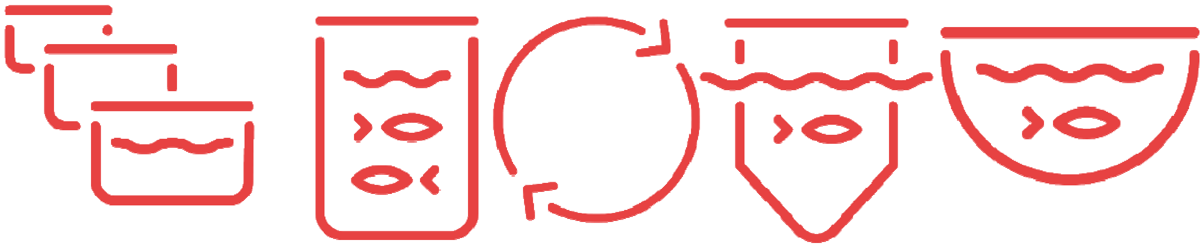
CtrlAQUA Research to Optimize Closed-Containment Systems for Atlantic Salmon Post-Smolt Production



sfi Senter for forskningsdrevet innovasjon
Norges forskningsråd

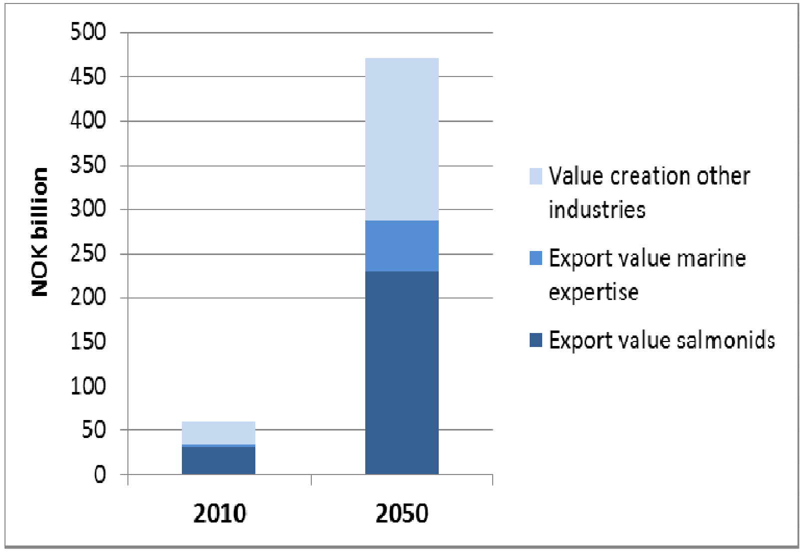
Bendik Fyhn Terjesen
Centre Director, CtrlAQUA SFI
Senior Research Scientist, Nofima

Nofima

CtrlAQUA

Salmon farming in 2050

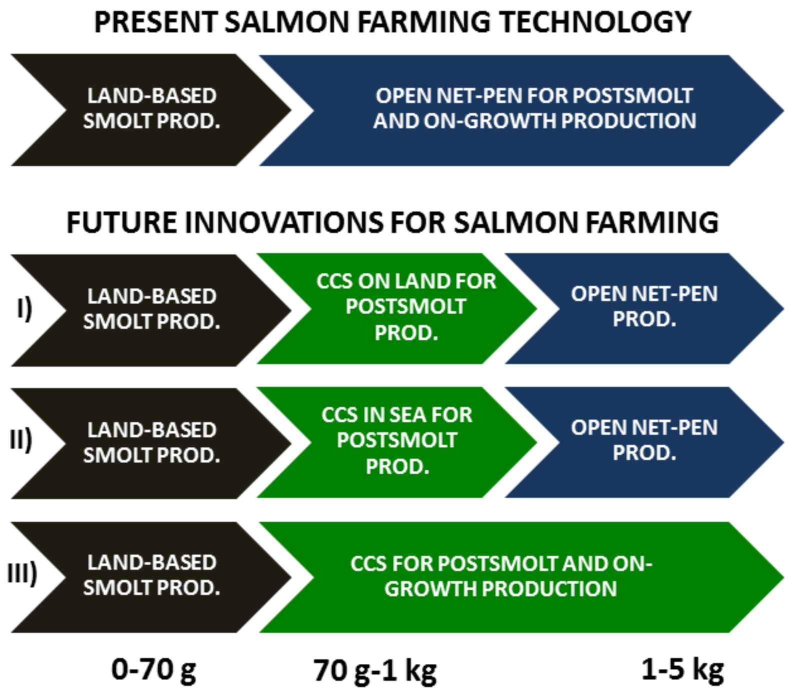
- **Multi-million ton salmon produced annually in 2050?**
  - ✓ It has been predicted that Norway alone will produce 5 mill. ton salmon in 2050 (Olafsen et al 2012)
  - ✓ 5x increase in production volume, 8x in total value creation
  - ✓ Large increases in related industries, such as water treatment 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Terjesen, unpublished, 2014.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

