The Economic Evaluation of a Closed Containment System For Salmon Aquaculture in British Columbia

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Table of Contents

Executive Summary **4**

List of Tables **7**

List of Figures **8**

Acknowledgements **9**

Introduction **10**

Background **12**

History 12

Industry: Economic Impacts and Prospects of the BC Salmon Industry 14

Problem Statement: **16**

Importance of the study 16

Purpose of this paper 17

Literature Review **18**

Conclusion of critique of reviewed literature: 25

Evaluation of Various Methods: **27**

1) Open-Net Pens (Current Practice) 28

2) Ocean –Based Closed Confinement Flow Thorough Systems (Flexible Walls) 29

3) Land Based Closed Containment 34

4) Ocean-Based Closed Containment Overview 39

Methodology **41**

Overview 41

Ocean-Based Closed Containment Costs **42**

Factors Affecting Cost of Closed Containment **44**

Location 44

Production levels and fish density 45

Energy Consumption 46

Economies of Scale 47

Environment 50

Other Costs 51

Results **53**

Conclusion **54**

Observations 54

Scope of Study/Lessons Learned 57

Recommendations 59

Literature Cites **60**

Executive Summary

There has been substantial pressure from environmental groups as well as the British Columbia Government to move towards a sustainable and environmental way of salmon fish farming. The current method of open net fish farming, where no barrier is created between the farmed salmon and the environment has been argued to be hazardous to the environment. In May 2007, the legislature's sustainable aquaculture committee stated that there is "serious or irreversible harm" in the current practice of salmon fish farming. The report recommended a "rapid, phased transition" away from the current practice to a closed containment method of salmon fish farming.

Several closed containment methods attempted in the past have not been economically feasible. The ones that I will discuss in this paper are the closed containment method with flexible walls and land based closed containment. The closed containment with flexible walls method gives little confidence to users. The land-based closed containment method is limited due to high costs and the scarcity of land. This paper will discuss and evaluate the feasibility of the new suggested method of salmon fish farming which is the ocean-based closed containment method. From my findings, the ocean-based closed containment method is approximately three times higher in cost than the current method of open-net fish farming. However, the long term cost reduction effects which includes economies of scale and advances in knowledge and farming technique using this new method have still yet to be determined.

The methodology that I have chosen to use for this analysis is secondary research from published papers, journals, articles, government reports and past farm data. The key literature that I have reviewed for this paper is the full report from the British Columbia Ministry of Agriculture, Food and Fisheries, June 2003. Performance Evaluation of a Pilot Scale Land-Based Salmon Farm, Final Report to the Special Committee on Sustainable Aquaculture, (May 2007) as well as several other key published papers on salmon farming.

The result of my research has found that the other attempted techniques, which include land-based closed containment method and the flexible walls closed containment method, are high in costs and do not give user confidence. The ocean-based closed containment method is roughly three times the cost of the open-net pens farming technique. This paper attempts to provide and cope with the uncertainty of the costs that adds difficulty to the real world industrial location problems. While there may be many possible variations to this framework, my paper explores the very basic requirement of closed containment which is the location, fish feed, energy, economies of scale and environmental impacts. Although an attempt has been made in this research to provide an analysis of the costs of the ocean-based closed containment, a more thorough analysis is still necessary to provide an accurate picture of the actual costs in the long run of the method.

To date, the ocean-based closed containment method is regarded as a viable option, however, due to the limitations of data and the time constraint of this project, a thorough analysis of a real life commercial scale ocean-based salmon farm could not be provided. The results of this paper can be used to assist with the future evaluations of the long-term effects of the ocean-based closed containment method of salmon fish farming technique.

List of Tables

Table 1: Cost of Net Pen System vs. SARGO System 34

Table 2: Advantages of Using Land Based Fish Farms 35

Table 3: Performance Evaluation for a Pilot Scale Land-Based Salmon Farm, Ministry of Agriculture Food and Fisheries, June 2003 37

Table 4: Land Based Fish Farm vs. Net Pen Farm 39

Table 5: 1995 data from SRAC Publication No.456 48

Table 6: Statistics Canada 65

List of Figures

Figure 1: Flow through systems with solid walls 30

Figure 2: Schematic drawing of Future SEA Technologies' system 32

Figure 3: SARGO Sample 33

Figure 4: Cost Factors for Land Based Closed Containment 38

Figure 5: Closed Containment 40

Figure 6: Closed Containment Costs 43

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Introduction

British Columbia Aquaculture has been one of the fastest growing food production activities in the world. One of the newest and fastest growing types of aquaculture is salmon farming. British Columbia is the world's fourth largest farmed salmon producing region, fourth to Norway, Chile and the UK. The current practice in salmon farming is primarily open pen salmon farms. Net pens range in size but are generally approximately $30m^2$ in width. Simply put, nets are placed into the water and the salmon are farmed inside the nets. There are many social, economical and environmental issues associated with the use of open net fish farms and will be further discussed in this paper. An alternative method is Closed Containment method, which is defined as either a land or a floating barrier technology that ensures no contact between wild and farmed fish with minimal release of waste into the marine environment.

In a meeting by the BC legislature committee held in Victoria, BC, it was argued that the current fish farming practice is too risky since it creates no barrier between the farmed salmon and the environment. The legislature results stated that the current fish farming practices (open net fish farms) are simply too risky to continue and innovation is needed to move all fish farms into a closed-containment method. (The Canadian Press, May 16, 2007 issue). The legislature's sustainable aquaculture committee says the risk of "serious or irreversible harm" to wild salmon, particularly if they are hit with sea lice infestations in the vicinity of fish farms, makes it urgent for government to force the industry to overhaul its farming practices. The report recommends a "rapid, phased transition" away from conventional open-pen sea farming to closed containment pens that provide an impenetrable biological barrier between wild and farmed salmon. (The Vancouver Sun, May 17, 2007) [1]

The BC government and the industry will begin immediately to fund the development of the technology within three years, and allow the industry another two years for their transition.

It has been argued that the commercial scale land-based closed containment farm were significantly higher in cost than the current open-net pen practice. My research paper is to investigate, compare and contrast how much more costly the closed containments are relative to the open nets. In this research paper, I will briefly discuss the problems associated with that of the open net fish farming technique, using literature searches to support and explain such problems. I will then compare the two methods, and discuss the key issues pertaining to the closed containment versus the open net method. Lastly, I will provide a cost analysis of implementing the closed containment as an alternate method to fish farming and determine and conclude on my argument of the best method of salmon fish farming available.

A goal of this report is to expand and deepen the current public understanding about the potential impacts of open net fish farming technique versus the ocean-based closed containment method. This will be done through examining, evaluating and accessing the secondary information available through literature

[1] http://www.canada.com/vancouversun/story.html?id=47bffed4-2ce5-4316-904a-03f141b79679&k=791

searches. As well, the paper will explore alternative methods of salmon fish farming such as land based closed containment as well as flow through systems. A cost benefit analysis for the ocean-based closed containment will be completed for a thorough evaluation of the viability of the new technique.

I hypothesize that the closed containment is initially more costly than the open net fish farming technique because of the set up costs. It is my research topic to find out how feasible the land-based as compared to the ocean-based closed containments are and if possible, how much more expensive these alternatives are as methods of salmon fish farming. My aim is that my analysis will include data that permits a discussion of potential environmental impacts and economies of scale.

Background

History

In a global context, the fish populations are rapidly collapsing because of over-harvesting. As well, this effect is also a result of the dramatic increase in demand and consumption of fish protein. Furthermore, there has been a rapid degradation of marine ecosystems due to changes in ocean temperatures, which has resulted in a negative effect to fish stocks. There has been considerable discussion to develop and adopt technologies that can deliver best practices to minimize further impacts to marine ecosystems and therefore meet the ever-growing demand for seafood. British Columbia is fortunate to have an environment that has the potential to produce a large quantity of cultured salmon. In addition, British Columbia, because of the location, has great opportunities for increasing aquaculture production through the adoption of state-of-the-art technologies.

The salmon industry in BC is divided into three major sectors, aquaculture, commercial fishing and sport fishing. Salmon farming in British Columbia has grown dramatically in the past two decades. In the years 1982 to 2005, BC salmon farming production rose substantially, overtaking the wild salmon harvest, producing at 70,600 tones or 73% of BC's combined harvest of wild and farmed salmon. The average landed price in 2005 was $1.30 per kg for wild salmon and $4.50 per kg for farmed salmon. [2]

Salmon farming began in the 1970s with small local farms, which started on the Sunshine Coast producing Coho and Chinook salmon. In the 1980s, large international corporations bought out the local farms and started farming Atlantic salmon. The fish farming production was at 27,000 tones in 1995 with Atlantic salmon accounting for 67% of the total production. In 1995, the provincial government placed a memorandum for all new fish farm licenses and conducted an environmental impact assessment review.

