fry and are moved into tanks in the freshwater hatchery.



SMOLT

After about 18 months, the fry become smolts and are large enough to move to saltwater farms.



ADULT SALMON

The smolts stay in their ocean farms until they are large enough to be harvested (5-6 kg). This can take up to two years.

BACKGROUND

Land based fish farming technology is a well-established method for producing a wide range of saltwater and freshwater fish species.

With a history that began in the mid-late 19th century, fish hatcheries and then fish culture facilities with a focus on genetics, originated in Canada, Norway and the United States around the same period and for the same reasons – to restock declining commercial and recreational fish stocks, specifically cod and Atlantic salmon. Today, aquaculture continues to use this original concept of land based systems during the freshwater stage of salmon development and for land based breeding programs.

The technology has advanced significantly in the 21st century, allowing for increased salmon smolt size and weight before transferring them to their natural marine environment. There are hundreds of land based fish farming systems operating in the world today (Gardner Pinfold, 2014). In Norway, there are approximately 190 land based fish farms in operation, primarily salmon smolt farms and smaller facilities with various other species. The largest operation has a capacity to produce more than 3000 metric tonnes of smolt per annum but that has never been met.¹

However, for land based farming from egg to harvest to become a leading form of production for a commodity product like Atlantic salmon, a number of crucial questions still remain unanswered about the economics of land based farming and its radically different challenges of energy, land and water use, and fish welfare. This paper presents an overview of these four challenges.

¹<http://niri.com/fish-farming/facts-about-land-based-farming/>

1800'S

Land based fish farms (hatcheries) in North America and Europe – government run to address declining salmon and cod stocks; smolt were regularly transported between North America and Europe.

1900'S

New fish production demands, hundreds of hatcheries for smolt production and enhancement around the world. Private and government ownership. Aquaculture becomes commercialized in Norway and then in North America.

2000'S

Ongoing collapse of fisheries, additional increase in global demand for seafood, land based systems continue to advance to meet aquaculture demands.

THE HISTORY OF LAND BASED SYSTEMS

“One of the most consistent of all realities is that no matter who you are, or where you are, you need safe, nutritious, affordable food—every day.”

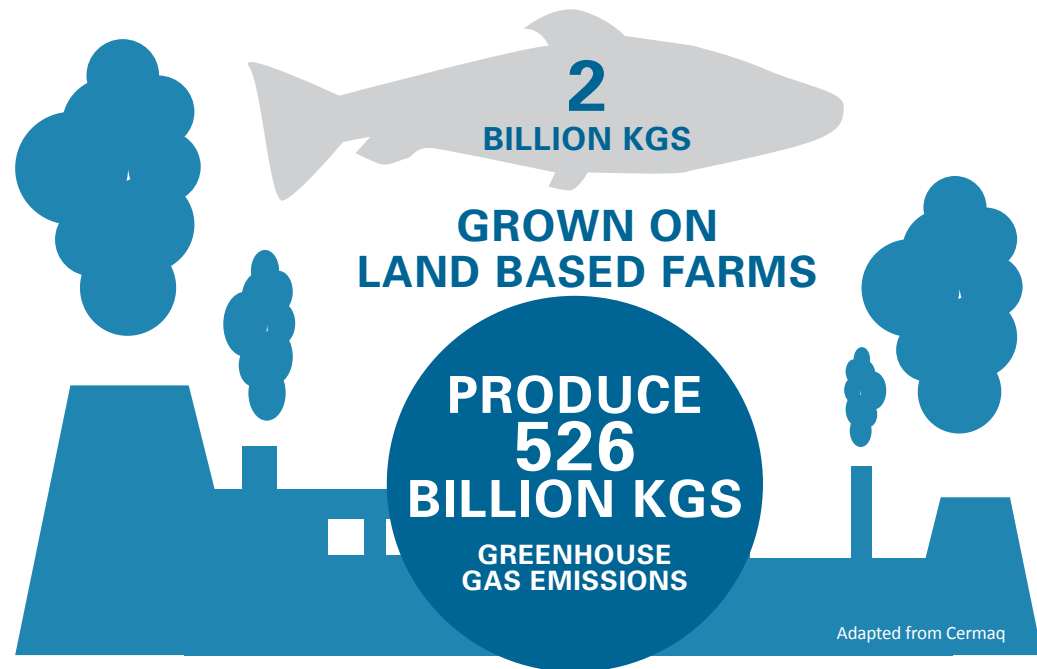
Jeff Simmons, Elanco President



For approximately half of their life cycle, farmed salmon are raised in an enclosed environment in freshwater hatcheries.

For the remaining half of the fish's life cycle, marine pens utilize ocean tides to move water and provide fresh oxygen to the fish. By comparison, land based farms compensate for that natural environment (i.e., flow, temperature and oxygen) by pumping water, heating/cooling water, and injecting oxygen - requiring consistent and significant amounts of energy to do so and increasing the risk of loss in the event of a power failure. A brief period without power will kill all fish in a short time because of the high density of fish in these land based systems that require continual access to oxygen pumps and filtering to replicate grow-out environments.

It has been suggested that farming Atlantic salmon on land has potential if you can select sites with cheap power in close proximity to key markets (Summerfelt, et al., 2012). However, the Government of Canada recognized that closed containment aquaculture carries its own set of environmental effects and the carbon footprint generated by closed containment facilities drawing electricity may be significant (2013). A recent report by the Scottish Salmon Producers Organisation (SSPO) considered land based RAS for full production on land of all grow out stages not financially viable, with the high-energy use and carbon footprint making it an environmentally unfriendly option².



Energy use and emission of carbon dioxide is one of the major global challenges society is facing as it seeks to feed a growing population with higher expectations with respect to standards of living. Future food production methods must seek to reduce the environmental impacts associated with food production not increase them. The development of the aquaculture industry should not convert to production methods which are less energy effective and have a higher contribution to CO² emissions.

² available from enquiries@scottishsalmon.co.uk

GROWING THE GLOBAL SUPPLY OF SALMON ON LAND



would require the same amount of **ENERGY** per year needed to power a city of **1.2 MILLION PEOPLE**





FISH WELFARE

Farmers have a stewardship responsibility for their animals. Fish are in their care and rely on the farmer to provide conditions that are as close to natural as possible and in which the fish will thrive. Two of the key indicators that salmon in land based systems may not be thriving are precocious maturation and decreased or subnormal growth rates. An additional challenge is that once a pathogen gets into a land based system it is virtually impossible to remove unless the system is depopulated and all the biological filters are disinfected. There have been a number of documented cases of fish health problems that have caused a complete loss of the fish due to pathogens in closed containment systems.

The papers reviewed agree that in order for land based Atlantic salmon farms to be profitable, farmers have to raise fish at much higher densities than in marine systems.

