Salmon Aquaculture GHG Emissions

A Preliminary Comparison of Land-Based Closed Containment and Open Ocean Net-Pen Aquaculture

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Forward / Executive Summary

Critics of land-based closed containment salmon production frequently cite that this production method is not desirable, in part, because of its large greenhouse gas (GHG) footprint. This Report provides a preliminary comparison of the production footprint for two salmon farm scenarios: an open ocean net-pen and a land-based closed containment recirculating aquaculture system (RAS).

The Report models the GHG emission for 2000 metric tons of production at an open ocean net-pen farm in the Broughton Archipelago and compares this with the scenario for a land-based farm of commensurate production in Port Hardy.

The analysis accounts for GHG emissions released from the point of feed production leaving the manufacturing gate in Vancouver to the final harvest of fish at the processing plant.

The findings are that the total GHG emissions from open net-pens are substantially higher (5x-10x) than they would be for a modern, efficient closed containment design based in British Columbia. The prime reasons for the lower GHG emissions for closed containment are the use of BC Hydro for power (low fossils fuel use) and the controlled handling of sewage/waste.

This Report indicates that, in consideration of reducing GHG emissions, closed containment technologies should be employed by the aquaculture industry.

It is also important to note that economic support for transitioning the industry from high emissions to low emissions can generate additional revenue from the Pacific Carbon Trust that currently provides $25 MT per CO_2 reduced. This number will rise with time thereby further favouring closed containment aquaculture.

Reviewers

Technical reviews of this document were solicited from independent industry experts.

Points of clarification, scientific or technical critique raised by the reviewers were considered and incorporated into the release version of this document. Any technical errors or difference from peer-reviewed articles remain the error(s) of the author.

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Aquaculture Technology Description

This Report compares the operating scenarios for two salmon aquaculture production methods: open ocean net-pen and land-based recirculating aquaculture system (RAS) closed containment. The analysis is undertaken by accruing greenhouse gas (GHG) emissions from when the feed leaves the production plant in Vancouver to the delivery of fish at the processing plant. The analysis is focused upon simple GHG operating emissions and does not account for farm construction or include a wider Life Cycle Assessment (LCA) which would include adiabatic depletion, human toxicity potential, marine toxicity potential, acidification, eutrophication and cumulative energy demand.

Open Ocean Net-Pen Farm Summary Description

The open net-pen farm is assumed to be located in the Broughton Archipelago and producing 2000 MT per 18 month cycle. Feed is delivered by tug and barge every ten days directly from Vancouver via the Fraser River. The power consumption of the farm is comprised of several generators running to service crew living quarters, feed supply and photo manipulation lights to enhance growth and retard sexual development. These generators are diesel fueled. The practice of using compressors to support airlift pumps and mats to protect crops during plankton blooms has not been accounted for – this is known to be a high energy consumer but the practice has a very low occurrence rate. Thus, this has not been estimated or accrued in the analysis due to lack of accurate operational data.

Crews are exchanged every 4 days by fast aluminum water taxi class boats. Harvest is assumed to occur via converted fishing vessels with a modest 30 tonne capacity. Harvest fish are then assumed to be transported by these boats to a Port Hardy processing plant.

Solid waste is not captured and assumed to fall to the ocean floor.

Land-Based Closed Containment Farm Summary Description

The modeled land-based RAS closed containment farm is assumed to be located near a processing plant in the Port Hardy area on Vancouver Island. Feed is transported by 32 MT flatbed diesel truck from the Vancouver feed mill (EWOS - Skredding, Vancouver). The farm is based on a modern farm design from AKVA, InterAqua, Billings or PR Aqua and consumes electricity at a production rate of 3 kwh/kg or less. This number does not include heating water to an elevated temperature to get a faster fish growth rate. Thus heating costs for higher temperature production are computed assuming the use of heat pump technology and the associated GHG emissions are captured in this analysis.

All solid sewage is captured and appropriately processed. Harvest fish are then transported to an “adjacent” fish processing plant.

GHG Operating Analysis

Two summaries for greenhouse gas emissions from RAS closed containment and open ocean net-pens are provided below in Table 1 and Table 2. For each major contributing component the total tonnage of CO_2 for every 2000 MT of fish production is tabulated. Supporting each contribution is a numerical list of the key input data and assumptions. These key data values have been sourced on–line from appropriate agencies, peer-reviewed documents or from conversations with aquaculture specialists currently working in the industry.