The price trends of the BC farmed salmon had experienced a number of price changes in the past two decades.

[2] Final Report to the Special Committee on Sustainable Aquaculture, May 2007

- 1987-1991 – Prices fell from higher levels first associated with the new product with the increase in BC production
- 1990s - With Japanese's sluggish economy and reduced production costs, there was a downward push in the farmed salmon prices
- 2000-2002 - With global production there was a leading drop in world prices
- 2004 - Present- Prices have rebounded with higher US market demands

Industry: Economic Impacts and Prospects of the BC Salmon Industry

Aside from being the fourth largest farmed salmon producer in the world, British Columbia's farmed salmon is also the province's largest agricultural export. Salmon farming accounts for $371 million in direct output and contributed $134 million to provincial GDP in 2005. Firstly, the industry also provided 1,500 full-time equivalent jobs. [3] Wild salmon accounts for $216 million in direct output and $67 million in GDP. As well, it provides approximately 1,600 full-time equivalent jobs. Lastly, salmon sport fishing accounts for $231 million in output and contributes $116 million to provincial GDP and 2,280 full-time equivalent jobs. [4]

British Columbia's salmon farming industry nearly doubled in size from 1997 to 2005. This includes both production output and output value. The figures for

[3] Final Report to the Special Committee on Sustainable Aquaculture, May 2007
[4] MMK Consulting Data produced on behalf of BC Legislative Assembly's Special Committee on Sustainable Aquaculture

2006 show a more than 15% increase in volume over 2005. In wild commercial salmon, data shows a significant decline from 1997 to 2005. The output values show a decrease of more than 30%. Lastly, in salmon sport fishing, the economic indicators have also shown an overall decline in fishing activity since 1997. The salmon farming industry's economic prospects are assessed as strong in the short to medium term.

Problem Statement:

Importance of the study

British Columbia wild salmon's health as well as fish farm's impacts to the environment had been an issue on the rise for the BC parliament. A Special Committee on Sustainable Aquaculture was called in 2005 to review the current state of the aquaculture in BC. The result of the review was published in the Final Report to the Parliament in May 2007 where it suggested that a "rapid, phased transition" to ocean-based closed containment beginning immediately after the release of the report. Within three years, the ocean-based closed containment must be developed and in two years after that, the industry must transition to this method. The long term cost of the ocean-based closed containment of salmon fish farming is still yet to be determined although legislature has requested that all fish farms be transitioned to this method in five years. As well, the committee recommended that the provincial and federal government along with the salmon aquaculture industry must finance and conduct a full size commercial scale ocean-based fish farm. Lastly, the committee recommended that the provincial government provides incentives to the aquaculture industry for the transition to this technology. Suggestions to help with the financing of the transition includes possible tax credits, training credits, incentives to support technology transition and incentives on training of new technology.

Purpose of this paper

The purpose of this paper is to use information from various sources including literature reviews, government data and industry analysis to provide and analyze the costs of different methods of salmon farming, in particular, a concentration on the ocean-based closed containment method of salmon farming. It is not the intent of this paper, to give a complete analysis of the ocean based closed containment method. A complete analysis would include factoring in cost benefits from all sources such as environment, fish feed, and fish health. This paper is an attempt to provide a first step to an analysis to the feasibility of the ocean-based closed containment method of salmon fish farming in British Columbia through researching secondary data, pilot fish farms, government published papers and data available from salmon fishing publications.

Literature Review

The literature review indicated that there has not been sufficient research and analyses performed on closed containment salmon fish farming technique. Particularly, there have not been many published papers on the proper economic analysis comparing the cost of open-net cages to a closed tank system. The definition of a "proper analysis" includes factoring the disease outbreaks, algae blooms, secondary income generated from waste collection, fish feed, economies of scale, economic value per fish, and social impacts. The viability of the implementation, long term economies of scale, environmental cost savings from social impacts of the environmentally safer method of the ocean-based closed containment technology into a viable commercial operation is still yet unknown. My research was to focus on the cost of implementing, maintaining and sustaining the ocean-based closed containment method of salmon farming through an analysis of closed containment salmon aquaculture tanks and comparing that to the open net fish farms.

From my literature review I found there had only been very few implementation projects performed in the past decade for closed containment method of salmon fish farming. In an article by Pendleton, in 2005 titled "Closing in on Environmentally Sound Salmon Aquaculture: A Fresh Look at the Economics of Closed Tank Systems", Pendleton described in detail on one of the three closed containment projects. Two out of the three closed containment projects performed were by private fish farming corporations in which no data were released to the public. I was able to gather the full report on the British Columbia Ministry of Agriculture, Food and Fisheries. June 2003. Performance Evaluation of a Pilot Scale Land-Based Salmon Farm, in which I will further discuss and provide critical key methods and my insights on the report. Another key report relevant to my research paper was the Final Report of the Special Committee on Sustainable Aquaculture for the Third Session of the Thirty-Eighth Parliament, which reported the committee's activities from November 2005-May 2007 (Volume One & Two). Volume one of the reports provided the economic trends, economic impacts, economics prospects with recommendations to Parliament. Furthermore, Volume two provided the prospects of the BC salmon industry. Because of the timelines of this report, it was especially relevant to my research paper on closed containment and on salmon fish farming, particularly in British Columbia. Other key literatures that I found to be relevant were literature that provided information on the impacts the open net fish farms that include factors such as sea lice, fish health and fish escapes. As well, the literature also provided key information on the salmon production in BC and the industry growth globally.

In my literature review, I will discuss a few key studies that were particularly useful to my topic of costs. These studies include: pilot studies of closed containment reports, government issued documents as well as academic journals that have performed research in the past ten years on the open net fish farms. I will then conclude with the review of each of literature and describe in detail why I think some information may have been neglected or why the research done on the topic is so minimal.

A request for proposal by the Ministry of Agriculture, Food and Fisheries in the summer of 2000 was granted in June 2003 to Agrimarine's for a proposal to renew an existing land-based salmon farm in Cedar. The Ministry of Agriculture, Food and Fisheries wanted to attract public interest and investments to test and experiment the new technology.

The land-based closed containment method used in this study was the implementation of eight 18-foot deep concrete tanks, holding 750,000 liters of seawater. The results of this pilot project found that the average cost of production across all the three tested species which included Coho, Chinook and Atlantic was roughly $5.02 per pound (Table 1). [5] The feed conversion rate was at 1.2. It was found that the performance of the Coho in the land based system tanks was comparable to those of the Atlantic salmon in the open nets. It is important to note that the price derived from this project did not include the cost of boxes or transportation from the processor to the distributors. It would be estimated that the cost of transportation would be $0.15 per pound, and distributor price at $3.40. The price of Coho in 2002 was around $2.24. The rental cost of the four tanks was $97,880. The original cost for the site was $1 million for the land and $7 million for construction. In 1997, it was estimated that the capital costs for 1000 tonnes land-based facility were roughly $21 to $27 million with full water re-use systems. Depreciating this over 20 years would result in an annual cost of $1 - $2 million. This is roughly 10 to 20 times the rental

[5] Performance Evaluation for a Pilot Scale Land-Based Salmon Farm, Ministry of Agriculture Food and Fisheries, June 2003

fee. The key result of this study was that the land-based closed containment, given the current re-circulation method, is not a feasible method of salmon fish farming.

A shortcoming of this report was that the project indicated that a land-based closed containment of salmon fish farming was most likely not economically viable although the project did not have significant data on the improvements in economies of scale, reduced oxygen costs and improved techniques over the years. Accurate inventory and cost accounting are also key factors in reducing costs of production. Nevertheless, the project given the high cost of capital expenditure and the scarcity of land required to implement the new land based facility is not economically viable for fish farming.

In evaluating the current method of open-net fish farms, a key publication that I found useful and relevant was the Nash, Colin E. 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. *Aquaculture* 183, (3-4). Nash expands on the key business risks to open net fish farms. One of which is the production lost to the marine mammals because of direct predation. The second is the lost production in the fish due to the loss in body weight. The loss in fish feed through the nets due to the poor feed conversion efficiency whereby predators or other fishes are able to feed on the fish feed. Lastly, Nash also evaluates the loss of production in the form of fish escape through holes in the net pen walls. The three key issues as mentioned by

Nash, would all be prevented by a closed containment method of salmon fish farming.

