Effects of water salinity and exercise on Atlantic salmon performance as postsmolts in land-based closed-containment systems

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Background

- Loss of fish in Norwegian production at same level now, ~20% during cage phase, as 12 years ago (Arealutvalget 04/02/11)
- Much of the loss of fish, and feed intake and growth reduction, occur early after stocking small smolts in sea (<100 g/ind) (e.g. Oehme et al., 2010)

Mass specific feeding rate of 1+ salmon (SFR, % day\(^{-1}\)) stocked at sea late May

• Lice problems are considerable in cage production
• One possible solution can be to reduce the time spent in traditional “open” cages in sea
• The Ministry of Fisheries and Coastal Affairs in Norway recently opened for an increase in fish size in land-based facilities, from 250 g to 1 kg

• A larger smolt for stocking at sea,
  ✓ may reduce lice-problems,
  ✓ may reduce loss of fish, and improve growth
  ✓ may reduce prod. time, especially in areas with low winter temp

• Several Norwegian companies and R&D institutions joined forces in 2012 to explore how such post-smolt production can be done, in the RCN project OPP “Optimized Postsmolt Production”
Main objective in OPP

To develop basic and applied knowledge about how the time spent in open cages in sea can be reduced, by increasing the time on land or in semi-closed systems at sea, and to determine the consequences for the performance, physiology, and welfare of the fish and production costs
Combination-lines, to 1 kg in closed-containment systems

Closed-containment on land
- Smolt prod in freshwater RAS land-based
- Postsmolt in seawater? RAS land-based
- Shorter period in cages before slaughter

Semi-closed containment in sea
- Smolt prod in freshwater RAS land-based
- Postsmolts in semi-closed containment in sea
- Shorter period in cages before slaughter
**OPP: Problems to tackle**

- **Problem:** Cato Lyngøy, former Group Technical Manager Technology & Environment Marine Harvest, and chairman in OPP:
  
  «So far we have not seen any closed-containment system that is sufficiently cost-effective, for production of a postsmolt up to 1 kg, neither on land or in sea»
  
  (IntraFish, 29/10/12)

- **Problem:** Insufficient biological knowledge of what the physiological requirements of Atlantic salmon postsmolts are in closed containment systems, for optimal technology performance, fish performance, welfare, and health

To be tested in OPP: Land-based RAS (recirculating aquaculture systems) for production to 1 kg

![Photo: Aquafarm Equipment](image1)

To be tested in OPP: Production in semi-closed containment systems in sea to 1 kg (21 000 m³ vol, 450 m³/min flow)

![Photo: Aquafarm Equipment](image2)
Salinity in land-based RAS, combination-line

- SW-RAS may have higher running costs than FW-RAS due to:
  - $\text{CO}_2$ removal efficiencies are lower in SW than in FW (e.g. Moran, 2010)
  - Ammonia removal is lower in SW compared to FW (e.g. Chen et al, 2006)
- Results in need for larger installation and/or higher flow
- Or can postsmolts be kept at lower salinity in RAS, and still handle full-strength SW at stocking in sea?
Objectives and experimental design, effects of salinity and exercise for postsmolt in RAS

✓ What is optimal salinity for postsmolts in RAS, in terms of survival, health, and maturation to 1 kg size?
✓ Can lower salinity reduce maintenance costs and increase available energy for growth?
✓ Can exercise through water velocity contribute to these factors, and interact with salinity treatment?

Terjesen et al., unpubl.
Methods

- 3 separate RAS with salinities 12, 22 and 32 ppt, and two exercise levels, i.e. a 3x2 factorial study
- 7 200, 70 g smolts were stocked in 12 tanks (3.2 m²), duplicate/treatment
- 12:12h light:dark during the experiment, 12-13°C, high marine protein commercial diet (Havsbrun, 3-4 mm pellet), feed intake measurements
- On-line measurements of e.g flow, pH, ORP, temperature, O₂
- A range of tissue samples collected, for trad. physiology, histology, and molecular physiology
RAS configuration during trial

RAS 2

1. Make-up water with flowmeter
2. Degasser
3. Belt filter w/sludge discharge
4. Pump sump w/overflow
5. Pump sump w/overflow
6. Moving bed bioreactor
7. Ozone side-stream
8. Ozone injection w/degas separator

Central water treatment room

Experimental hall 1/2/3

1. Fish tank
2. Fish tank
3. Fish tank
4. Swirl separator w/sludge discharge
5. Sidewall drain

Terjesen et al., unpubl.
Swimming speed (BL/s) to ~250 g

Mean ± range (n=2 tanks per treatment)