Conventional marine systems raise fish at a density of about 25 kilograms of fish per cubic metre at their peak size. In order for a land based farm to be profitable, Summerfelt (2012) suggested it would have to farm fish at densities of 80kg /m³ or higher while the CSAS (2008) report used an average stocking density of 50kg/m³ at peak size.

Raising adult salmon in the marine environment where they are stocked at densities that use less than four per cent of the pen space allowing for natural schooling activity versus prolonged exposure to technically created environments produces less stress and consequently a better fish.

The Nofima study (2013) supported the case that land based facilities do not eliminate environmental or disease concerns, noting that in a 20-year period a number of land based production systems were tested, and were not successful for a variety of reasons including incidents of winter-ulcer disease in the fish.

MARINE FARM

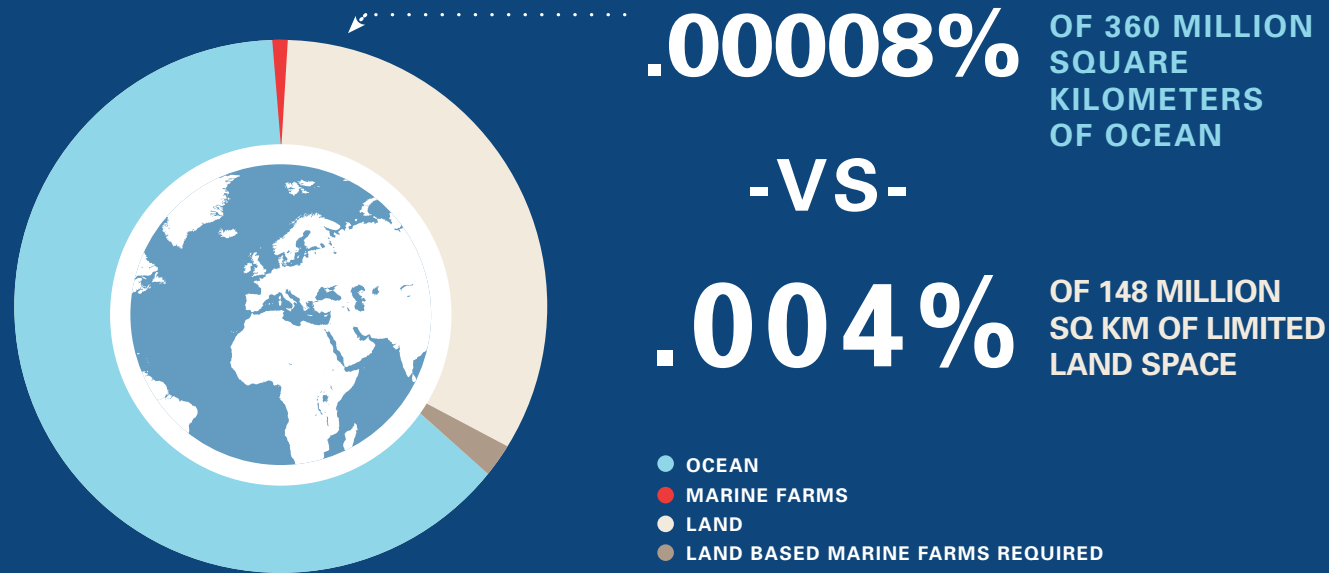
DENSITY OF 15-25KG
OF FISH PER CUBIC METRE AT THEIR PEAK SIZE

LAND BASED FARM

DENSITY OF 50-80KG
OF FISH PER CUBIC METRE AT THEIR PEAK SIZE

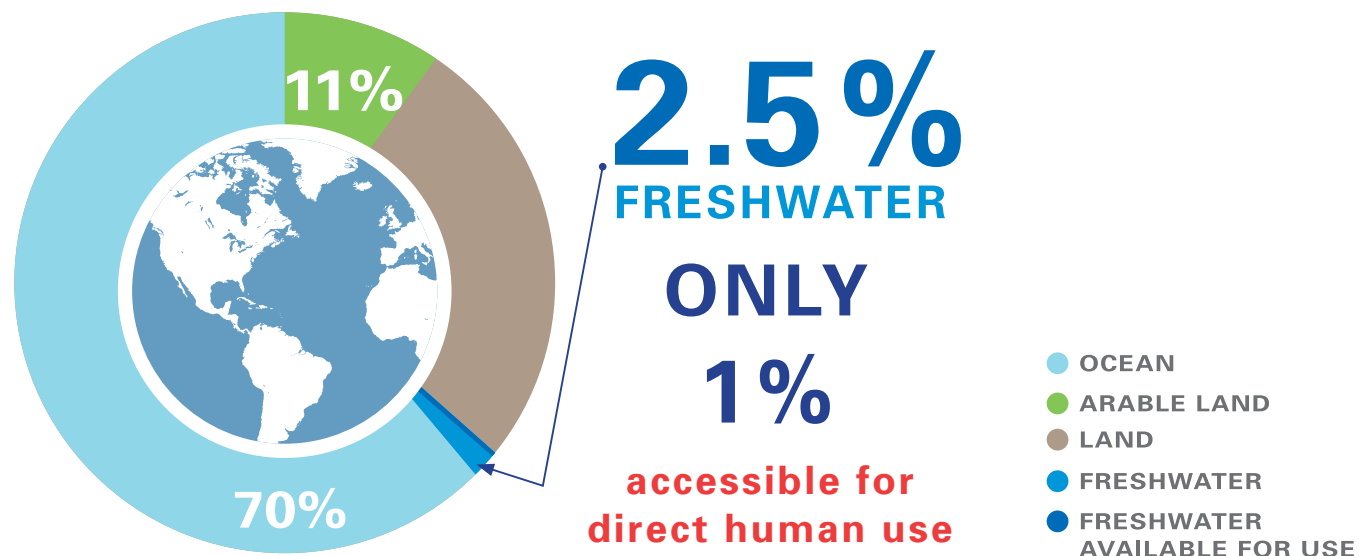


WATER AND LAND USE

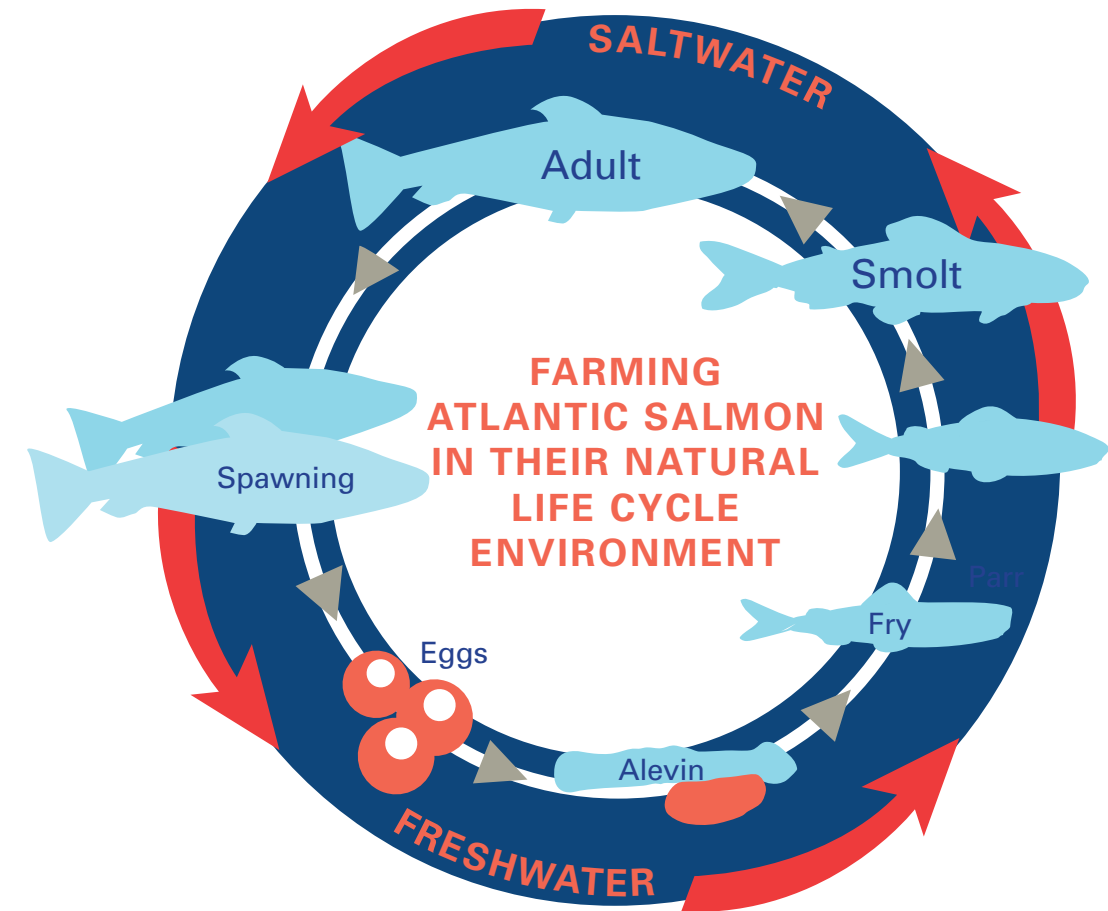


Water resources are decreasing while global demand for fresh water is increasing.

Although over 70 per cent of the earth's surface is covered by water, only 2.5 per cent is fresh water; the remaining 97.5 per cent is ocean. Of the 2.5 per cent, only one per cent is accessible for direct human use. This is the water found in lakes, rivers, reservoirs and underground sources³. Moving all marine Atlantic salmon operations to land based farms may place additional pressure on freshwater resources for food production. Freshwater is in some cases used partly or wholly during the final growing phase because of a lack of access to seawater or because of the necessity to run the production with a lower salinity for physiological reasons.



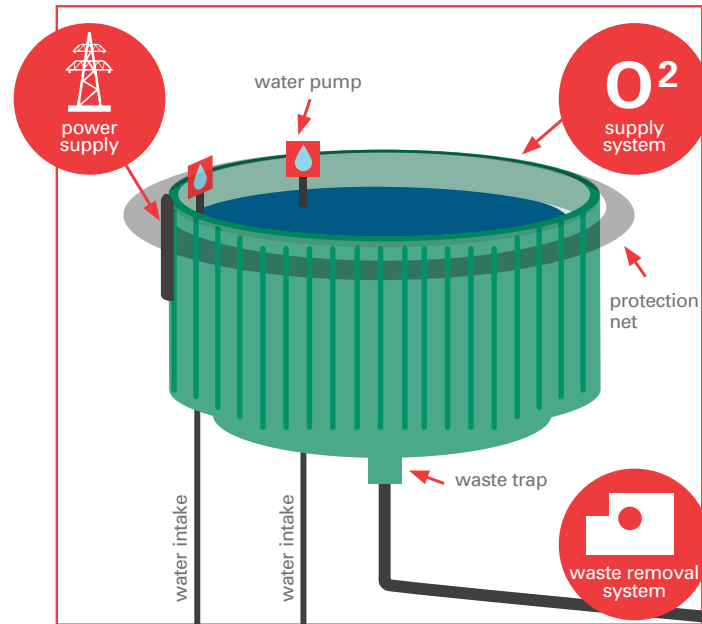