> "In the sea lion season in Puget Sound, for example, one farm lost 86,000 salmon in 1996 through bites alone (not escapees through holes), and another 114,000 fish in 1997. The farm later went into receivership. In Canada, salmon losses from predation mortality and escapes due to predator net damage accounted for nearly 200,000 fish in 1989 (Ruggeberg and Booth, 1989), or 1% of total production. By 1996, total predation costs were estimated as high as C$10 million (EAO, 1997). In Tasmania, Australia, 235 attacks by male fur seals were recorded in 4 months on 15 farms producing Atlantic salmon and rainbow trout, and one farm lost more than A $500,000 of fish in 1 year (Pemberton and Shaughnessy, 1993)."[6]

The key methodology used in Nash's research was using past data from open net fish farms. My main critique of this research was that the data are not relevant enough as the industry, as well as cost has dramatically changed since then. Cost of selling as well as the cost of production had increased since then. The latest data in the report were in the 1990s.

A very relevant report submitted to Coastal Alliance for Aquaculture authored by L. Pendleton on the economics of closed tank systems provided a much-needed insight to my research paper. The article highlights the lack of a proper analysis of closed containment system of salmon fish farming. Pendleton argues that the closed tank can prevent the transmission of such disease parasites, waste and fish escapes but have higher capital costs which have discouraged a wide scale adoption of this technology. Pendleton questions whether the closed containment method of salmon aquaculture is:

[6] Nash, Colin E. [Reprint author]. 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. *Aquaculture* 183, (3-4).

1. Financially viable or profitable
2. Financially competitive with current net-pen technology
3. Economically superior from society's perspective [7]

Of the three open net systems, the article concentrated on the data that were only available for Future SEA Technologies and Mariculture Systems. The article's key findings found that the pilot projects fall short of providing long term financial and economic impact of the closed containment systems. By using small scales to evaluate the cost, it does not put into account the economies of scale and efficiency in techniques or the economic value of environmental and social impacts, and long term financial returns. The article argues that results from the projects have been presented in dollars per kg of fish produced when the results should really show the marginal cost for each additional output. As well, it argues that the cost must be provided in units that reflect the inputs in which the costs are associated with. In time horizons, it argues that the existing reports only focuses on short term and in order to properly analyze the cost of the closed containment, a long term (15-20 years) analysis is required. With this closed containment technology being so recent, it is difficult to properly compare it with the full matured open net pen technology. The environmental costs and environment factors such as government taxes, subsidies, impact on disease outbreak and waste management should also be put into consideration when examining the closed containment method of salmon fish farming.

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[7] Pendleton, L. 2005. Closing in on Environmentally Sound Salmon Aquaculture: A Fresh Look at the Economics of Closed Tank Systems.

Pendleton argues that: "Such an analysis would:

- Determine whether closed tank aquaculture would be likely to produce "normal" or better financial returns for potential investors;
- Examine the degree to which closed tank aquaculture would represent a sound economic investment from society's perspective, including an analysis of the potential "savings" to society if closed tank can overcome many of the environmental concerns posed by net-pen aquaculture; and,
- Determine if there are market failures that have prevented the adoption of closed tank systems."[8]

I agree with Pendleton's argument that sufficient research has not been completed to date for a thorough analysis of the closed containment method. Since the technology is still relatively new, economies of scale and increased efficiency due to increased knowledge of the method is still yet to be determined. The long-term efficiencies and benefits of the method still remain to be demonstrated.

In evaluating the energy consumption of the closed containment versus other systems, there has been limited literature completed to date. In my literature review up to 2007, there had been less than 10 published studies on the energy requirement of aquaculture systems, of which only three dealt with salmon producing systems (Folke, 1988; Pitcher, 1977; Tyedmers, 2000). My review of

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[8] Pendleton, L. 2005. Closing in on Environmentally Sound Salmon Aquaculture: A Fresh Look at the Economics of Closed Tank Systems.

the literature indicated that there has not been one single standard approach in evaluating the energy use, which is useful for comparisons between the methods.

Conclusion of critique of reviewed literature:

To date, there have been minimal publicly available reports that are recent and relevant to the studies on fish farming using the closed containment method, particularly in British Columbia. There has been no published literature to provide relevant financial data on a commercial size ocean-based closed containment salmon fish farming.

One conclusion that can be drawn from the lack of literature is that the closed containment technology is still a relatively new technology. The long term positive or negative effect of the closed containment method is still not known. Only smaller pilot projects have been completed to date of which none can provide data on the long-term effects of the methods.

A second conclusion that I argue is that if the method of closed containment method is proved to be more financially feasible and effective in the long run for salmon fish farms, it could force the open net pens to adopt the closed containment method at costs to the fish farms. Many of the private research done by farm companies, if any, may not have been released to the public as to avoid the unwanted set up and implementation costs of the closed containment methods. Since the legislation was only passed in July 2007, the release of such private research may not have been made to the public yet.

The following research paper will focus on the key elements for implementing the closed containment method of salmon fish farming as well as providing an estimated cost of the implementing, sustaining and maintaining the closed containment method. In addition I will attempt to provide suggestions to potential savings that would result from using the new method. With that information I will explore which of the closed containment methods could be a better method of salmon fish farming as opposed to the current open net pen method.

Evaluation of Various Methods:

I have identified four methods of salmon fish farming which may be feasible in British Columbia. They are listed as per each of the four subheadings headings:

1) net pens
2) land-based flow through
3) ocean-based floating flow through and recycle (or partial recycle)
4) ocean-based closed containment.

It is found that net pens are harmful to the environment and the water. Alternatively, flow through systems do not give enough user confidence due to the use of fabric bags. It is argued that these bags can easily break causing the farmed salmon to be exposed to the outside environment. As well, with the higher costs compared to open nets, the flow through systems may not be the best solution to creating a barrier between the farmed salmon and the outside environment. The land-based closed containment is argued to be expensive due to high land and energy costs. The option of ocean-based closed containment is the most recommended and is seen to be the most viable and economic option of salmon fish farming. Each of the four above-mentioned methods will be discussed in the subsections further below.

1) Open-Net Pens (Current Practice)

Currently, British Columbia's salmon farming uses open net pens. Each net pen ranges in size and there are generally 12 pens per site which can hold up to thousands of fishes. The open-net pen fish farms are generally 30m^2 in width and can hold up to twelve pens per sites. There are currently 130 farm sites in BC and 60-80 are stocked at any given time.

Open pen net farms are essentially nets that are placed into the water to farm fish. In net pen farming, water is being flown through with natural water currents with no human intervention. However, issues arise with infection of the natural water and the environment, since there is no barrier between the farmed salmon and the environment. It is estimated that net pens are roughly three times cheaper than that of the closed containment methods.

The most commonly used netting material is a flexible nylon since it is relatively inexpensive and can be treated with chemicals against anti-fouling. Some other types of netting material include rigid plastic, galvanized or plastic coated steel.

The current open-net pen salmon farms, as currently operated have raised many concerns about the impact to the marine environment such as fish waste, salmon escapes and sea lice. Problems associated with open-net-cage salmon farming include: [9]

- Sea lice and disease from farmed salmon threaten wild stocks.

[9] http://www.davidsuzuki.org/Oceans/Aquaculture/Salmon/default.asp

- Pollution from farms contaminates surrounding waters.
- Drugs, including antibiotics, are required to keep farmed fish healthy.
- Escapes of farmed fish (alien species) threaten native wild fish.
- Net loss: Farmed fish are fed pellets made from other fish, depleting other fish species on a global scale.

