Closed Containment as a Technical Solution – Global Overview

Steven Summerfelt
Aquaculture Is Expanding to Meet World Fish Demand


See www.wri.org/publication/improving-aquaculture for full paper.
Salmon Farming is Efficient

<table>
<thead>
<tr>
<th>Efficiency metric</th>
<th>Salmon</th>
<th>Poultry</th>
<th>Swine</th>
<th>Beef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed conversion</td>
<td>1.2</td>
<td>2.2</td>
<td>3</td>
<td>4-10</td>
</tr>
<tr>
<td>Protein retention</td>
<td>24%</td>
<td>21%</td>
<td>18%</td>
<td>15%</td>
</tr>
<tr>
<td>Edible yield</td>
<td>68%</td>
<td>46%</td>
<td>52%</td>
<td>41%</td>
</tr>
<tr>
<td>Edible meat per 100 kg fed</td>
<td>57 kg</td>
<td>21 kg</td>
<td>17 kg</td>
<td>4-10 kg</td>
</tr>
</tbody>
</table>

*as summarized in Marine Harvest’s 2014 *Salmon Farming Industry Handbook*
Closed Containment For Salmon

• Floating Tanks
  – Solid wall for fish exclusion
  – Typically, no filtration on inlet or outlet flows
  – No water recycling
  – Lakes & sheltered ocean

• Recirculating Aquaculture Systems
  – Land-Based
  – Giant water treatment systems
  – Tiny inlet & outlet flows
Closed Containment Systems

• Both technologies used for salmon production

- Broodstock
- Hatchery
- Smolt
- Growout
- Finishing
- Harvest
- Processing
- Marketing & Distribution
Economics of Land-Raised Salmon

- Similar production costs between land-reared and ocean pen-reared salmon
- ROI of ocean pen-reared salmon is twice that of RAS-reared salmon, when RAS salmon is sold at 30% prem.
  - 80% higher CapEx for RAS
  - Gap is narrowing
RAS Water Treatment System

- Biofiltration
- Aeration-CO2 Strip
- Oxygenation
- Solids Removal
- Color/Fines Removal
- Solids Thickening
- Alkalinity/pH Control
- Culture Tanks
RAS Have Permitted Discharges

Discharge to spring pond at Freshwater Institute

Infiltration Basins at Kuterra
RAS Reclaim Nutrients
RAS Excludes Obligate Pathogens

- **Healthier Fish**
  - Reduce mortality, improve health and performance
  - Reduce or eliminate vaccine, antibiotic, & pesticide use
  - Avoid losses from and costs of mitigating sea lice, viruses (ISA, PD), amoeba, bacteria, toxic algae, superchill
RAS for Salmon Growout
Addresses Market Needs

• Ranked “Best Choice”
• Local & fresh
• Highly traceable
• Consistent production
  – Similar product every week of the year
• No pesticides and no (or reduced) antibiotics
• Environmentally friendly
• All are opportunities to market and brand
# Land-Based Salmon Growout

RAS Already Stocked with Salmon

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>KUTERRA</td>
<td>2.</td>
<td>Golden Eagle Aqua</td>
</tr>
<tr>
<td></td>
<td>(Canada)</td>
<td></td>
<td>(Canada)</td>
</tr>
<tr>
<td>5.</td>
<td>Sustainable Blue</td>
<td>6.</td>
<td>BDV</td>
</tr>
<tr>
<td></td>
<td>(Canada)</td>
<td></td>
<td>(France)</td>
</tr>
<tr>
<td>9.</td>
<td>Swiss Alpine</td>
<td>10.</td>
<td>Jurassic Salmon</td>
</tr>
<tr>
<td></td>
<td>(Switzerland)</td>
<td></td>
<td>(Poland)</td>
</tr>
<tr>
<td></td>
<td>(USA)</td>
<td></td>
<td>(Denmark)</td>
</tr>
<tr>
<td>4.</td>
<td>CanAqua</td>
<td>8.</td>
<td>Danish Salmon</td>
</tr>
<tr>
<td></td>
<td>(Canada)</td>
<td></td>
<td>(Denmark)</td>
</tr>
<tr>
<td>12.</td>
<td>Shandong Oriental</td>
<td></td>
<td>(China)</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12
**Land-Based Salmon Growout**