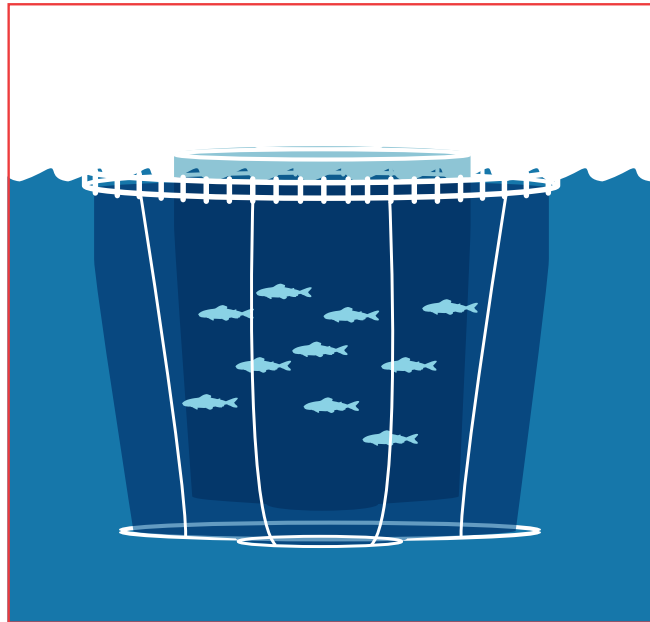
³ http://www.globalchange.umich.edu/globalchange2/current/lectures/freshwater_supply/freshwater.html
⁴ <http://www.fao.org/docrep/003/t0800e/t0800e0a.htm>



Every wild and farmed newly hatched salmon takes its first breath in freshwater. The clear un-salty surroundings of a river, stream, pond or tank are home for the first important juvenile stage of the salmon's life, putting it among a small elite club of species that move from pools and streams out to sea as adults and eventually back to spawn in later years and begin the cycle all over again. Freshwater is essential for the early life stage of salmon, just as it is for us and for all the main terrestrial plant and animal life on the planet. That is why it is so important to conserve it and to use it wisely, putting technology to work to provide the very best start for the young fish to grow. In current aquaculture practices, during the smolt stage of a salmon life, fish are returned to their natural environment, the ocean. This provides the fish with appropriate density to swim and school naturally while providing a healthy valuable product for consumers. Whether growing salmon in freshwater or saltwater land based farms, accessing water and replicating the natural environment of the ocean (i.e., salinity, temperature, oxygen, nitrogen, etc.) is essential for the adult stage of Atlantic salmon. Fluctuations in water quality can have detrimental effects on fish and create challenges for farmers, making it critical that these fluctuations are well managed. Even if it were technically and economically feasible, and if enough coastal land and water were available, the current production in Canada alone would require 28,000 football fields, 33,719 acres, or 136 square kilometers of land to grow fish in appropriate densities and water depths in land based systems. This number could multiply by tens in Norway where plans were announced to produce 20,000 tonnes of salmon in land based systems by 2018⁵.