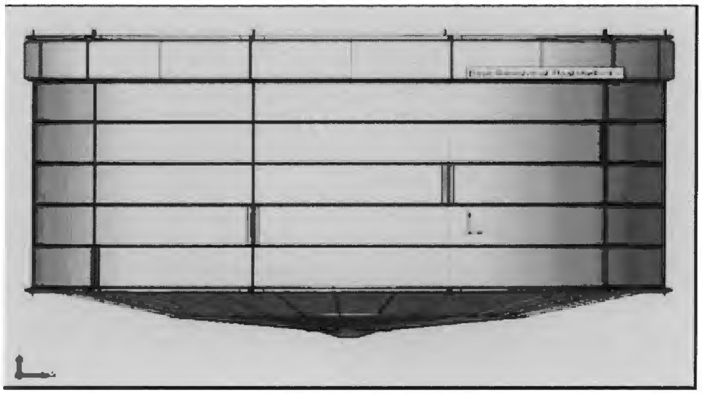
A recent meeting by the BC legislature committee held in Victoria, BC stated that the current fish farming practices (open net fish farms) are simply too risky to continue and innovation is needed to move all fish farms into a new, ocean-based-containment method. (The Canadian Press, May 16, 2007 issue). The BC government and the industry will begin immediately to fund the development of the technology so that within three years, the industry can take another two years to transition. Hence, the current industry's method of open net pen method of salmon fish farmed must be phased out and the key issue currently is to find the most feasible way to farm salmon fish.

2) Ocean –Based Closed Confinement Flow Through Systems (Flexible Walls)

There have been several companies that have developed the closed containment method of ocean based salmon fish farming. The alternatives to open net pen include, closed confinement flow through systems in the water where bags are placed in the water to farm the salmon instead of in open net pens. Another is the land-based closed containment where the salmon are farmed on land in closed containments.

The companies that have developed closed containment methods include Procean AS (Norway), FutureSEA Technologies (Canada) which developed a flexible membrane while, Mariculture Systems (USA) developed a HDPE rigid-walled floating tank system. (Figure 1).

Figure 1: Flow through systems with solid walls[10]



A flow through system allows for water, either pumped or gravity fed, to flow through the fish tanks and then is pumped to flow waste. The water is typically fully saturated with oxygen; where the fish will reduce this level before the water is discharging. This method is often referred to as "one time" use of the water. Some methods of land-based closed containment and ocean-based closed containment use the method of flow through either through one time use or partial recycle systems where secondary methods of water treatment are implemented to extend the water usage. Because flow through systems are essentially fabric bags where water is pumped through, there is a perceived lack

[10] **Source:** www.sargo.net

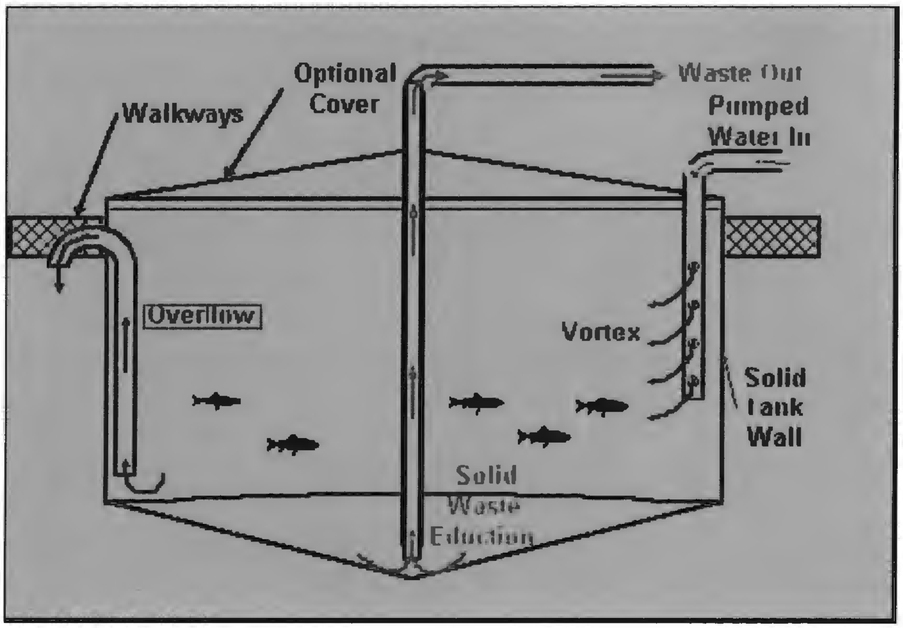
in strength in the fabric material which causes lack of confidence in this method. Fabric can tear and break, resulting in potential escapes of farmed salmon.

Another operating concept is a floating flow through containment system but with solid walls and floor instead of fabric bags, also called a rigid flow through system (Figure 2). This system was developed by Future SEA Technologies where water is being pumped into the bags and the shapes of the bags are maintained. Figure 2 represents a 15 meter in diameter by 11 meters deep sample which has a total rearing volume of 2,000 cubic meters. The rigid walls increase resistance to marine attacks and have better confinement characteristics. The waste is concentrated and stored where it will be disposed weekly. However, because these methods have walls, it is necessary to pump water through the system to provide dissolved oxygen and remove metabolic waste (Colt, 1991; Colt and Tomasso, 2001). Energy is one of the high cost drivers in this particular method of salmon fish farming.

Figure 2: Schematic drawing of Future SEA Technologies' system

The sidewall of each reservoir is a rigid cylindrical tank fabricated from a minimum 5/16" thick sheets of solid High Density Polyethylene HDPE. The standard reservoirs are 18.5-meters (62.75 feet) inside diameter by 10.75-meters (35.3 feet) deep at the sidewall, with 9.3-meters (29.6 feet) below the waterline. The recycle system separates the solid wastes from water. The solids can be pumped to land based collection pit/pond which, when dried, can be sold as fertilizer. One tank has a rearing volume of each tank is 2500 cubic meters. Each tank is capable of producing 125 metric tons of fish per grow-out cycle. The system as specified above has not yet been tested though opportunities for such testing are being sought. Its project operating and financial performance is as per below (Table 1) [11]

Figure 3: SARGO Sample



[11] www.sargo.net

Table 1: Cost of Net Pen System vs. SARGO System

Assumption	NetPen System	SARGO Flow Through System
Size - Pens, Reservoirs (meters)	15 x 15 x 6	18.5 Dia. x 10
Volume - Pens, Reservoirs (m3)	1,800	2,500
Loading Density @ Harvest (Kg/m3)	10	50
Number Required @ 440 Metric Tons per Year	40	4
Total Installed Cost for System	$2,000,000.00	$1,700,000.00
Production Cost per Pound - Smolts	$0.24	$0.17
Production Cost per Pound - Feed	$0.68	$0.57
Production Cost per Pound – Labor	$0.36	$0.09
Production Cost per Pound - Other	$0.22	$0.21
Total Cost per Pound	$1.50	$1.04
Cost Advantage per Pound of Fish	-0-	$0.46

3) Land Based Closed Containment

Land based closed containment systems are essentially large concrete cylinders that are placed above water and on the land. Inside, the systems are used to farm salmon. It is argued that these land based containments are high in costs because of scarcity of land as well as high energy costs. For this method, enough land has to be available at the correct elevation above sea level and be of close proximity to the ocean. The land-based closed containment farms are significantly higher in cost than the current net pen practice. As well, this method could create a number of significant environmental impacts such as massive increase in the use of energy and the waste disposal. This type of fish farming system is very similar to the flow through closed containment systems but located on land. It allows for better access and control of rearing tanks, but requires a significant increase in pumping power. This requires a standby power system that must be mandatory on-site to ensure fish's survival.

The land based closed containment method reduces risks associated with the industry's current system of open-net pens. With this method, there is virtually zero risk associated with sea lice and exposure to the marine environment. As well, as compared to the current method, it allows for a much greater number of stocking densities and faster growth rates. The faster growth rate of the monitored salmon allows for a faster turnover in production of salmons which reduces costs and allows for a greater number of production per year with the same initial set up costs. In addition, a land-based closed containment can reduce food consumption because of the greater monitoring of the fish feed. Other advantages also include pollution control and cost in harvesting. Since this method is on land it can reduce the costs of transportation and delivery. The advantages to the land based closed containment is summarized as per table below in Table 2.

Table 2: Advantages of Using Land Based Fish Farms

Advantages Of Using Land Based Fish Farms
1. Greatly reduce risks: Reduces mortality, stress and disease level and very little risk of foul weather damage
2. Much higher stocking densities are achieved
3. Much faster growth than net pens
4. Lower food consumption
5. Reduced cost of harvesting/slaughtering and packaging
6. Elaborate pollution control is an integral part of the system
7. Complete separation of cultured and wild environments, minimizing risk of an accident to zero

A pilot project in an attempt to determine the cost of land-based closed containment fish farming was the Agri*Marine's* proposal. AgriMarine proposed to renew operations at a pre-existing land-based salmon farm in Cedar, B.C. The facility was initially built for the production of farmed salmon by Hagensborg Resources in the 1980's. The site was an eight 18ft deep concrete tanks with each tank holding 750 m3 (750,000 liters) of seawater. The project's results found that the cost of production for this site across all three species was $5.02 per pound. According the AgriMarine, the price that the fish was received was $3.25 per pound, which did not include transportation or distributor costs. The result of this project concluded that the cost of farming the salmon exceeds the cost that the market is willing to purchase at. This project resulted in data to further argue that producing farmed salmon, particularly at this site, is not an economically viable option.