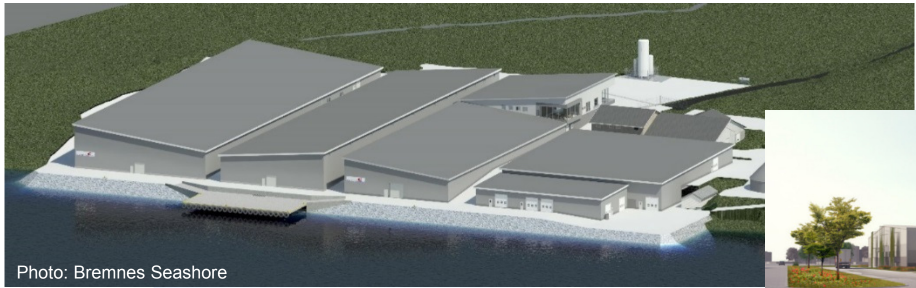


Photo: Bremnes Seashore


Photo: Fredrikstad Seafood


Photo: Hatchery International


Photo: Medvind24

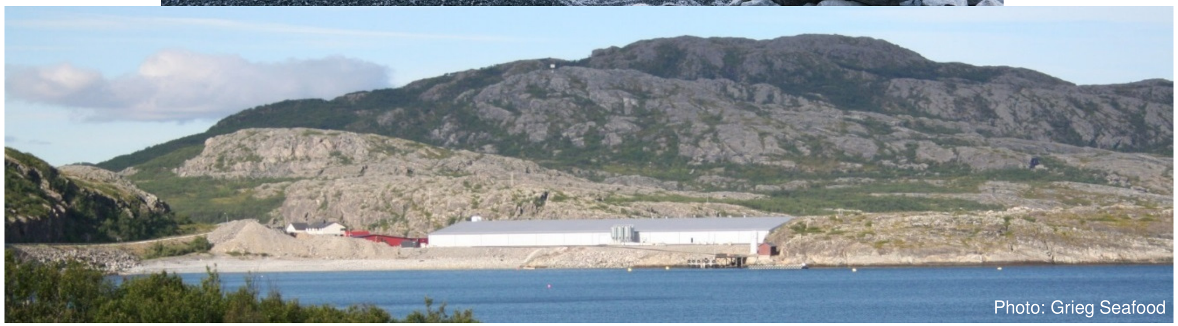


Photo: Grieg Seafood


Photo: Sævareid

CtrlAQUA Nofima

Development licences in sea: many closed-containment systems in submitted proposals (>200 000 tons/yr total)