⁵ <http://www.intrafish.com/news/article1429100.ece>

LAND BASED VS NET PEN SYSTEMS



Depending on location and the land based system used, water (fresh and salt) may or may not be an immediate issue. For example, a freshwater grow out recirculating aquaculture system (RAS) can reuse 99 per cent of the water given the appropriate conditions while a flow through system will not. For every 75,000 MT of salmon grown at the stocking density⁶ recommended for 4kg adult salmon, 4.16 billion litres (BL) of water is needed just to fill the tanks to grow the fish. In addition, another one to two per cent daily addition of make-up water is needed. Then, when the fish are ready for harvest, a 10 day depuration period is needed to rid the fish of the musty growing water taste. Depuration should be a total tank replacement with clean water every hour (i.e., 4.16 BL/h); for each 24 hours, 99.8 BL of water is needed, so for a 10 day depuration period, 998 BL of water would be needed.

This also highlights the fact that there are a number of variables that need to be considered for each system that are unique to the local environment (Standing Committee on Fisheries and Oceans, 2013). In addition, a full production grow out system using saltwater would require that land based marine salmon farms be built close to the seawater. This could create conflict with other users of the coastal lands and ocean waters and could generate another set of challenges related to fish health, energy use and waste management in these typical flow through systems.

As noted by the Canadian Geographic⁷ these saltwater flow-through processes must pump water from nearby sources and then back out, which with filtering may break down the waste, but does not contain it. Even if new systems are designed to fully collect any waste that may be created, the pumping of saltwater to land based farms will increase energy use, and subsequently greenhouse gases.

⁶ http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/1998/98_151_e.pdf ⁷ <http://www.canadiangeographic.ca/magazine/s004/indepth/portrait.asp>

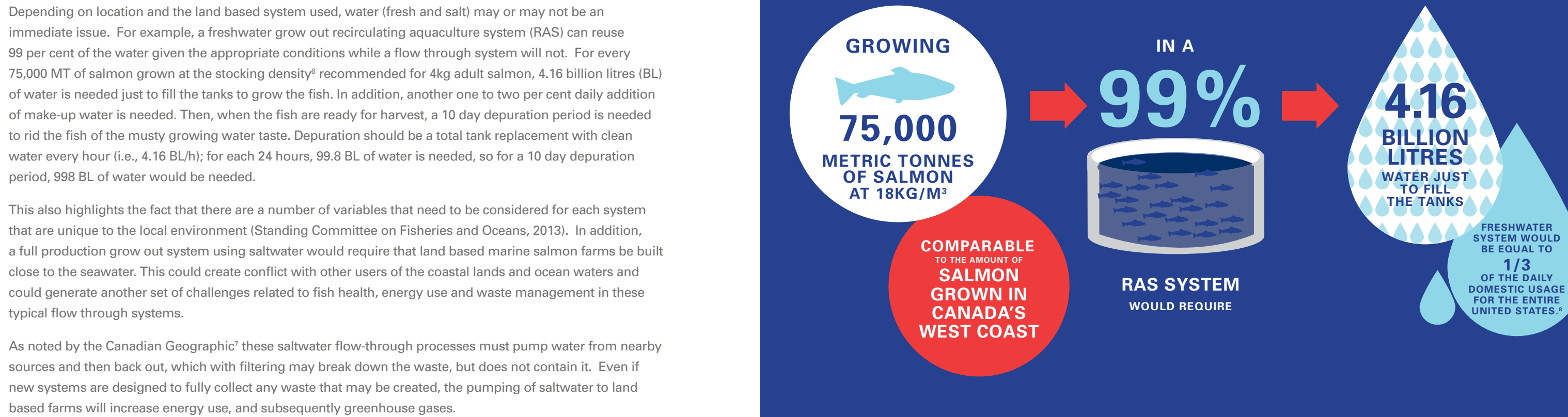
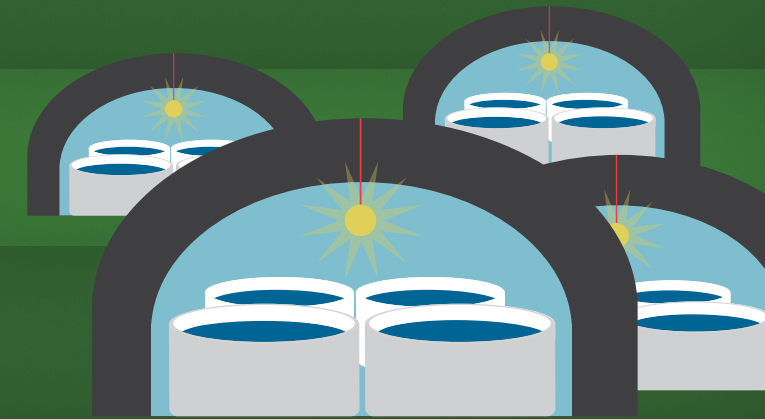
TO MOVE CANADA'S CURRENT SALMON PRODUCTION TO LAND BASED SYSTEMS WOULD REQUIRE

28,000

CANADIAN FOOTBALL FIELDS

33,719 ACRES, OR 136 SQUARE KILOMETERS OF LAND

TO GROW FISH IN APPROPRIATE DENSITIES



⁸ <http://water.usgs.gov/edu/wateruse-total.html>



SOCIO-ECONOMIC REALITIES



This report has focused on the common challenges of land based fish farming found within the papers referenced. However, it is important that we acknowledge the socio-economic challenges of land based fish farming systems. Although many communications in the media have suggested industry has not moved to land based systems due to increased capital investment (i.e., design and engineering, land acquisition, water and power installation, and buildings) requirements, it is the overall operational feasibility that has not yet been developed for scales of more than 1000 tonnes.

Table 1 provides one example adapted from a Government of Canada study (Boulet, Struthers, & Gilbert, 2010) which outlines the cost and return on investment (pre-tax) on the full production grow out of 2500MT of Atlantic salmon in the British Columbia environment and regulatory regime.