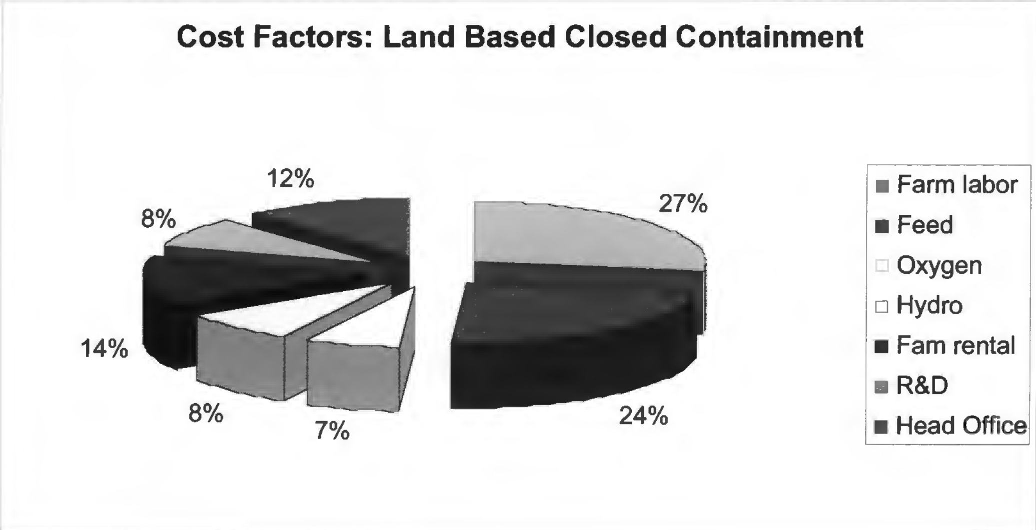
Table 3 represents the data from the above project, which shows the cost of production for Chinook and Coho salmon. The price that was received was much less than the cost to produce and in the case of the Chinook, the cost greatly exceeds the selling price.

Table 3: Performance Evaluation for a Pilot Scale Land-Based Salmon Farm, Ministry of Agriculture Food and Fisheries, June 2003

Species	Chinook	Coho
Total number of smolts	21000.00	25220.00
Ponding weight (grams)	142.00	18.00
Total pieces at harvest	7400.00	21792.00
Total pounds at harvest	25513.00	102760.00
Total harvest weight	3.45	4.72
Cost of production	**$ 12.81**	**$ 3.70**
Cost Factors		
Farm labor	189,239	
Feed	166,179	
Oxygen	47,465	
Hydro	56,839	
Farm rental	97,880	
R&D	55,852	
Head Office	82,592	
Total	**$696,046**	

A comparison between the cost of the land based closed containment systems versus the open pen net farms is below (Table 4). From the cost analysis, it is almost certain that the cost of the land based systems is much higher than the net pen farm systems and that the land based fish farming technique is not an economically feasible option given the current technology at that time. The data in Table 4 show the initial operating capital for a land-based fish farm is much greater than that of the open net pen farm systems. In order to set up the land-based fish farm, an initial set up, construction and operating capital totals to $10,800,000 compared to the net pen farm system of $ 1,500,000. However, the table shows that the annual gross profits are higher for the land based fish farm. Not only are the set up costs higher, the value of land also varies and since the location of the site must be near water, the costs of the site are typically extremely high and the land is rare and valuable. If this method was to be used over a longer period of time, the annual profits might be able to offset the initial set up costs.

Figure 4: Cost Factors for Land Based Closed Containment



In conclusion, land based systems of closed containment systems for salmon do not appear to be economically viable given the technology method at the time of the project in June 2003. Nevertheless, land-based closed containment system is the only method that minimizes the risk of an accident of exposing the farmed salmon to the marine environment to close to zero.

The table below represents the cost of the pilot project of the land-based closed containment versus the current method of net pen farm system. The return on investment is close to 100%, which makes it seem a viable method. The initial set up cost is extremely high as compared to the net pen farm systems. It would be burdensome for a fish farm to have to finance $10,000,000 to set up this new method. However, it would be possible for fish farms, if the government was to subsidize some of the set up costs to take away some of the financial burden from the fish farms.

Table 4: Land Based Fish Farm vs. Net Pen Farm

LAND BASED FISH FARM 800m3 20 Tanks- Diameter 12m x 4m high (Diameter 39 ft x 13 ft high)	**Cost**	**NET PEN FARM SYSTEM 800m3 14 sq. nets (12x12x4m depth (39x39x14ft.depth)**	**Cost**
Construction and Set up Costs	$ 8,000,000.00	Construction and Set up Costs	$ 960,000.00
Initial Operating Capital	$ 2,800,000.00	Initial Operating Capital	$ 540,000.00
Annual Gross Production	845000 kg	Annual Gross Production	120000kg
Annual Revenue at $12.50/kg	$10,562,000.00	Annual Revenue at $12.50/kg	$1,500,000.00
Annual Production Cost: $3.035/kg	$ 2,560,000.00	Annual Production Cost: $3.035/kg	$ 360,000.00
Annual Gross Profits	**$ 8,002,000.00**	**Annual Gross Profits**	**$1,140,000.00**

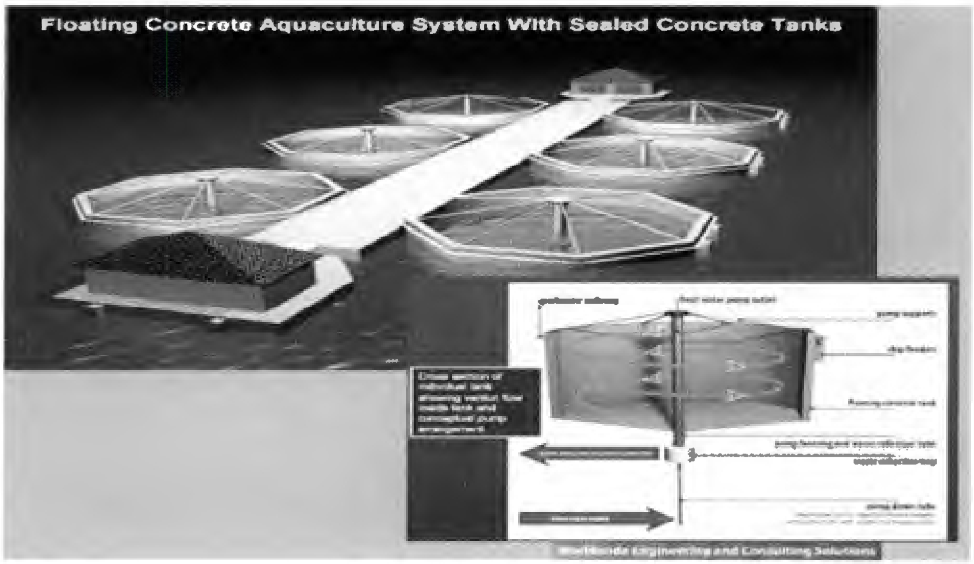
4) Ocean-Based Closed Containment Overview

Since land and energy for the land-based closed containment method of salmon fish farming are rare and high in cost, another option is to bring the fish farm closer to the water. We have seen that the flexible bags in the water to create barrier results in low user confidence, a suggested solution may be the ocean-based closed containment method where the salmon can be farmed in the closed containments inside the ocean. The close proximity can allow for cheaper pumping energy costs and circumvents the scarcity of land, an issue associated with land-based fish farming.

Ocean-based closed containment are defined as a floating barrier technology that has no contact between wild and farmed fish which results in minimal waste released into the environment. These tanks float in the water, similar to the open net cages but use less energy than the land-based system. They do require inputs of energy for water pumping in order to have proper oxygenation. Currently, all commercial closed containment systems are operating to sell high priced and niche products. These include salmon smolts, Tilapia, hybrid striped bass and turbot. The system for low priced markets such as salmon still remains to be determined. The following sections will be an analysis of the cost of the closed containment and parameters in which the cost was derived.