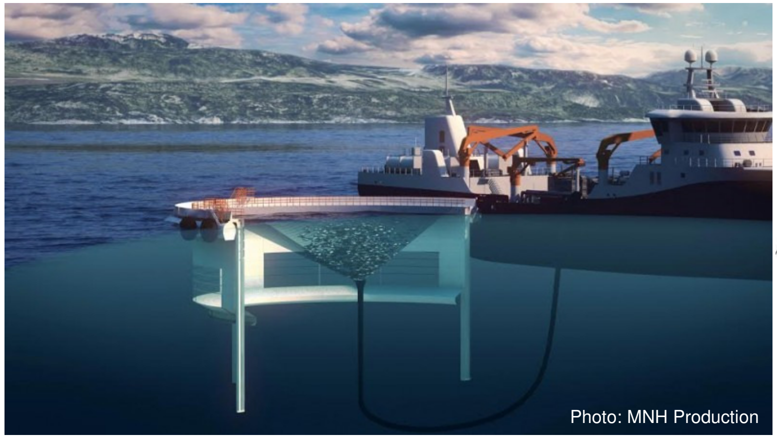


Photo: MNH Production

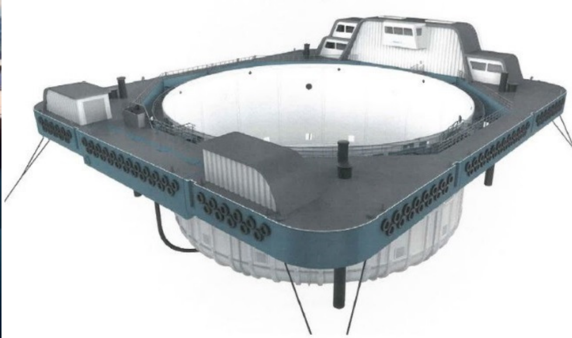


Photo: Aquafarm Equipment

Photo: ØDP

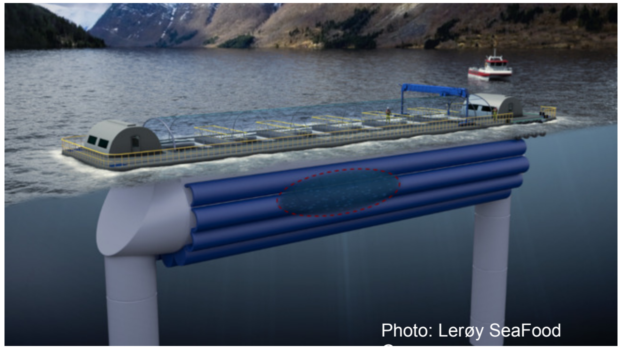


Photo: Lerøy SeaFood

Photo: Hauge Aqua

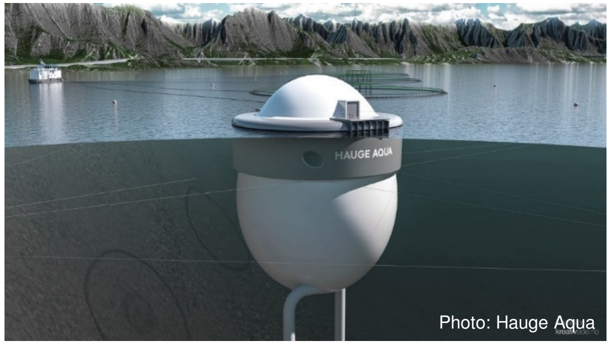


Photo: Hauge Aqua

CtrlAQUA Nofima

What is the capacity for closed system production, in operation or planned in Norway?

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)

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

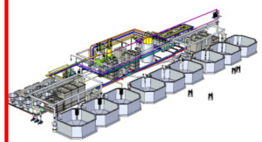
Licenses: 14 300 ton land + 10 700 ton sea = 25 000 ton

Signals: 20 000 ton i land-based systems to harvest

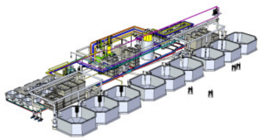
Closed systems on land

Smolt in closed systems (RAS) land-based → **Postsmolt in closed systems (RAS) land-based** → **To harvest size in RAS land-based**

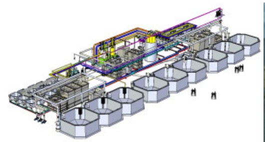
0-80 g



80 g – 1 kg



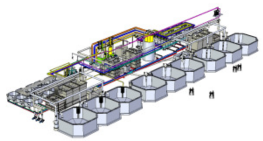
1 kg – 5 kg



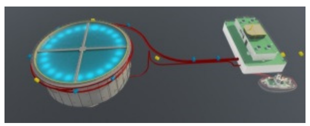
Closed systems in sea

Smolt in closed systems (RAS) land-based → **Postsmolt in floating closed systems sea** → **Short time in open net pens, coastal or offshore**

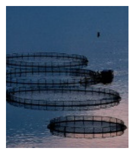
0-80 g



80 g – 1 kg



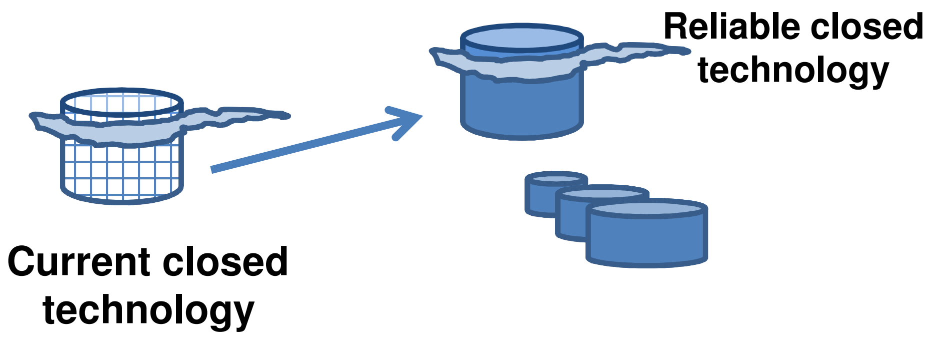
1 kg – 5 kg



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



21 CtrlAQUA SFI partners

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

CtrlAQUA focus areas

Innovations for industry-reliable closed systems

Photo: Terje Aamodt

Dept.
Preventive Fish Health

Dept.
Production & Welfare

Dept.
Technology & Environment

Dept.
Training & recruitment

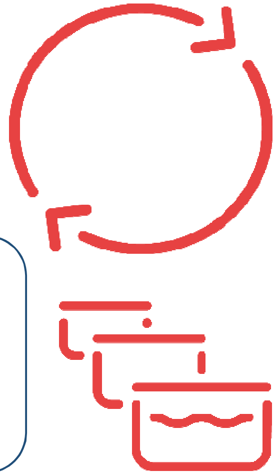
Closed systems today

CtrlAQUA Nofima

Some of the 18 current CtrlAQUA projects

SENSOR: Sensor protection & maintenance in closed systems

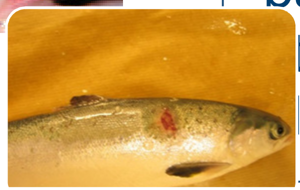
CO2RAS: To determine optimal CO_2 levels for use in dimen-sioning of RAS for post-smolts