Table 1 Land-Based Closed Containment Operating Carbon Footprint Assessment

Item	**GHG MT CO_2**	**Supporting Data & Assumptions**
Electric Power	150 MT	2000 MT fish production 25 g/kwh BC Hydro CO_2 footprint 3 kwh/kg fish production
Electric Heat	49 MT	50 kg/m^3 production 12 ^{o}C rearing temperature 8 ^{o}C influent temperature 7x COP heat pump performance 20% m^3 daily discharge of production volume 2000 MT production
Feed Delivery Truck	3.3 MT	60 g-MT-km diesel fuel per MT per kilo 1.1 fcr feed conversion ratio 2000 MT production volume 400 km haulage distance
Anaerobic Waste Processing	564.6 MT 300Mwh	Solids processed in an anaerobic digester $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \rightarrow 6CO_2$ + energy 1.1 fcr feed conversion ration 2000 MT production volume 0.25 wcr waste conversion ratio (fish) 0.7 available digestible solids ratio Available energy from methane 800 kw/tonne of waste
Harvest Truck	0.2 MT	60 g-MT-km diesel fuel per MT per kilo 1.1 fcr feed conversion ratio 2000 MT production volume <30 km haulage distance
Total GHG Production	**766.5 MT**	**MT CO_2 / 2000 MT Production**

Land GHG transportation studies vary with results between 30-120 g-MT-km for 32 MT truck transport being cited. Also sparse data is available for tug and barge transport. However, a key thesis from Simon Fraser University (1) that studied this issue for Vancouver's Lower Mainland found that tug and barge transportation burns 40% less fuel than road truck transport. The table below reflects this comparison.

Table 2 Open Ocean Net-Pen Operating Carbon Footprint Assessment

Item	GHG MT CO_2	Supporting Data & Assumptions
Diesel Generator Electric Power	296 MT	Residential (15 kw) 8 - 16hr/day @ 1/2 load Lighting (40 kw) 12 hrs/day x 7 months/cycle @ ¾ load Feeding (40 kw) 8 hrs/day @ ½ load 0.35 liters/kwh generator efficiency 2.63 kgCO_2/liter diesel footprint Calculation can be independently cross-checked from industry data which estimates 5.57 cents/kg-fish fuel bill over 40,000 MT in 2009 = 110,000 litres of fuel per 2000 MT fish production
Labour /Crew Boat	13 MT	4 days frequency of shift 15 liters/hr crew boat consumption 30 nm delivery run 3 liters/nm crew boat consumption 2.63 kg CO_2/liter diesel footprint
Feed Delivery Tug & Barge	1.3 MT	60 g-MT-km diesel fuel per MT per kilo 1.1 fcr feed conversion ratio 2000 MT production volume 400 km haulage distance 0.4 40% efficiency of truck footprint
Ocean Floor Anaerobic Waste Decomposition	283 MT CO_2 7416 MT CH_4	Solids decompose in an anaerobic conditions $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$ 1.1 fcr feed conversion ration 2000 MT production volume 0.25 wcr waste conversion ratio (fish) 0.7 available digestible solids ratio 72 x CH_4 MT multiplier for CO_2 (IPCC 100 year)
Harvest Boats	70 MT	30 MT load/delivery trip 10 hr harvest trip 40 liters/hour consumption 2.63 kg CO_2/liter diesel footprint
Total GHG Production	**8054 MT** **970 MT**	**MT CO_2 / 2000 MT Production assuming methane** **MT CO_2 / 2000 MT Production assuming no methane**

Results

Figure 1 and Figure 2 below compare the weight of GHG emissions for open ocean net-pen and land-based closed containment. The numbers in this analysis are consistent with previous work by Tyedmers (2) and Colt (3) when corrected for operation in British Columbia and referenced to a modern, high efficiency RAS closed containment system.