Table 1: Technology Comparison: Capital, Operational Costs, and Return on Equity - ROE (3 year)

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

This significantly reduced ROE, which assumes zero technology-related production problems and no fish health issues, would, as reinforced in the research review, have a negative socio-economic effect because of the reduced number of service industries throughout the entire supply chain and subsequently fewer job opportunities in both Canada (Boulet, Struthers, & Gilbert, 2010) and Norway (Nofima, 2013). The 2013 study by the Freshwater Institute and Norwegian research organization SINTEF (2011) found that a land based indoor salmon farm was more than three times as expensive to operate as a traditional ocean salmon farm. This could ultimately have a negative effect on the sector's contribution to the global economy as well as tax contributions in respective countries, provinces and communities.

From a broader perspective, this approach undermines the vital socio-economic role which salmon farming provides in coastal communities. There is also a potentially significant issue of devaluing the retail price of the final product by removing (a) the cachet associated with "country of origin" labelling, (b) the question of whether consumers are prepared to pay a high price for an "urban" salmon, and (c) the fact that it is illegal to label fish grown for their entire life in a recirculation unit as "organic", regardless of stocking density, feed etc.⁹

The reports also recognize that a reorganization of the salmon industry with increased use of land based farms would encourage a relocation of the production closer to the main markets. This would have major socio-economic impact on economically fragile peripheral coastal communities around the world.

⁹ COMMISSION REGULATION (EC) No 710/2009 of 5 August 2009 amending Regulation (EC) No 889/2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007, as regards laying down detailed rules on organic aquaculture animal and seaweed production. (Article 25g Specific rules for aquatic containment systems 1. Closed recirculation aquaculture animal production facilities are prohibited, with the exception of hatcheries and nurseries or for the production of species used for organic feed organisms.)

CONCLUSIONS

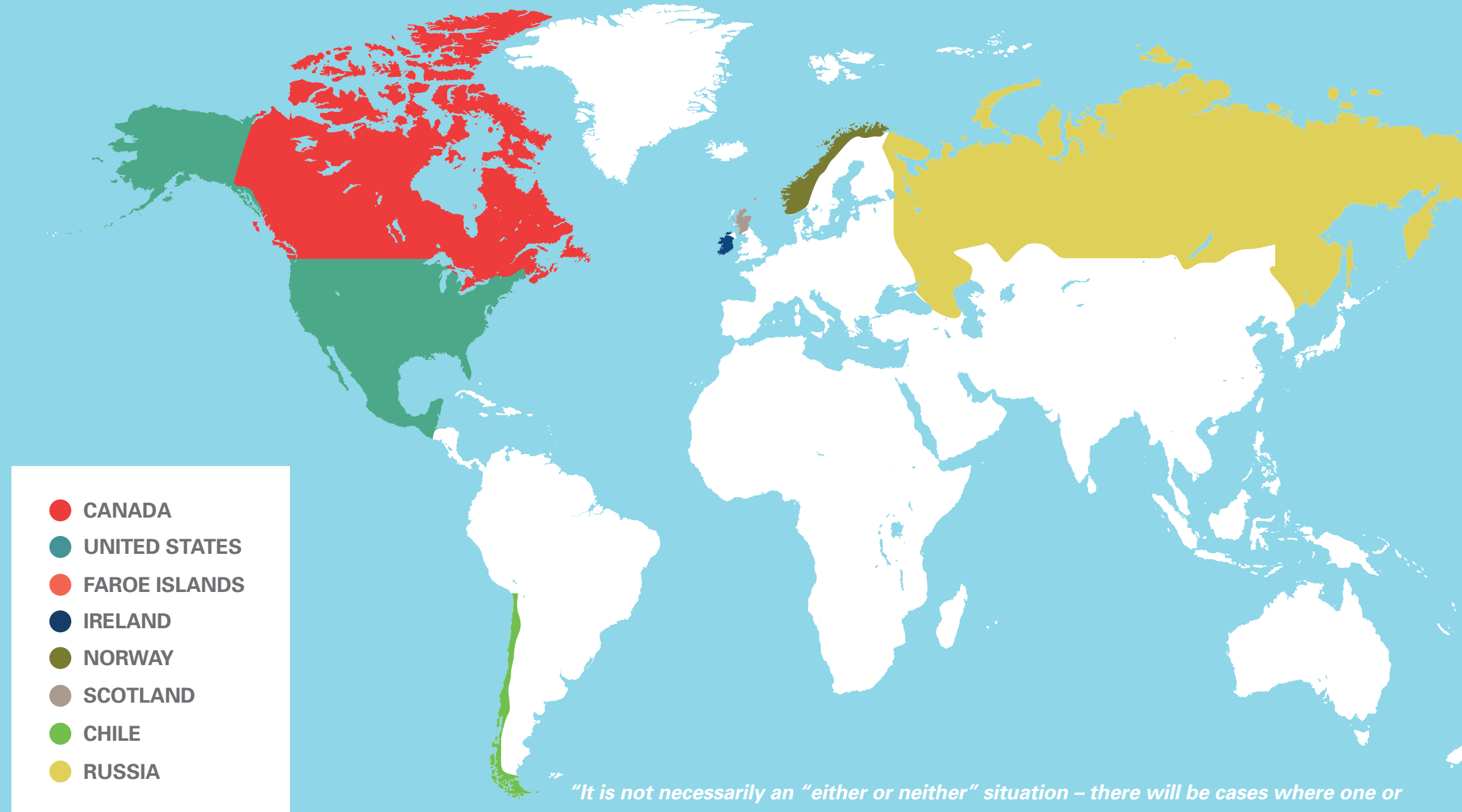
This report has provided a short overview of the evolution of land based fish farming systems. As this report has shown, growing fish on land is not a new concept. Its origin and current application, remains based on the reality that wild fish stocks have continued to decline while the human population is increasing, and with it the demand for food. Although land based salmon farming technology continues to advance around the world, since its inception to conduct wild stock enhancements in the 19th century, its success to date remains both scale and location dependent. Canada, the United States, Norway and Scotland have seen some recent advancement; in relatively small-scale full cycle grow out of between 300 - 1000 tonnes. However, the industry in all countries continues to invest heavily in research and technology to be feasible at a commercial scale that can meet the global market demands.

Salmon farmers know land based salmon farming must be conducted in a way that recognizes the unique conditions, purpose and needs of each application. These include the responsible use of limited freshwater supplies, electricity and land demands already witnessing tremendous stress for food production, as well as ensuring an appropriate environment to meet each species' life cycle requirements, to produce a quality fish for consumers. Although some may suggest land based fish farming will eliminate the risk of escapes, experience and research have shown there is no guarantee of that, as has been shown since the early days of smolt production for the enhancement of wild salmon stocks.

Finally, the reports reviewed agree – land based fish farms have a quantifiable ecological impact in contrast to the many vague unfounded impacts attributed to traditional net pen production. It is also a documented fact that in such systems fish health challenges can and do occur, that escapes due to handling and human error do occur, and that not 100 per cent of farming waste will be eliminated or contained. The authorities define the acceptable impacts from food production; however, the industry itself has the experience and knowledge necessary to choose the best technology for each farm that will meet the authorities' expectations of the industry.