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

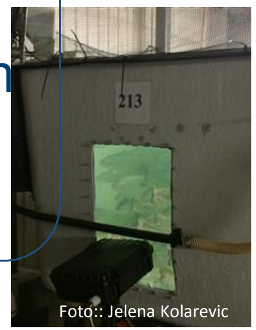
PHOTO and BENCHMARK: Health and performance in post-smolts when using novel production protocols

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

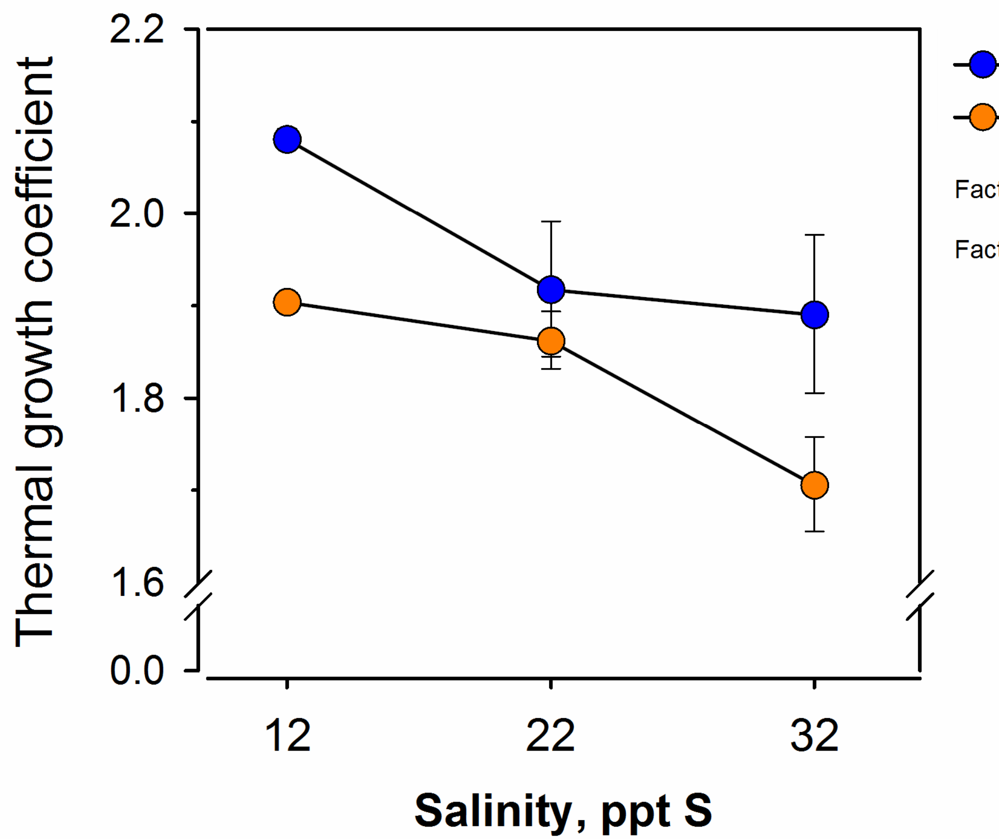


BARRIER/SalmoFutura: Barrier-functions (against pathogens) related to salt balance, and chronic and acute stress in post-smolts reared in closed systems