Figure 1 Land-Based Closed Containment GHG Emissions Total = 766 MT

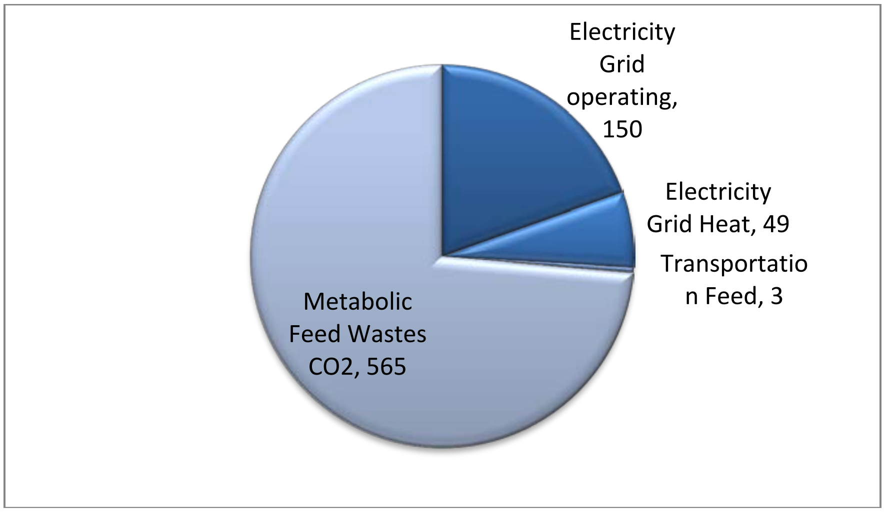
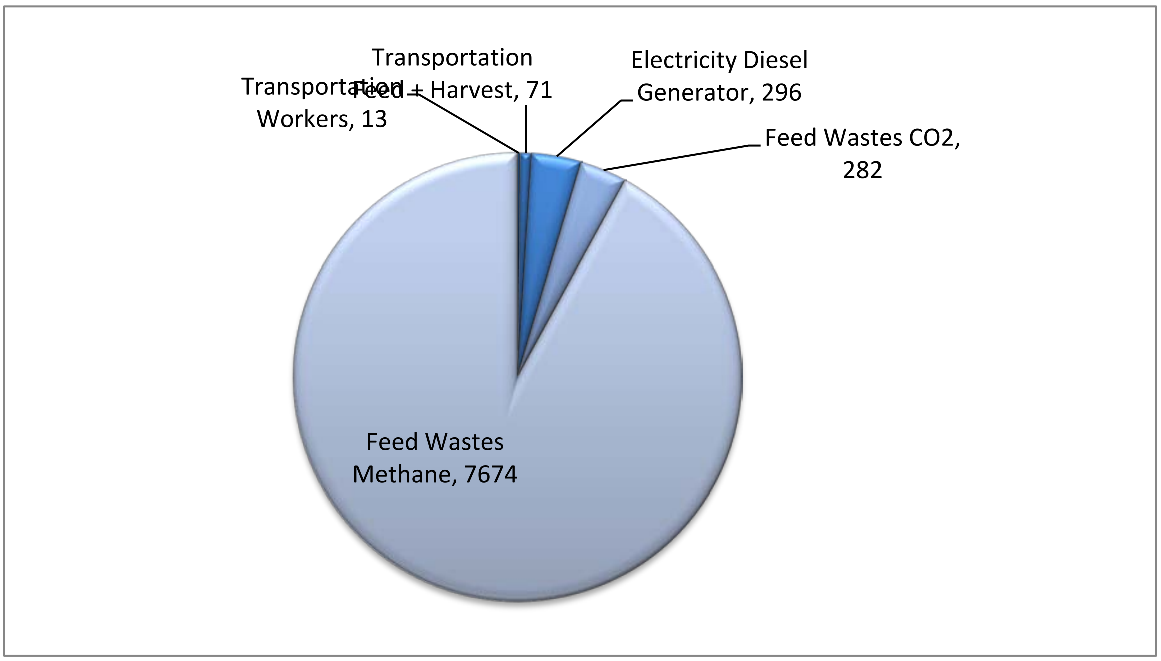


Figure 2 Open Ocean Net-Pen GHG Emissions Total = 8054 MT



The results reveal two key observations. Open ocean net-pens have the ability to have a significantly higher (up to 10x) GHG footprint than land-based farms. In all previous analysis, the GHG contribution from the solid marine waste-stream appears not to have been considered. Solid wastes in anaerobic marine conditions decompose to methane and carbon dioxide in equal concentrations (4) leaving less that 3% solid waste. For the purposes of this analysis only 70% of the organic solid waste was considered available for anaerobic decomposition. These conditions are often found in the thick benthic fouling under the net-pens. Recently methane off-gassing has been video documented from beneath a farm in the Broughton Archipelago (5), supporting this concern.

If methane off-gassing is ignored or discounted then the footprint for an open net-pen farm falls to approximately 1000 MT. This provides a design margin and would allow the closed containment farms electricity issue to degrade from 3 kwh/kg to 5 kw/kg – almost halving the current design performance.

Both observations reveal from an operation perspective that closed containment farms cannot be dismissed as being energy hogs or greenhouse gas polluters. They are at worst a little superior to open net-pens and at best represent a massive 10x improvement over the current industrial open ocean net-pen aquaculture practice for GHG emissions.

Conclusions

This brief analysis was undertaken to simply ground-truth the existing peer-reviewed analysis in the context of British Columbian operations. By reflecting upon modern closed containment farm designs and by considering waste GHG emissions, the potential for improved industrial aquaculture practice is illuminated.

It must be acknowledged that this Report has not considered a full Life Cycle Assessment that includes adiabatic depletion, human toxicity potential, marine toxicity potential, acidification, eutrophication and cumulative energy demand. Such analysis has been previously conducted but did not consider a modern RAS farm design operating in B.C.

It is also important to note that economic support for transitioning the industry from high emissions (net-pen) to low emissions (closed containment) can generate additional revenue from the Pacific Carbon Trust that currently provides $25 per MT CO_2 reduced. This value will rise more with time which would further favor closed containment aquaculture while further penalizing the existing net-pen industry that will pay an increasing cost for fuel.

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