The salmon farming industry understands the value of land based salmon farming as well as its limitations. As such, it will continue to collaborate with researchers, governments and ENGOs to understand the socio-economic and environmental realities of land based fish farming systems, both the opportunities and limitations, to advance the technology and apply it on a case-by-case, species-by-species basis as technology advances.

ATLANTIC SALMON GLOBAL LAND BASED CLOSED SYSTEMS



“It is not necessarily an “either or neither” situation – there will be cases where one or the other [land based and net pen] will be the most appropriate choice depending on size of operation, location and traditions, etc.”

Ivar Warrer-Hansen, Head of Business Developments, Inter Aqua Advance A/S.

APPENDIX A: EXAMPLES AND STATUS OF LAND BASED AND CLOSED SYSTEMS

Adapted from Warrer-Hansen, Technologies for viable salmon aquaculture: An examination of land based closed containment aquaculture, 2015

COMPANY	COUNTRY	PLANNED PRODUCTION	STATUS
Namgis/Kuterra	Canada	300MT/annum	Heavily subsidized project. Capital cost estimated at \$7.5M but reached \$9.7M. Estimated cost is ~\$30 million when stocked compared with a Fisheries and Oceans Canada (DFO) estimate of \$5 million to install and stock a net-pen operation. ¹⁰ Achieving a level of production equivalent to ~250 metric tonnes/year. If this level of production cannot be increased, capital costs would be roughly 12 times higher than the norm in the net pen industry. ¹¹
BDV SAS	France	100MT/annum	System operating for 3 years. Simplistic design with two tanks. Design not suitable for up-scaling. Fish grown in 20 ppt salinity.
Freshwater Institute	United States	Cohorts @ 5.4MT	Research facility; fish sold in local markets. This initiative is providing data on growth rate, survival, fish density, and early maturation of male salmon within a freshwater commercial-scale closed containment system.
Danish Salmon	Denmark	2,000MT/annum	Began operation April 2015; no conclusion on performance yet.
Shandong Oriental Ocean Co.	China	300MT/annum	Difficulty in meeting projections (Seafood Source Feb 12/14)
Little Cedar Falls	Canada	100MT/annum Steelhead Salmon	Report a harvest of 2MT weekly
Bell Aquaculture	United States	100MT/annum Coho	Media sources report in spring/summer 2015 and again in February 2016 business is being sued by creditors.
Sustainable Blue	Canada	100MT/annum Coho	Electricity failure caused it to close. Restarted in 2015 and now marketing fish.
Langsand Laks AS	Denmark	1,000MT/annum	755MT achieved. Problems with disease due to inadequate sterilization of water in-take. System closed for reconstruction.
Swift Aquaculture	Canada	1000MT/annum Coho	Raises eight to ten tonnes of coho salmon per year and using waste water from the tanks to grow watercress and wasabi.
AgriMarine Holdings Inc.	Canada, China and Norway	Licensed for 1200MT/annum	In development

COMPANY	COUNTRY	PLANNED PRODUCTION	STATUS
PLANNED OR UNDER CONSTRUCTION			
Xinjiang E'he Construction & Investment Co.	China	1,000MT/annum	Announced but no information
Salmo Scania	Sweden	6,000MT/annum	Planned construction
Swiss Alpine Salmon	Switzerland	600MT/annum	Planned for 2015
Hansholm	Denmark	2,500MT/annum	Planned for 2015
Namgis	Canada	2,000MT/annum	Planned expansion for 2016
Hudson Valley Farms	United States	1,000MT/annum Steelhead trout	Planned for 2016; building cost roughly \$10-\$15US per kg
FishFrom	Scotland	3,000MT/annum	Seeking investment of \$31.7 million US since 2013

LAND BASED SYSTEMS & OCEAN BASED SOLID WALL SYSTEMS TRIALED/BUT NOW CLOSED			
Aqua Seed Corp/ Sweet Springs	United States	100MT/annum Coho	Growth under expected/closed down
Teton Fisheries /Miller Colony	United States	100MT/annum Coho	Opened in 2010; closed 2012
Middle Bay/ AgriMarine	Canada	Chinook	Solid wall ocean tank installed 2011. Storm in March 2012 resulted in structural damage; fish that did not escape were harvested. Planned installation of new tanks did not take place.

¹⁰ <http://www.vancouversun.com/news/metro/salmon-farming+comes+ashore+land-based+aquaculture/7562924/story.html> ¹¹ http://aquaculturenorthamerica.com/finfish/land-based-salmon-still-not-investor-ready_1/#sthash.M0kqs7wZ.dpuf

APPENDIX B: A SUMMARY OF THE REFERENCED PAPERS

Warrer-Hansen, I., Potential for Land Based Salmon Growout in Recirculating Aquaculture Systems (RAS) in Ireland. Ireland. 2015.

This report, commissioned by the Irish Salmon Growers' Association, assessed the viability of land based salmon production in recirculation aquaculture systems (RAS) under Irish conditions. The report included detailed information on capital expenditure and operational costs as well as the market situation for salmon in 2014/2015. The report did not make comparisons with respect to economics between land based production and conventional production. This was due to in part to the lack of comparison data available because the bulk of Irish salmon production is organic and land based salmon production in RAS would not be eligible for EU organic status. The report described in detail all technical aspects of RAS production and system design and operations as well as important biological aspects of land based salmon production. It concluded that RAS is a proven technology and that it has a valuable role to play in the freshwater part of the life cycle of the salmon. The authors noted that the Irish industry could gain efficiencies by using RAS to increase smolt size/weight prior to transfer to sea, which would enhance productivity with a faster turnover of stock, reduced disease risk (including parasites such as sea lice) and improve overall efficiency of marine site use. The study noted that it was possible to produce a market-size salmon in RAS and that some pilot-scale units have managed to place approximately 1,000 tonnes in the marketplace over the last few years.

<http://www.ifa.ie/wp-content/uploads/2015/09/Land-based-report-IWH-final-Aug-2015.pdf>

Gardner Pinfold; Feasibility of Land Based Closed-Containment Atlantic Salmon Operations in Nova Scotia. Canada. 2014.

This study incorporated accepted design parameters and operating assumptions and used current (at the time) capital and operating costs for Nova Scotia conditions. The authors cautioned readers that some assumptions had not been confirmed in actual commercial operating conditions, particularly in larger scale systems. The authors pointed out that there are concerns with land based systems regarding water use (use of groundwater, harmful metals and depurating water source) and energy costs. Critical biological factors were noted as feed conversion, thermal growth coefficient and mortality, and technical factors included temperature, stocking density, energy requirements and labour. Financial analysis suggested that land based closed containment systems operate at an economic disadvantage because much of their cost goes toward creating the growing conditions that occur naturally within the ocean (water chemical properties and temperature, current and tidal action). The report challenged the notion that economic viability can be improved because land based product can demand a higher price in the market place. They argued that as competitors enter the market with the same product or close substitutes, that the premium price would be eroded and cautioned that consumer tastes and preferences may also change.