BIOMASS: Machine vision for biomass in closed systems

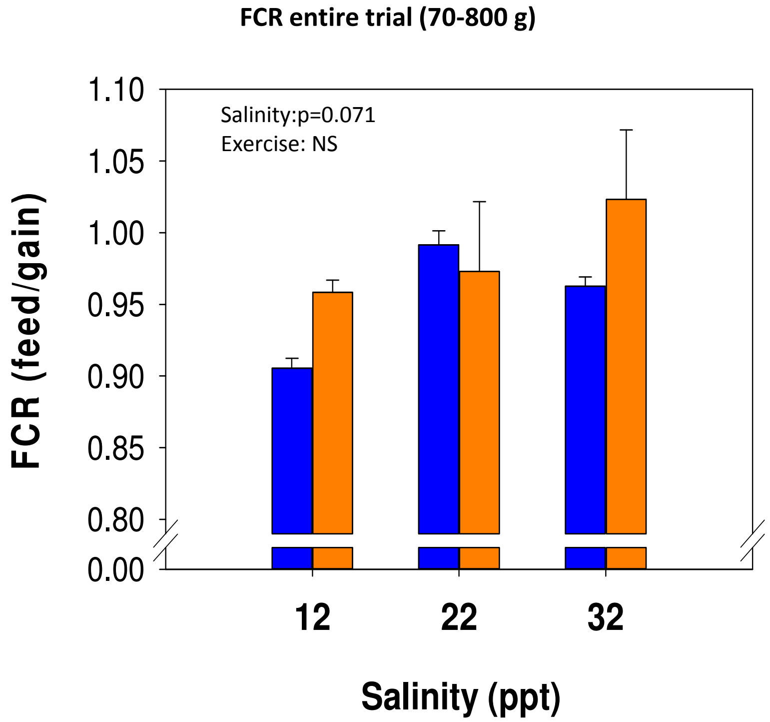


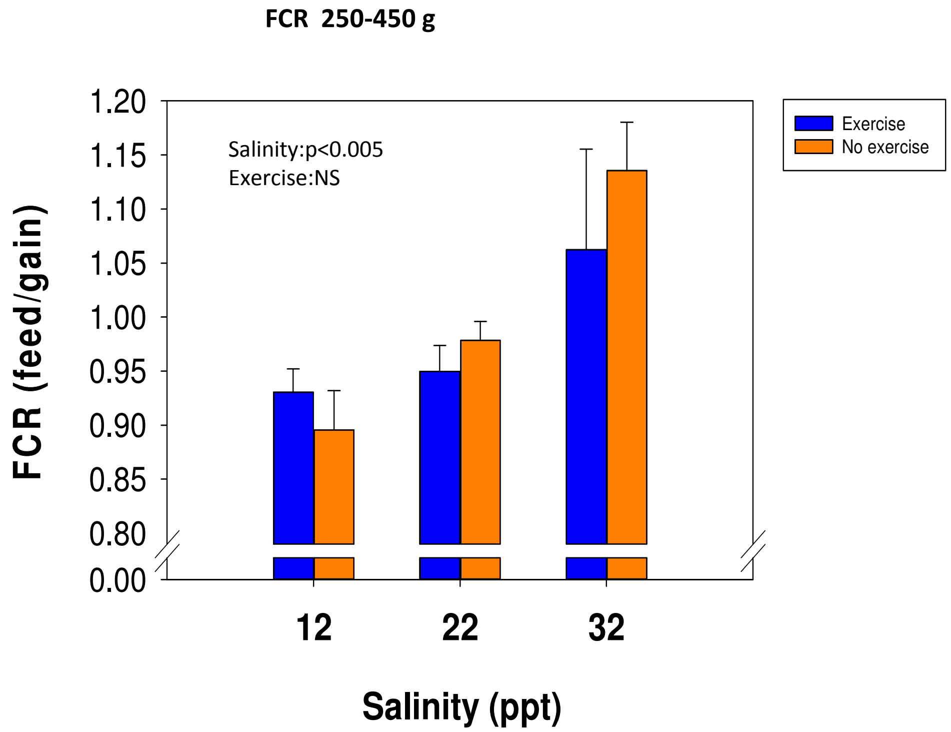
Growth rate improved in RAS with lower salinity and more exercise



Ytrestøyl, T., Takle, H., Kolarevic, J., Calabrese, S., Rosseland, B., Teien, H.-C., Nilsen, T.O., Stefansson, S., Handeland, S., Terjesen, BF., 2013. Effects of salinity and exercise on performance and physiology of Atlantic salmon postsmolts reared in RAS, Abstracts Aquaculture Europe 2013. European Aquaculture Society, Trondheim, 465.

Improved feed utilization at lower RAS salinities (FCR, feed:gain)