A visual sample of the closed containment is shown below. The diagram represents concrete tanks with oxygen circulation systems that are placed into the ocean to farm salmon. Within each tank, a number of salmon depending on the size of the tanks can be farmed. The concrete creates a barrier between the outside environment and the farmed salmon.

Figure 5: Closed Containment



Methodology

The method that I have chosen to use for this paper is to review secondary data sources. I have researched and gathered some data samples from fish farms with data on the cost to produce salmon and the price that it can be sold at. As well, I have included suggestions to other factors that could influence the cost of this method. A chart for the justification for reduction in costs due to economies of scale has also been included in this section.

Overview

This section describes the assessment of the costs and benefits of the ocean based closed containment method. A closed containment method creates a barrier between the wild and the farmed salmon while reducing the high land and energy costs associated with land-based closed containments. Although, the land-based closed containment method has been proven with the technology available at the time not feasible due to high set up costs, the ocean-based closed containment method's feasibility is still yet to be determined. Research has shown that salmon fish can grow more effectively in closed containments as oppose to open net pens. It is further argued that in terms of rate of growth, production per unit of rearing capacity, and food conversion efficiency, closed containments are noticeably more efficient. The following will evaluate some of the factors affecting cost of the ocean-based closed containment method of salmon fish farming.

Ocean-Based Closed Containment Costs

A sample data of a closed containment method of salmon fish farming was derived from 1995 numbers (Figure 5). The farm was closed shortly after opening due to the high cost of production at £ 4.10 versus the selling price of £ 3.80. As well, the full breakdown of the production costs was not provided in the data.

From the data provided, the cost of the production was higher than the cost of selling price and hence, the method was considered not viable at that time. Furthermore, there was no government legislation to enforce the use of closed containment fish farms. However, in the analysis, the sample fish farm did not use economies of scale to reduce the production costs nor were any other cost factors such as environment, environmental impacts from fish farming, included in their calculations of costs and selling price. From the data, it would seem that the fish farm was not viable, however, I would argue that given more time, the cost could have been significantly reduced because of the greater gain in knowledge of farming techniques using new methods, the economies of scale and the reduction in fish feed being wasted due to the closed containment. Since the highest cost drivers are site and labor for fish farms, if labor can be kept consistent with the current practice (i.e.: use the same amount of labor hours with increased skilled farm employees) the costs may be comparable to the current open-net pens in the long run.

An example of an attempt to pilot the use of the new closed containments would be floating fiber-glass tanks in the 'Middle Bay Sustainable Aquaculture

Initiative' where a land based closed containment system is to be tested. The research is a proposal to implement a large-scale evaluation of the floating through system. It proposed to use solid walled tanks instead of fabric bags. This project initially proposed to use concrete tanks but the cost and weight was not justifiable. Four rearing tanks were constructed (7.5 m deep x 30 m diameter, 5500 m3 in volume). The project will be located north of Campbell River and has received $1.2 million in funding from Gordon and Betty Moore Foundation and will receive $2.4 million from the Canadian government. The first tank will be constructed using FRP (fiberglass re-enforced plastic) and will be expected to launch in February 2008.

Figure 6: Closed Containment Costs[12]

Sample Cost of Closed Containment Method (1995)	
Species produced	Atlantic
System volume	2640 m3 (4400 m2)
Annual production	100 tonnes
Max. potential production	120 tonnes
Total water exchange (system volumes/hour)	0.5
Total new (makeup) water per hour	1250 m3/hr (350L/s)
Makeup water pump head	18 m
Pumping energy	(350x18x1000) (102000x0.7) = **88kW**
Method of re-oxygenation	Aeration 140m3/min = **36kW**
Energy per kg fish produced	(88 +36)X24x365 = 1086240 kW-h p.a.; 9kW-h per kg @ £0.07 per unit = **£0.63 per kg**
Normal maximum stocking density	Average 25 kg/m2 = 42 kg/m3
Time to market size	30 months
FCR	0.8:1 (Juveniles) to 1.6:1 (Adults)
Average mortality to market size	22%
Production Cost	*** £ 4.10 per Kg live weight** [13]
Selling Price (live-weight before processing)	**£ 3.80 per Kg live weight**

[12] Numbers derived from Golden Sea Produce, Fish Farm in Scotland

[13] Sunday, December 31, 1995: 1 British Pound = 2.11718 Canadian Dollar

Factors Affecting Cost of Closed Containment

Location

Location is a key cost factor in evaluating whether the closed containment method of salmon fish farming is viable. In order to find a suitable location, there has to be substantial and suitable amounts of water supply. In a closed containment, extensive amounts of water have to be pumped into the systems. Pumping head is a major consideration since the site must be close to water to conserve energy. A closer location to the water allows for reduction in energy costs used for pumping. Upon deciding on a location for implementing the closed containment fish farm, key cost drivers that are important with regards to the location of fish farms are[14]

- Logistics (i.e.: access to shipping fish to market, or processing plants)
- Availability and transport costs of key supplies such as fish feed
- Employees and nature of vicinity where they are located
- Location of key services (i.e.: maintenance)
- Distance to markets
- Availability of liquid oxygen

The factors as they are listed above can greatly reduce the cost of production per fish if a suitable location is found. A shorter distance of shipping fish to the market and processing plants can greatly reduce delivery and transportation

[14] J.Ritchlin, 2006. Testimony to the Special Committee on Sustainable Aquaculture in Minutes and Hansard. http://ww.leg.bc.ca/CMT/38thparl/session-2/awuaculture/hansard/W60607p.htm(2of 98) [10/11/2007 8:52A:04AM]

costs. As well, if the location selected has enough human and fish farming resources, it can also reduce these costs for the fish farms. Being able to hire skilled employees to manage, oversee and maintain the fish farms in a location where there is sufficient supply of skilled labor can reduce the labor costs of hiring and training. Furthermore, in choosing a site location or an ocean-based closed containment, waves, energy and wind data will also have to be factored in before selecting a site. Weather is unpredictable and hence, a very close monitoring of the waves and wind data will be necessary and evaluation for a longer time period in order to select the appropriate location of the ocean-based site. All these factors that are associated to location, which includes consultation fees and time spent on locating a site is important in deriving the true cost of implementing the ocean-based closed containment method since these factors can determine the higher initial set up costs.

Production levels and fish density

Upon reviewing the published literature of salmon fish farming worldwide, little to none of the fish farms was able to grow at levels of 1,000mt or more in British Columbia. In recent data of fish farms, between years 1980- 1990's, the levels were normally 500mt per year or less. Reasons for this could be because large fish farms are rare since it has only become more recent that studies show economies of scale can drive costs down. Another reason would be the scarcity of land where only a limited amount of land was available for the fish farms. Lastly, fish farmers have been conservative as a large scale fish farm has a high fixed cost of capital. The question arises whether closed containments can allow for higher volumes of fish to be farmed at one time since it can allow for higher stocking densities and higher output per unit of system volume.

One of the claims for the closed containment method as being more efficient would be the less feed wastage since feed is fed directly to the fishes with none being wasted into the water. Fish feed accounts for 50% of the cost of production in fish farms. Even a 0.1 feed conversion ratio (FCR) improvement is significant to fish farms. This could significantly offset the other costs of closed containment system. Recent studies in BC farms have indicated FCR below 1.2:1, which is impressive. It is also argued that the closed containment can allow for a faster fish growth due to temperature regulation. Currently, typical time to grow smolts to an average of 5.5 kg (salmon demands in BC to be at least 3kg of above) is 22 to 23 months. If the growth can be accelerated, more fish can be produced in shorter periods of time, which can also offset the cost of the closed containments initial set up costs.

Energy Consumption

Energy demand to run a fish farm is a key factor to the many failures in closed containment fish farms. With the ocean-based closed containments, the tide and the pumping head distances can be reduced to allow for floating through systems. The pumping heads can be kept at a minimum distance to reduce energy costs. However, there is a risk associated with ocean based in that concrete tanks can overturn in bad weather and therefore allowing fish and disease escapes.