<http://novascotia.ca/fish/documents/Closed-Containment-FINAL.pdf>

Government of Canada; Closed Containment Salmon Aquaculture: Report of the Standing Committee on Fisheries and Ocean. Canada. 2013.

In October 2011, the Canadian Parliament Standing Committee on Fisheries and Oceans undertook a study on closed containment salmon aquaculture. The final report was developed following 18 meetings with scientists and academics, the aquaculture industry, consultants, Aboriginal groups, environmental organizations, coastal communities, retailers, recreational and traditional fishermen. Committee members recognized that closed containment aquaculture carries its own set of environmental effects and the carbon footprint generated by closed containment facilities drawing electricity, pumping in water, filtering waste, may be significant. The report concluded that closed containment technologies are well developed and have been used for decades for a number of different species of fish when proven feasible.

<http://www.parl.gc.ca/HousePublications/Publication.aspx?DocId=5994887&File=66>

Nofima; Oppdrettsteknologi Og Konkurransesposisjon (Translated: Farming Technology And Competitive Position). Norway. 2013.

This report noted that several onshore production systems were tested from 1970 through 1990 and the experiences were shared via Braaten et al 2010. Overall, these systems were not successful for a variety of reasons including that flow through systems experienced incidents of winter-ulcer disease in the fish. Recirculating aquaculture systems provided good control of conditions and can be beneficial for smolt production if the facility is designed and operated properly; however, they were not successful for full grow-out. Energy costs were significant associated with pumping water and would not be eliminated even in a facility where 99 per cent of the water flow is recirculated. Energy is also used to pump water ashore or from freshwater sources and to heat or cool water. The report discusses challenges in optimizing fish health management parameters including biosecurity, water quality, salinity levels and tolerance to high fish densities.

The report questioned the extent of feed-based pollution from marine farms and suggested that the increase in material resources and energy negate any value in collecting feed and solid waste. The report challenged the extent to which onshore systems provide a solution to sea lice, spread of disease and fish escapes due to the limited experience and knowledge from the full-scale operation of farms on land.

The authors noted that the potential exists for technical solutions to be found that would eliminate farm fish escapes and reduce problems of lice. They noted that this was the better option than the environmental impact from increased material, resource and energy consumption of land based operations – which would be less irreversible. The report also challenged the notion that the topography and/or access to suitable land are available to support the infrastructure necessary to develop land based operations. The report questioned the impact that relocating production on land and the subsequent shift to highly skilled labour would have on socio economic conditions within coastal communities. A move to land based operations would also affect the entire supply chain associated with the industry including processing facilities and the service and supply sector.

APPENDIX B: A SUMMARY OF THE REFERENCED PAPERS

Summerfelt, et al.; Freshwater Grow Out Trial Of St. John River Strain Atlantic Salmon in a Commercial-Scale, Land Based Closed Containment. Canada. 2012.

This report summarized the results of an Atlantic salmon grow-out trial in a freshwater closed-containment system at The Conservation Fund's Freshwater Institute (TCFFA) (West Virginia, USA), with grant support provided by the Atlantic Salmon Federation (New Brunswick, Canada). The initiative provided data on growth rate, survival, fish densities, feed conversion, primary variable costs, waste loads, fish health, pesticide/antibiotic use and other key parameters for Atlantic salmon production to food-size over 12 months within the Institute's freshwater closed containment system. The findings of this study were intended to assist future decision-making by the North American salmon farming industry, government regulators, funders, and conservation advocates, resulting in better-informed decisions as the industry continues to grow.

The report noted that the majority (approximately 80 per cent) of male salmon observed reached sexual maturity within the 24-month grow-out trial. The fillet color and yield of maturing males was found to be lower than for non-mature fish, a serious constraint to production in land based closed-containment systems. The Conservation Fund Freshwater Institute suggested that based on previous research at the Institute an all-female strain (the Gaspé strain) could be produced to eliminate early maturing male salmon, as done in other species such as trout and Arctic char. They also noted that the Atlantic salmon egg source should provide eyed eggs at least once every six months to maximize the production capacity within land based closed-containment systems. Assuming that all female-eyed eggs were available four times annually, the capital cost for this egg to plate facility would be estimated at approximately \$31 million; production cost was estimated at \$3.90-\$4.00 per kg of head on gutted salmon.

http://0101.nccdn.net/1_5/05c/2da/0c0/summerfelt2013growoutatl-salm.pdf

SINTEF; Oppdrett Av Laks Og Orret I Lukkede Anlegg Forprosjekt (Translated: Salmon and Trout in Closed Containment Pilot Project). Norway. 2011.

This report summarized the status of knowledge of closed farms and a number of proposals for new designs and materials; to date there were few systems that had been tested with fish or that had reported results in a scientific verifiable format. The report provided an overview of the various closed systems but concluded that closed aquaculture facilities could not currently be regarded as commercialized and that considerable effort was needed to understand the technological, biological and economic factors required to succeed in making full life cycle salmon farming viable. The authors raised concerns that considerably more space is required along the coast if closed systems were to be used. While there may be some possibilities available for closed systems, the authors concluded that there may be increased opportunities to expand technological development to reduce the environmental impact of ocean based farms. The project group concluded increased knowledge was required in the fields of biology, construction, management and economics, before any consideration in the development of closed construction technology for full grow out of salmon. A research pilot project was recommended that would be subject to scientific criteria in terms of method descriptions, reproducibility, expressive power and peer review. They recommended the development, design and large-scale testing of future closed plant types should occur in open collaboration with key equipment manufacturers.

<https://www.sintef.no/en/projects/salmon-farming-in-closed-systems-preliminary-proje/>

Boulet, Struthers, & Gilbert; Feasibility Study of Closed Containment Options for the British Columbia Aquaculture Industry. Canada. 2010.

This study used financial analysis tools to conduct an analysis of two technologies warranting a more in-depth financial and sensitivity analysis, net pens and recirculation aquaculture systems (RAS). This study considered financial elements only. The results of the analysis showed that while RAS technology is marginally viable from a financial perspective, returns were significantly higher for net pen. RAS technologies were projected to be considerably more sensitive to market forces (e.g., exchange rate and market price) and may likely prove non-profitable within a range of variability that has actually been experienced by the Canadian salmon aquaculture industry. These sensitivities are due largely to the high initial capital investment and subsequent costs associated with it. Although RAS production showed efficiencies in biological feed conversion ratio (FCR), temperature stability, and improved environmental control, the presence of higher capital costs, energy costs and labour requirements significantly affected its overall profitability. The report concluded that the findings need to be assessed, and their assumptions validated in a real-life scenario. Potential next steps included a pilot scale or demonstration system capable of producing salmon at commercially viable levels to demonstrate the technical and financial feasibility of closed-containment rearing of salmon under real world conditions. The study authors also suggest that a life-cycle analysis of such a demonstration facility should also be undertaken and compared with that of net pen production as outcomes of such further analyses would be required in order to determine next steps and to guide government policy direction as it relates to closed-containment for salmon aquaculture.