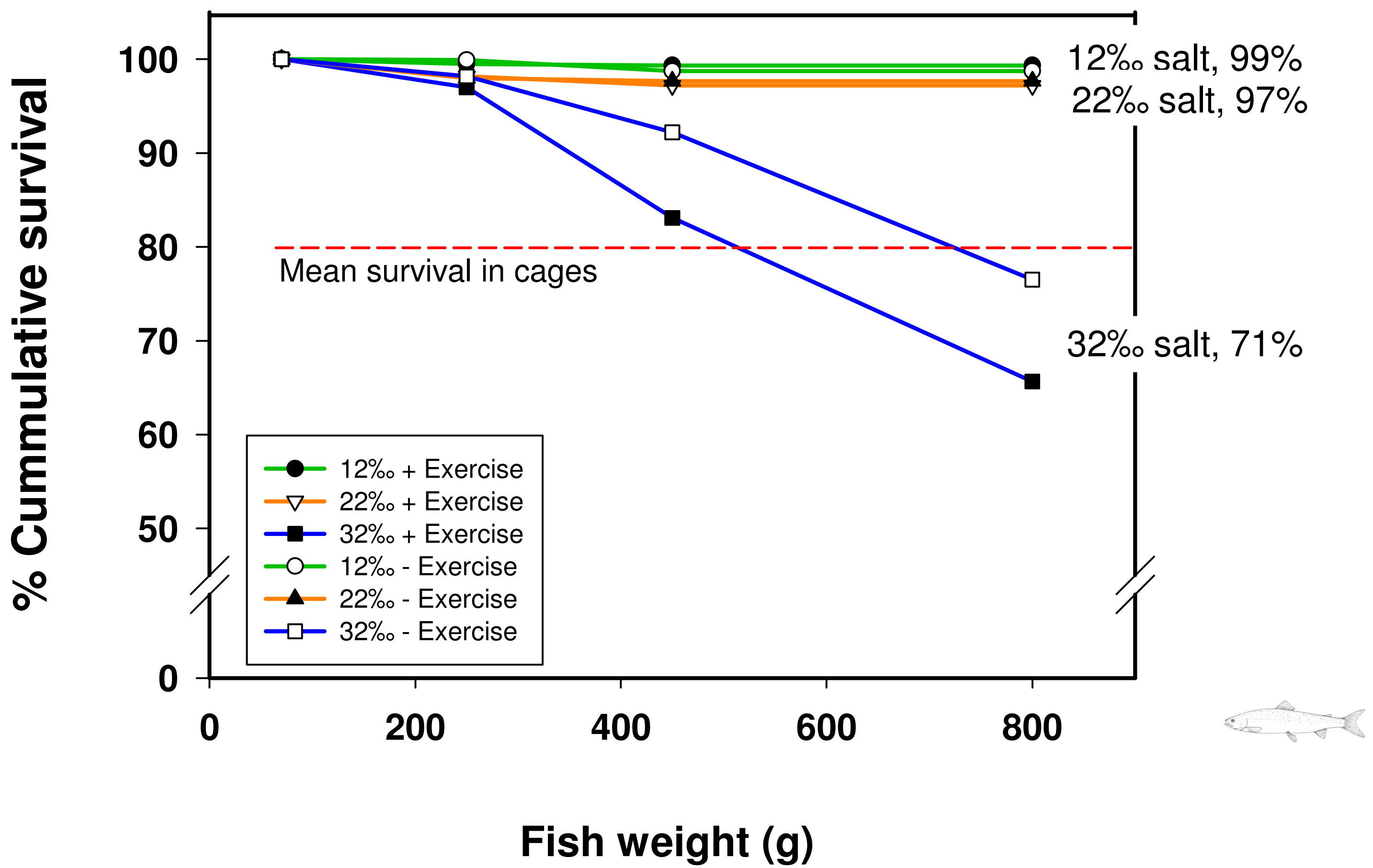




Ytrestøyl, T., Takle, H., Kolarevic, J., Calabrese, S., Rosseland, B., Teien, H.-C., Nilsen, T.O., Stefansson, S., Handeland, S., Terjesen, BF., 2013. Effects of salinity and exercise on performance and physiology of Atlantic salmon postsmolts reared in RAS, Abstracts Aquaculture Europe 2013. European Aquaculture Society, Trondheim, 465.