Facilities Already Growing Salmon

<table>
<thead>
<tr>
<th>Facility</th>
<th>Location</th>
<th>Production Capacity</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuterra Canada (BC)</td>
<td></td>
<td>400 MT</td>
<td>2014</td>
</tr>
<tr>
<td>Golden Eagle Aqua Canada (BC)</td>
<td></td>
<td>~100 MT</td>
<td>~2014</td>
</tr>
<tr>
<td>CanAqua Canada (NS)</td>
<td></td>
<td>~100 MT</td>
<td>2015</td>
</tr>
<tr>
<td>Sustainable Blue Canada (NS)</td>
<td></td>
<td>185 MT</td>
<td>2015</td>
</tr>
<tr>
<td>Freshwater Institute USA (WV)</td>
<td></td>
<td>20 MT</td>
<td>2012</td>
</tr>
<tr>
<td>Superior Fresh USA (WI)</td>
<td></td>
<td>70 MT</td>
<td>2018</td>
</tr>
<tr>
<td>BDV France</td>
<td></td>
<td>50 MT</td>
<td>2013</td>
</tr>
<tr>
<td>Atlantic Sapphire/L.L. Denmark</td>
<td></td>
<td>800 MT</td>
<td>2013</td>
</tr>
<tr>
<td>Danish Salmon Denmark</td>
<td></td>
<td>2,000 MT</td>
<td>2015</td>
</tr>
<tr>
<td>Jurassic Salmon Poland</td>
<td></td>
<td>1,000 MT</td>
<td>2016</td>
</tr>
<tr>
<td>Swiss Alpine Switzerland</td>
<td></td>
<td>600 MT</td>
<td>2017</td>
</tr>
<tr>
<td>Yantai/Shandong China</td>
<td></td>
<td>1,000 MT</td>
<td>2012</td>
</tr>
<tr>
<td>Xinjiang Irtysh River China</td>
<td></td>
<td>1,000 MT</td>
<td>2017</td>
</tr>
</tbody>
</table>
Superior Fresh LLC, Northfield, WI

- 1st commercial land-based Atl. salmon farm in USA
- 1st aquaponic Atl. salmon & leafy green in world
  - ~1000 MT/yr leafy green production
- Zero discharge from production system
## Land-Based Salmon Growout

**Facilities Under Construction/Expansion or Planned**

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Location</th>
<th>Capacity (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nordic Aquafarms</td>
<td>Norway</td>
<td>2,400 MT</td>
</tr>
<tr>
<td>Atlantic Sapphire/L.L.</td>
<td>Denmark</td>
<td>2,000 MT</td>
</tr>
<tr>
<td>Agri Asia</td>
<td>China</td>
<td>250 MT</td>
</tr>
<tr>
<td>Atlantic Sapphire/Miami</td>
<td>USA (FL)</td>
<td>5,000 MT</td>
</tr>
<tr>
<td>Inland Seas</td>
<td>USA (IA)</td>
<td>2,000 MT</td>
</tr>
<tr>
<td>Anon.</td>
<td>USA</td>
<td>5,000 MT</td>
</tr>
<tr>
<td>SmögenLax Aquaculture</td>
<td>Sweden</td>
<td>1,000 MT</td>
</tr>
<tr>
<td>Akvafarm Rjukan</td>
<td>Norway</td>
<td>10,000 MT</td>
</tr>
<tr>
<td>Niri</td>
<td>Scotland</td>
<td>2,000 MT</td>
</tr>
<tr>
<td>FishFrom</td>
<td>Scotland</td>
<td>3,600 MT</td>
</tr>
<tr>
<td>A. Salmon South Africa</td>
<td>South Africa</td>
<td>1,500 MT</td>
</tr>
</tbody>
</table>
Land-Based Trout/Steelhead Growout

RAS Already Stocked with Fish

1. Taste of BC, 100 MT (Canada)
2. Riverence, 100 MT (USA)
3. Bell Aquaculture, 1000 MT (USA)
4. Hudson Valley 1200 MT (USA)
5. Fifax AB, 3000 MT (Finland)
6. Danish Model Farms, 16,000 MT (Denmark)
7. Hayashi, 200 MT (Japan)
Freshwater Institute Growout Trials

1. **USDA ARS** (finished 2011)
   - Gaspe and St John River strain

2. **Atlantic Salmon Federation** (finished 2012)
   - St John River strain salmon @ 40 kg/m³

3. **Gordon & Betty Moore Foundation** (finished 2013)
   - Cascade strain salmon @ 100 kg/m³

4. **GBMF & ASF** (finished 2014)
   - Cascade strain salmon @ 2 photoperiods and 120 kg/m³ biomass density

5. **GBMF & Salmobreed** (finished 2015)
   - Norwegian strain salmon @ 2 feed strategies and 95 kg/m³ density

6. **GBMF, ASF, & Salmobreed** (finished 2016)
   - Norwegian strain salmon @ 94 kg/m³ with custom **sustainable feed formulation**

7. **No funding** (2016 to 2017)
   - Norwegian strain salmon @ 90 kg/m³ with custom **natural & sustainable feed formulation**

8. **No funding** (2017 to 2018)
   - **All-female Icelandic strain** now 250 g
Freshwater Institute Growout Trials

• Consistent growth after 500 g, independent of:
  – Feed-type, density, strain
CtrlAQUA Research to Optimize Closed-Containment Systems for Atlantic Salmon Post-Smolt Production

Bendik Fyhn Terjesen
Centre Director, CtrlAQUA SFI
Senior Research Scientist, Nofima
Norwegian Salmon Farming in 2050

- Multi-million ton salmon produced annually in 2050?
  - It has been predicted that Norway alone will produce 5 mill. ton salmon in 2050 (Olafsen et al 2012)
  - 5x increase in production volume, 8x in total value creation
  - Large increases in related industries, such as water treatment technologies
  - This prediction assumes that sustainability issues are solved, such as sea lice, escapes, and high fish mortality

Envisioned value generation (in NOK) provided limiting factors for growth in the aquaculture value chain are addressed. Value estimates from Olafsen et al (2012). 1 US$ ~ 8.5 NOK
How do we combat sea lice and other challenges in the future?