<http://www.dfo-mpo.gc.ca/aquaculture/programs-programmes/BC-aquaculture-CB-eng.pdf>

Wright, A. S., and Arianpoo, N.; An Examination of Land Based Closed Containment Aquaculture (Draft). Canada. 2010.

Prepared for the SOS Solutions Advisory Committee, established to provide advice to the SOS Marine Conservation Fund's Save our Salmon Initiative, this report documented an investigation into the feasibility of land based closed containment technology for utilization in the British Columbia aquaculture industry. The report concluded that land based closed containment are economically and technically viable using commercial off-the-shelf components. They presented a design that, if refined, would allow for substantial reductions in both capital and operating expenses. The economics associated with the report allowed an investment of approximately \$12 million to operate a farm that yielded 1000MT of 5kg fish and 750MT of fillet and plate-size fish per annum. That harvest allowed revenue streams of between \$10 million and \$20 million per annum depending upon the harvest and supplementary crop production strategies that were adopted. Final annual income after costs ranged between \$5 million and \$13 million, depending on harvest and supplementary harvest strategies. The authors noted that the report did not claim to contain all of the information that may be required and advised that individual investors should conduct their own independent analysis of the opportunities and the data contained or referred to in the report.

<http://www.farmedanddangerous.org/wp-content/uploads/2011/01/technologies-viable-salmon-aquaculture-draft-2010.pdf>

APPENDIX B: A SUMMARY OF THE REFERENCED PAPERS

Grant, A. and Muir, J., Closed Containment Systems for Farmed Atlantic Salmon in Scotland - An Appraisal. Scotland. 2009.

This assessment, commissioned by the Scottish Salmon Producers Organization, focused on four categories of closed containment systems: simple flexible or semi-constrained impermeable bags suspended from appropriate structures, using established mooring and platform technologies, solid floating structures, land based tank or raceway systems and land based recycle systems. The report examined evidence for the ability of current and emerging closed system aquaculture technologies to replace net-pens in both fresh and seawater for Atlantic salmon production in Scotland. This assessment discussed system issues including preliminary design (i.e. concepts and materials, control systems, disinfection, waste management), scalability, robustness and resilience, performance standards, site criteria, biological interactions and failure protection. It also considered operational issues such as husbandry and management, water quality, fish health and welfare. Performance measures included the economics (capital and operating costs, life cycle analysis and footprint, key sensitivities, insurance and other costs), consumer perception and competition. The results of the study recognized that work is ongoing but for the marine growing stage, current closed containment environmental footprints are much higher with respect to energy (which also implies carbon and global warming impacts) and availability of sites for onshore systems is problematic, and there are no commercially scalable systems currently available for realistic production alternatives. The authors concluded that while closed containment systems for the freshwater production stage have merit, as currently proposed or developed these systems do not offer adequate advantages, and that the many disadvantages are insufficient to balance against the proposed merits for full grow-out of salmon.

EcoPlan International Inc. (EPI); Global Assessment of Closed System Aquaculture. Canada. 2008.

The David Suzuki Foundation and the Georgia Strait Alliance retained EPI to provide a review of commercial closed system aquaculture (CSA) technologies throughout the world, emphasizing those technologies and species most relevant to British Columbia. Commissioned to provide information to aid in assessing the economic and technical growth potential of aquaculture in the CSA sector, it examined a variety of technologies and methods used in commercial production as well as several emerging technologies, highlighting advantages and disadvantages of each. The report concluded that aquaculture will remain important in providing fish for the global food supply and new technologies, trade, consumer demands and regulatory changes will influence the development of CSA. It noted that technological advancements (i.e., energy efficiencies), regulatory developments and the selection of species would need to recognize the local variables such as climate, water availability, alternative energies, access, and socio economic conditions, amongst others, to determine local suitability of CSA.

<http://www.farmedanddangerous.org/wp-content/uploads/2011/01/ClosedSystemAqua-FINAL.pdf>

Canadian Science Advisory Secretariat, Fisheries and Oceans Canada; Assessing Potential Technologies for Closed Containment Saltwater Salmon Aquaculture. Canada. 2008.

The Canadian Science Advisory Secretariat (CSAS) of Fisheries and Oceans Canada facilitated a scientific review of potential closed containment technologies that engaged international experts, academia, industry and conservation organizations. This review took a methodical approach to examining five types of production systems: conventional net pen; floating, closed-confinement systems with rigid walls; floating, closed-confinement systems with flexible walls; land based flow-through system; and, a land based reuse system. The CSAS review was based on information from over 40 case studies of various types of closed containment technologies attempted for the commercial scale production of finfish, including Atlantic salmon and peer-reviewed expert technical papers. At the time of the review, no commercial-scale closed-containment systems for the exclusive full life cycle production of Atlantic salmon were operating. Land based recirculating systems were generally producing less than 1,000 metric tonnes per year and scaling up was expected to create technical and operation challenges, as RAS had not been proven for adult salmon. The study noted additional attention should be given to the development of closed-containment technology in floating, in-water installations. Any work that had been done was focused primarily on developing vessels for containing the fish waste and feed. The report recommended research focused in the areas of economics, technology, fish health and welfare and waste input/outputs to gain the knowledge required to evaluate the overall performance of any closed-containment system on a commercial production scale.

http://www.dfo-mpo.gc.ca/csas-sccs/publications/SAR-AS/2008/SAR-AS2008_001_e.pdf

Pacific Salmon Forum Final Report and Recommendations to the Government of British Columbia. Canada. 2009.

The Forum's report to government concluded that while several British Columbia groups as well as the Special Committee on Sustainable Aquaculture had called for the imposition of water-based or land based closed containment technology for salmon farming, due to the high degree of public misinformation on closed containment, many questions needed to be answered before it could be considered viable. To resolve these questions the Forum recommended that the Province establish an independent technical committee to develop the specifications for a closed containment pilot project. This project would provide the information necessary to confirm the profitability of closed systems for salmon production.

Additional information can be found at <https://www.leg.bc.ca/content/legacy/Web/cmt/38thParl/session-3/aquaculture/reports/PDF/Rpt-AQUACULTURE-38-3-Volume1-2007-MAY-16.pdf#search=special%20committee%20on%20sustainable%20aquaculture%20final%20report>

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The following organizations contributed to the development of this report:

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NEWFOUNDLAND AQUACULTURE INDUSTRY ASSOCIATION

BRITISH COLUMBIA SALMON FARMERS ASSOCIATION

FAROE ISLAND SALMON FARMERS

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