A draft paper produced for Department of Fisheries and Oceans attempted to do an analysis to compare the resource and energy consumption of Atlantic salmon facility producing 2,500 metric tonnes/cycle. Data was derived from five different types of production systems, which included the open-net pen farms; land based closed containment as well as the closed systems with flexible and rigid walls. The results found that the open-net pen farms used the least amount of energy whereas the land-based closed containment method used the greatest amount of energy. However, the land based system's energy usage and cost can be substantially reduced if re-circulation technologies are employed. The ocean-based closed containment in terms of energy usage fell in the middle which can lead analysts to believe that the ocean-based method can be a better method than land-based closed containment method in terms of energy usage. The ocean-based method option's energy consumption is yet to be determined but the energy is almost for certain less than that of the land-based closed containment. However, it is arguable that land based systems can be a viable options if re-circulation technologies were used.

Economies of Scale

The following is an attempt to represent the cost savings through economies of scale (Table 5). Economies of scale are defined as a reduction in the long-run average and marginal costs due to an increase in size of an operating unit.[15] In the case of fish farming, the cost of producing one fish can be reduced if greater number of fishes is being farmed at the same time. Table 5 represents fish tanks (Tank A and Tank B) of different stock size and volume that are being compared against one another. The A1-A4 is the production stage for fish that remain within the same tank. As can be seen, the feed cost is reduced significantly and the feed conversion is improved as volumes in production increase. Through economies of scale, the cost to produce salmon in an ocean-based closed containment method can be reduced with time and hence, could justify for the higher initial costs of farming. In a closed containment method, high density fish rearing is possible because it allows for a more controlled rearing environment. In the 1995 data as per Table 5, as the size of the stocks increased, the survival rates and feed conversion rates increased. As well, the feed cost reduced. These are high cost savings for fish farms. With the reduction in mortality rates, there will be a greater amount of production and hence, more fish can be sold at the same time.

Table 5: 1995 Data from SRAC Publication No.456

Operating Parameters Per Production Unit						
		Growout tank				
	Tank A	Tank B	A1	A2	A3	A4
Water volume, gallons	1500	4000	15000	15000	15000	15000
Size stocked (grams)	1	15	30	135	250	385
Size harvested (grams)	15	60	135	250	385	567
Survival rate	85%	99%	99%	99%	99%	99%
Feed cost, per pound	$ 0.52	$ 0.38	$0.21	$0.21	$0.21	$0.21
Feed conversion	1	1.1	1.3	1.6	1.6	1.6

[15] http://www.businessdictionary.com/definition/economies-of-scale.html

In an ideal situation, the fish density, in theory, should not exceed the levels where the growth of the fish is compromised. In my literature review, I have found information that show the maximum loading density and how high the density in fish tanks can be without limiting the optimal fish growth. At a high rearing density, it is important to review and compare the water quality which includes the oxygen demands of the salmon as well as carbon dioxide and ammonia levels in the water.

The results found that the mean TGC (thermal growth coefficient) in a number of Atlantic salmon post-smolts studies is 2.7. This growth rate should be attainable in commercial size closed containment systems where the water quality can be controlled. The TGC can be used to estimate growth of Atlantic salmon within the temperature range between 4 and 14 °C which results in 2.3 for the industry's current open net pen system. The result is that the TGC of the closed containment is higher than that of the current industry practice. It is further argued that the closed containment can maintain a food conversion ratio of close to 1, whereas the ratio of current open net pens is 1.26 in the current commercial farms.

As this is not a scientific paper but rather a business and cost analysis paper, a further literature search and analysis on the fish conversion, oxygen levels and water quality will be required in order to provide a more thorough analysis for the results and justifications for limits on optimal fish growth using the closed containment method. Such in depth research is beyond the scope of this paper and the data on fish conversion, oxygen levels and water quality is found in the publications presented here.

Environment

Advocates of the closed containments argue that the closed containment method of salmon fish farming pose less risk to the environment than open net pens since the environmental impacts of the closed containments are internalized. Closed containment means that the environments of the farmed fish are being contained within the systems. As well, it can reduce the fish diseases since it can be contained in the closed containments whereas in open nets the environments of the wild and farmed fishes have no barrier. This raises the question: how can one evaluate the cost of environmental impacts in financial terms? One simple suggestion is to do a cost benefit analysis of the investment if it was to be performed versus if it was not to be performed. Furthermore, the levels of CO2 and nitrate levels can also be quantified. Another cost that would be difficult to quantify would be the public image of farmed fish polluting the environment, which may result in a decrease of purchases from the consumers.

From my literature review, I was able to find some preliminary data for total nitrogen and phosphorus levels per cycle. It is found that net pens produce 124,000 (kg/cycle) of nitrogen and 51,000 (kg/cycle of phosphorus. The close containment produces 98,000-106,000 (kg/cycle) of nitrogen and 32,000-35,000 (kg/cycle) of phosphorus. The closed containments produce significantly lower levels of nitrogen and phosphorus levels per cycle. Health perception of farmed fish is also a consideration when evaluating the systems.

These issues in relation to the environment are often difficult to quantify but can bear significant costs to the fish farms. A closed containment method can mitigate these costs to the environment which could potentially have high impacts to the net income of the farms. Since many benefits such as environmental improvements can not be determined using actual dollar figures, the environment impacts should nonetheless also be factored into the equation of evaluating the benefits of the ocean-based versus the land-based closed containment method. Land-based closed containment has close to zero risk of affecting the water but ocean-based still bear high risks as the farming is still in the waters. Because these potential pollution and environmental improvements, which could be factored into cost reduction, can only be justifiable in the long term, the actual costs or benefits are yet to be determined. An equation involving environmental impacts and or improvement should be included in evaluating the benefits of the different types of methods.

Other Costs

Other costs that are also extremely relevant for a thorough analysis of the ocean-based containment method include recirculation savings/costs, depreciation, finance and staffing. The recirculation of water and the degrees of water reuse can also affect the cost of the land and ocean-based closed containment method. If better techniques can be found where waste can be picked up with new systems designs, it could also potentially reduce costs. A more sophisticated technology is still waiting to be developed.

Other cost factors not yet mentioned in this paper are of the depreciation and financing costs. With land-based fish farms, land is required to be depreciated over time. However, with the ocean-based technology, should the ocean also be depreciated? If so, how should it be evaluated? The opportunity cost of putting in the initial investment for the new method versus other potential business opportunities is also a cost factor that should be evaluated when deciding on the initial investment of ocean-based closed containment method of salmon fish farming.

Lastly, the staffing costs to run the new technology would also be much greater than in the open-net fish farms as practiced in the industry today. Having skilled employees who are able to operate the closed containment will take much more training than that the current open-net pens method. Not only would it take time, it would take a lot of training in order to have trained the staff at their full efficiency levels. How should the cost of training, education and the time it takes for staff to "get the ball rolling" be evaluated?

Although I do not have answers nor literature reviews that have evaluated the questions that I have posed, I think that it is important to include discussion regarding these key cost factors for a more thorough analysis of the evaluation of the ocean-based closed containment method of salmon fish farming.

Results

Of the data that have been found and published on the cost and the viability of the closed containment method, none have proven that the closed containment method is a viable option. It is certain that the initial cost of the concrete ocean-based closed containment is significantly higher than the open net fish farming technique. There have been proposals such as the one from AgriMarine for a $1 million dollar grant for research that was submitted to granting agencies (Federal Western Economic Diversification) to research on the cost of the closed containment method. However, the grant request was rejected. Without government funding it would be very difficult for a private company to fund such a large scale research project as the initial set up costs are very high and the return on investment is yet to be determined.

Research still needs to be done to determine the long-term viability of the ocean-based closed containment, which should include all aspects such as the environmental savings, production level, fish feed and economies of scale. So far, the pilot projects that have been completed to date have not been able to come up with concrete numbers to justify for the sustainability of the method of salmon fish farming. It is still three times higher than that of the open net pens.

Commercial scale trials in British Columbia are still at the implementation stages. Perhaps, once it is up and running the economic and environmental benefits can be more closely studied and documented for determining the viability of the ocean-based closed containment method. A large scale project over a prolonged period of time would be invaluable to further establish viability of the methods.

Conclusion

Observations

Upon reviewing the literature, it quickly became apparent that no such large scale models of ocean-based, closed containment for salmon farming method over a prolonged period of time exist. A prolonged period of time would be fifteen to twenty years.

Researchers and fish farmers have attempted land-based closed containment method but have found that given the technology at the time, the costs greatly exceed the possible selling price of the salmon. It was then quickly regarded as not a viable way of salmon farming without further research for a prolonged period of time and advances in technology such as re-circulations. As noted in the methods of salmon farming, that while pilot models make reasonable research projects, they do not capture the characteristics of real-world cost problems.