Propose that the future of salmon farming is "a combination of different approaches, including partly onshore farming, offshore farming, and breeding of special types of fish that eat salmon lice."*

*BFT interview to Wall Street Journal “Fish Farming Explores Deeper, Cleaner Waters”, printed 18 April 2014.

Terjesen, unpublished, 2014. CCS = Closed-Containment Aquaculture Systems
Postsmolts are sea-water adapted salmon, up to ~1 kg

- CtrlAQUA working hypotheses on postsmolts from closed systems:
  - Less sea lice
  - Faster growth and reduced mortality
  - Improved fish welfare
  - Better exploitation of net pen licences
  - Reduced production time
  - Research is useful also for closed systems to harvest size
Several RAS for 1000-2000 ton/yr postsmolts or for harvest size now operating or being built in Norway
Development licences in sea: many closed-containment systems in submitted proposals (>200 000 tons/yr total)
What is the capacity for closed system production, in operation or planned in Norway?

Today: 25 000 ton/yr in closed systems as smolts in Norway

Closed systems on land

- Smolt in closed systems (RAS) land-based
  - 0-80 g

- Postsmolt in closed systems (RAS) land-based
  - 80 g – 1 kg

Closed systems in sea

- Smolt in closed systems (RAS) land-based
  - 0-80 g

- Postsmolt in floating closed systems sea
  - 80 g – 1 kg

To harvest size in RAS land-based

- 1 kg – 5 kg

Licenses: 14 300 ton land + 10 700 ton sea = 25 000 ton

Signals: 20 000 ton land-based systems to harvest

If all salmon in Norway to 1 kg in closed systems: 290 000 ton, 12x necessary!

Estimate closed system capacity: ~70 000 ton (operating + licences + plans)
CtrlAQUA SFI objective (2015-2023)

Develop technological and biological innovations to make closed-containment aquaculture systems (CCS) a reliable and economically viable technology, for use in strategic parts of the Atlantic salmon production cycle-

- thus contributing to solving the challenges limiting the envisioned growth in aquaculture
**Host institution:**
- Nofima

**R&D partners:**
- UNI Research
  - University of Bergen
- Norwegian University of Science and Technology (NTNU)
- The Freshwater Institute, WV, U.S.
- University of Gothenburg
- University of South-east Norway

**User partners:**

**Technology suppliers:**
- Krüger Kaldnes
- Storvik Aqua
- Aquafarm Equipment
- Oslofjord Ressurspark
- FishGLOBE
- Botngaard

**Farming companies:**
- Marine Harvest
- Cermaq
- Grieg SeaFood
- Lerøy SeaFood Group
- Bremnes Seashore
- Smøla Klekkeri & Settefisk

**Biotechnology companies:**
- Pharmaq
- Pharmaq Analytiq

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CtrlAQUA focus areas

Innovations for industry-reliable closed systems

Closed systems today

Dept. Technology & Environment
Dept. Production & Welfare
Dept. Preventive Fish Health
Dept. Training & recruitment

Photo: Terje Aamodt
Some of the 18 current CtrlAQUA projects

**SENSOR**: Sensor protection & maintenance in closed systems

**CO2RAS**: To determine optimal CO$_2$ levels for use in dimensioning of RAS for post-smolts

**PARTICLE**: Particle tolerance in post-smolts reared in recirculating aquaculture systems (RAS)

**HYDRO**: Hydrodynamic challenges in huge tanks >1000 m$^3$

**PHOTO and BENCHMARK**: Health and performance in post-smolts when using novel production protocols

**BIOMASS**: Machine vision for biomass in closed systems

**BARRIER/SalmoFutura**: Barrier-functions (against pathogens) related to salt balance, and chronic and acute stress in post-smolts reared in closed systems

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SAVE THE DATE!

2017 Aquaculture Innovation Workshop

An international summit on fish farming in closed-containment systems

NOVEMBER 29-30, 2017

Woske Center, Vancouver
Conclusions

• Land-raised salmon reduce/remove interaction of farmed with wild
• Increased investment is leading to advances in technology that is accelerating it’s deployment
• Capital and operating costs are being reduced by
  – improvements in technology & design,
  – standardization in equipment/construction methods,
  – economies of scale
• Research into fish performance, feeds, optimal conditions is also helping to improve economics/reduce risk
  – UBC
  – Freshwater Institute
  – Nofima/CTRLAQUA
Conclusions

• Developments in biologically sound technical systems have made food fish production in environmentally sustainable land based, closed-containment aquaculture systems an emerging opportunity.

• Economic success depends on market and business development
Acknowledgements