CtrlAQUA Nofima

Improved survival at low salinities, when kept in similar conditions throughout

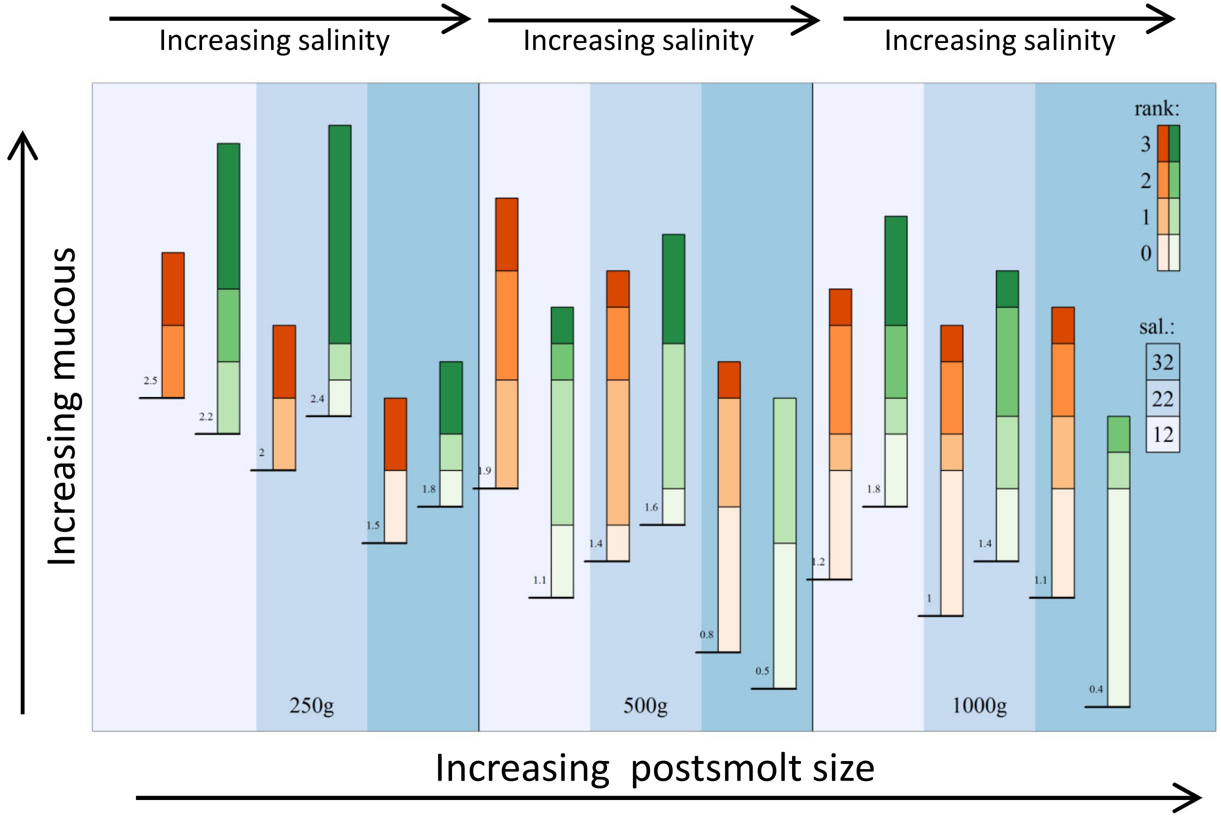


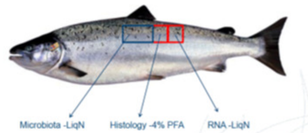
Ytrestøyl, T., Takle, H., Kolarevic, J., Calabrese, S., Rosseland, B., Teien, H.-C., Nilsen, T.O., Stefansson, S., Handeland, S., Terjesen, BF., 2013. Effects of salinity and exercise on performance and physiology of Atlantic salmon postsmolts reared in RAS, Abstracts Aquaculture Europe 2013. European Aquaculture Society, Trondheim, 465.

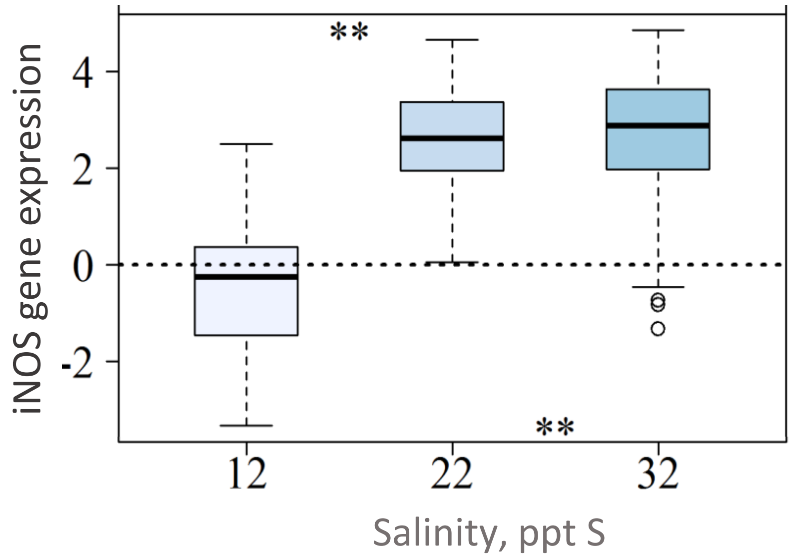
CtrlAQUA Nofima

Skin health and welfare

- ✓Important tissue for pathogen and parasite control
- ✓Significantly less mucous and more tissue damage, at higher salinity, and postsmolt size
- ✓Exercise had a negative effect on skin health at 22 and 32, but not at 12 ‰, at end of exp.
- ✓Up-regulation of stress-related genes HSP70 and iNOS in skin at 32,22 but not at 12‰