Terjesen et al., unpubl.
## RAS conditions

<table>
<thead>
<tr>
<th>RAS</th>
<th>Temp °C</th>
<th>pH</th>
<th>CO₂ mg/l</th>
<th>Alkalinity CaCO₃ mg/l</th>
<th>% Reused flow</th>
<th>% Water exchange /day</th>
<th>Feedload, % of capacity</th>
<th>Feedload/ water exh (kg/m³ /day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12‰</td>
<td>12.4±0.9</td>
<td>7.5±0.2</td>
<td>6.1±1.5</td>
<td>72±20</td>
<td>98.7±0.8</td>
<td>25±7</td>
<td>11.0±3.4</td>
<td>0.44±0.30</td>
</tr>
<tr>
<td>22‰</td>
<td>12.1±0.8</td>
<td>7.6±0.1</td>
<td>7.0±0.2</td>
<td>110±26</td>
<td>98.8±0.7</td>
<td>24±6</td>
<td>10.6±3.9</td>
<td>0.49±0.28</td>
</tr>
<tr>
<td>32‰</td>
<td>12.6±0.9</td>
<td>7.8±0.1</td>
<td>6.9±0.4</td>
<td>137±33</td>
<td>98.9±0.4</td>
<td>25±2</td>
<td>9.1±3.9</td>
<td>0.46±0.20</td>
</tr>
</tbody>
</table>
Water quality: TAN and NO$_2$-N concentration

Average TAN conc. at the tank outlet

Average NO$_2$-N conc. at the tank outlet

Terjesen et al., unpubl.
TAN removal efficiency over MBBR

Terjesen et al., unpubl.
CO$_2$ removal efficiency over countercurrent, forced-ventilated degasser

![Graph showing CO$_2$ removal efficiency vs CO$_2$ inlet concentrations]
Postmolt sampled at ~250 g, produced in 12 ppt S RAS

Ind. weight at ~250 g/ind

TGC to ~250 g/ind

Terjesen et al., unpubl.
Postmolts sampled at ~800 g, produced in RAS.

Salinity, ppt: 12, 22, 32

Thermal growth coefficient:
- Factor salinity: p<0.01
- Factor exercise: p<0.01

Final weight:
- Training: no training
- Salinity: p<0.01 Training: p<0.01

Terjesen et al., unpubl.
Results: Organ indexes at 250 and 800 g

Male gonad size 250 g/ind

Heart index 250 g/ind

Cardiosomatic index (% BW$^{-1}$)

Salinity

Male gonad size 800 g/ind

Heart index 800 g/ind

Cardiosomatic index (% BW$^{-1}$)

Salinity

Results: Organ indexes at 250 and 800 g

Terjesen et al., unpubl.
Why is growth higher at lower salinity and training?

Individual feed intake period 1 (BW 70-250 g)

Effect of salinity: $p<0.01$

Effect of exercise: $p<0.05$

Cumulative feed intake g per tank period 1-3

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Survival, when the postsmolts were kept at 12, 22, or 32‰, through the entire trial

Sensitive period

Mean survival in cages

Fish weight (g)
Survival when transfer from 0 ppt (start) or 12/22/32‰ to 32‰ at different sizes

At end of trial ~800 g

Change to 32‰ directly in existing 12 tanks

Terjesen et al., unpubl.
Summary survival, when the fish is transferred to 32‰ at different sizes.
Sea water tolerance when transferred to 32-34 ‰, for 72 hours, at different sizes

Plasma chloride

No significant effects of treatment (previous salinity or exercise)

11.09.2013 Terjesen et al., unpubl.
Welfare

- **External welfare indicators:**
  - In our experience a set of sensitive indicators (e.g. density)
  - Small, inconsistent effects on fin erosions
  - Earlier manifestation of cataracts in fish kept at 32‰ RAS, versus 12 and 22 ‰
  - More external skin damage in exercised fish at 22 and 32 ‰, versus non-exercised, but this was not found at 12‰.

Skin health

✓ Important organ for pathogen and parasite control
✓ Les mucous and more tissue damage, at increasing salinity, and size
✓ Exercise had a negative effect on skin health at 22 and 32, **but not at 12 ‰**
✓ Up-regulation of the stress related genes HSP70 and iNOS at 32, 22 vs 12‰
✓ We are establishing a skin analytical pipeline, since skin-health may be a particular problem
Industry-scale testing in OPP

- **Testing combination-line, closed-containment RAS**
  - Commenced in July at Grieg SeaFood, Finnmark, northern Norway, 12 and 22‰ salinity

- **Testing combination-line, semi-closed in sea**
  - Start testing in Oct. at Smøla Klekkeri and Settefisk, and in 21 000 m³ tank, Marine Harvest, western Norway.
Conclusions

- **Also salmon benefits from less salt and more exercise**
  - Closed-containment systems make environmental control possible
  - Lower salinity: increased feed intake, growth rate, improved skin health
  - **Combination with exercise maximized this effect**
  - No general maturation was observed, via GSI
  - Lower salinity improved removal efficiency of TAN and CO2
  - Such types of findings may contribute to reduced costs in closed-containment systems

- **Production in closed-containment to 1 kg may contribute to smaller losses in Norwegian production**
  - Best group, 12‰ + exercise = 99% survival -6% at transfer to 32‰, = 93% survival to ~900 g
  - BUT: at 400-700 g the fish was very sensitive to handling
  - This trial suggest a use for closed-containment RAS, also in grow-out phase in Norwegian aquaculture