I have provided the initial analysis for the ocean-based closed containment method of salmon fish farming which attempts to cope with the uncertainty of the costs that adds difficulty to the real world industrial location problems. While there may be many possible variations to this framework, the very basic requirement of closed containment is the location, fish feed, energy, economies of scale and environmental impacts. Although an attempt has been made in this research to provide an analysis of the costs of the ocean-based closed containment, a more thorough analysis is still necessary to provide an accurate picture of the actual costs in the long run of the method.

The cost of the ocean-based closed containment method of salmon farming is estimated to be three times that of the open-net fish farming technique. Although the cost of a closed containment method is higher, it is a better option of fish farming as compared to the current method of open net farms. An ocean-based closed containment method minimizes the exposure between wild and farmed salmon.

Ocean-based closed containment method, although it can minimize many risks as compared to the current method, it does not completely eliminate the risks to the water and surrounding environment. Key problems associated with ocean based closed containment method include location and weather. The ocean-based closed containment will have to be positioned in urban areas to be connected to the electrical grid. As well, the containments in the water would be perceived as unsightly. In addition, risks in changing harsh weather conditions could potentially affect the containments resulting in risks of failures for the method, which would expose potential harm to the environment.

The land-based closed containment method, although argued to be higher in initial set up costs would be the best available option that can completely separate the farmed salmon and the natural marine environment. It is the only method that has the least risk of fish escapes and disease transfers. As well, if a re-circulation technology is to be utilized, the land based system could be potentially be proven to be a cheaper or comparable method to farm salmon as opposed to the ocean based closed containment.

Until a better, less costly method can be found to farm salmon in a closed containment, I would argue that the best option is still the land-based containment method. Only this method has close to zero risk of fish escapes and disease transfer in addition to completely separating the farmed and wild salmon. It would be arguable that the land-based closed containment may be higher in cost than the ocean-based method. However, I am convinced that consumers would be willing to pay the slight price premium knowing that in the land-based closed containment, there is zero risk (as opposed to ocean-based) of fish disease, fish escapes and weather accidents that would potentially harm the environment.

Scope of Study/Lessons Learned

Since the model of ocean-based closed containment method of salmon fish farming has not been operated on a commercial scale, the benefits of the method in the long run are still yet to be determined. It is not feasible for this project, given the time and financial restraints, to compile a complete and thorough study of the cost of the ocean-based closed containment for a commercial sized farm. A thorough analysis would require various first sources of participation, which may include aquaculture scientists, architects and would require the fish farming industry to become involved in the research process from start to finish.

From the research to date, it is found that we can be certain that the closed containment systems reduce operating and environment risks as compared to the industry's open-net farming since it actively manages the pumping versus the open-net which is passive management. Passive management is the attempt to fix the situation after problems occur. In this ocean-based closed containment, farms are actively reducing the environmental risk by avoiding the waste and reducing the waste in the first place. In addition to environmental waste, the current proposed method will reduce risks such as phytoplankton blooms, predators, low DO2 and fish diseases exchanged between farmed and wild salmon.

From the research completed for this paper, it is found that failure on fish farms through utilizing other methods can be broadly segmented into equipment failures, water related failures, management failures and biological failures. In the past three decades, there have been many fish farms that have attempted to use alternate methods of salmon fish farming such as land based closed containment and flow through systems, of which none were successful. Given the financial and environmental risk involved with ocean-based closed containment, I would argue that land-based closed containment is currently the most promising alternative to open net. However, the fish farm will have to go through a very steep learning curve in order to gain competence, experience and an understanding in order to increase performance and thus, reduce costs. The main reason for many of the system failures in the past is that without a continuous flow of water or supplemental oxygen, there is a great risk of suffocating the fish. With better understanding of why other land-based fish farms have failed, and better monitoring of the currently operating fish farms, the odds of the land-based containment method being successful will be greatly increased.

Recommendations

My recommendations for the switch between open-net fish farming to land-based closed containment of salmon fish farming is as follows:

1. Government subsidizes larger amounts of grant funding to have a commercial size closed containment fish farms, including land based closed containment method, with re-circulation technology built for testing.
2. Analysis of this method for 5-10 years (longer term), even if the costs of production is higher in the first few years of the implementation.
3. An analysis of the benefits of reduction in environmental impacts as well as public negative perception of current practice.
4. Analysis of the cost reduction of economies of scale in production.
5. Further research on other alternative methods of salmon farming which should include scientists, industry and government participation.
6. An analysis that contain key financial data that would present the inputs and deliver key financial results such as production, profits and loss over long term, financing costs, loss in opportunity costs and internal rates of return.

Literature Cites

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Table 6: Statistics Canada 2004 Small Business Profiles- Animal Aquaculture

Report Criteria: 2004 ▸ Canada ▸ All Businesses ▸ % of Total Revenue ▸ 11251

STATISTICS CANADA
2004 SMALL BUSINESS PROFILES - Canada
NAICS Number 11251 Animal Aquaculture

Average of all Businesses	Whole Industry (Reliability)	Lower Half (50%)	Upper Half (50%)	Bottom Quartile (25%)	Lower Middle (25%)	Upper Middle (25%)	Top Quartile (25%)	Percent of Businesses Reporting
Number of Businesses	286							
Revenue Range:								
Low Value ($ 000)	30	30	217	30	89	217	609	
High Value ($ 000)	5000	217	5000	89	217	609	5000	
				(percent of total revenue)				
Total revenue	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Cost of sales (direct expenses)	**44.7**	**23.1**	**47.0**	**18.2**	**25.1**	**42.4**	**48.1**	**52.4**
Wages and benefits	7.0	7.3	7.0	4.7	5.5	8.4	6.6	20.3
Purchases, materials and sub-contracts	48.5	31.5	50.3	23.8	34.6	54.9	49.2	55.2
Opening inventory	27.6	14.1	29.0	19.2	12.0	37.3	26.9	38.5
Closing inventory	38.4	29.7	39.3	29.6	29.8	58.1	34.6	43.0
Operating expenses (indirect expenses)	**73.3**	**103.9**	**70.0**	**125.0**	**95.5**	**88.5**	**65.5**	**99.7**
Labour and commissions	19.3	30.3	17.1	29.8	30.5	30.1	13.9	77.3
Amortization and depletion	8.0	15.6	7.2	24.1	12.2	11.1	6.2	89.5
Repairs and maintenance	3.0	5.2	2.7	7.8	4.2	3.8	2.5	77.3
Utilities and telephone/telecommunication	2.4	5.1	2.1	6.8	4.4	3.5	1.7	84.6
Rent	1.5	2.7	1.4	3.8	2.5	2.7	1.1	49.7
Interest and bank charges	4.9	8.5	4.5	11.4	7.4	7.8	3.7	91.3
Professional and business fees	2.4	7.5	1.9	9.7	5.7	3.2	1.6	94.4
Advertising and promotion	0.5	0.4	0.5	0.5	0.4	0.4	0.5	49.7
Delivery, shipping and warehouse expenses	0.7	1.1	0.6	1.5	0.9	0.5	0.7	43.4
Insurance	1.9	2.3	1.8	2.4	2.2	2.4	1.7	76.6
Other expenses	28.7	25.1	30.2	27.3	24.3	22.9	32.0	96.9
Total expenses	**118.0**	**127.0**	**117.0**	**143.1**	**120.6**	**130.8**	**113.6**	**100.0**
Net profit/loss	**-18.0**	**-27.0**	**-17.0**	**-43.1**	**-20.6**	**-30.8**	**-13.6**	**100.0**
FINANCIAL RATIOS								
Interest coverage ratio	2.7	-2.2	-2.8	-2.8	-1.8	-3.0	-2.7	
Gross margin (%)	55.3	76.9	54.0	81.8	74.9	57.5	51.9	
PROFITABLE vs NON-PROFITABLE BUSINESSES			(thousands of dollars)					
Profitable								
Percent of businesses (%)	42.0							
Total revenue	462.9	108.1	879.3	62.0	149.4	403.3	1425.8	
Total expenses	402.7	84.0	743.4	43.6	120.5	317.0	1232.9	
Net profit	76.1	24.1	135.9	18.4	28.9	86.0	192.9	
Non-Profitable								
Total revenue	559.5	94.5	1002.6	52.9	137.2	352.5	1572.6	
Total expenses	779.0	160.8	1368.0	109.8	213.1	620.4	2018.9	
Net loss	-219.5	-66.3	-365.4	-57.0	-76.0	-267.8	-446.2	