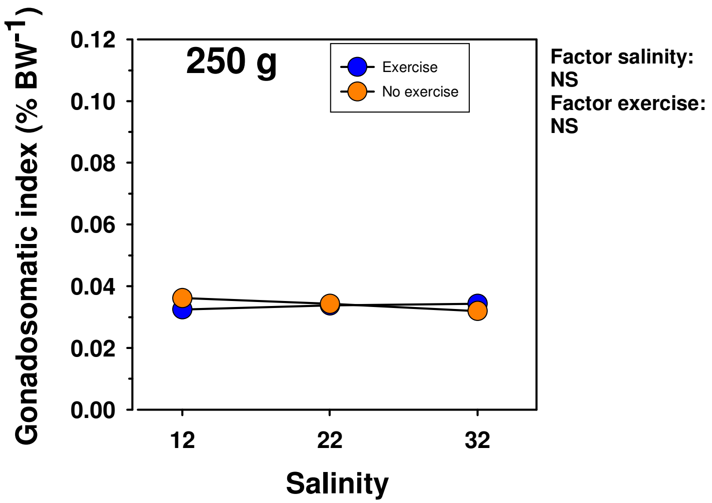


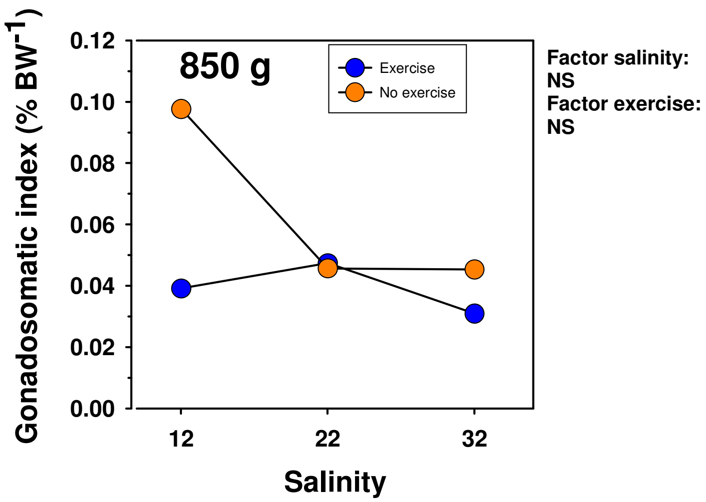




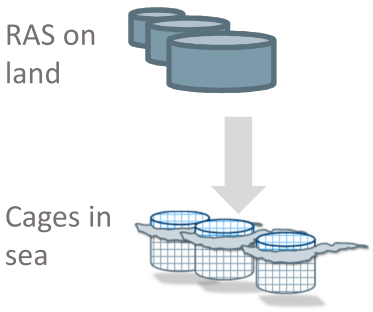
Ytrestøyl, T., Takle, H., Kolarevic, J., Calabrese, S., Rosseland, B., Teien, H.-C., Nilsen, T.O., Stefansson, S., Handeland, S., Terjesen, BF., 2013. Effects of salinity and exercise on performance and physiology of Atlantic salmon postsmolts reared in RAS, Abstracts Aquaculture Europe 2013. European Aquaculture Society, Trondheim, 465.

Little early maturation observed when using RAS postsmolt strategies at ~12.5°C





600 g - 2,600 g



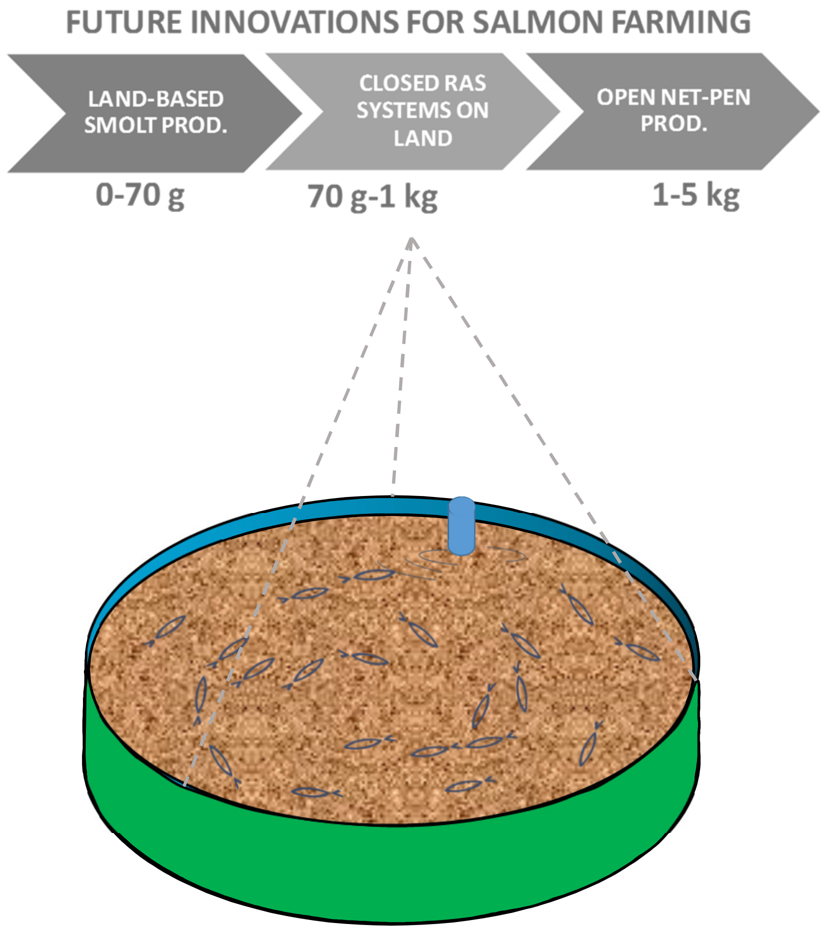
Treatment	Sampling	BW (g)	CF	GSI	HSI	CSI
RAS 12 ‰	May 2nd	**628±34**	1.34±0.07	0.07±0.03	1.11±0.16	0.09±0.03
RAS 12 ‰	June 6th	**971±57**	1.46±0.08	0.35±1.01	1.07±0.12	0.10±0.03
RAS 12 ‰	Oct 30th	**1696±46**	1.35±0.11	0.20±0.17	0.88±0.09	0.08±0.01
SW 600 g	Oct 30th	**2594±393**	1.42±0.1	0.10±0.04	1.18±0.13	0.09±0.03
SW 1000 g	Oct 30th	**1880±550**	1.28±0.2	0.13±0.08	1.33±0.17	0.10±0.01
	Treatment	p<0.0001	P=0.005	NS	p<0.001	NS
	sampling	p<0.0001	p<0.0001	0.032	p<0.001	NS

Ytrestøyl, T., Takle, H., Kolarevic, J., Calabrese, S., Rosseland, B., Teien, H.-C., Nilsen, T.O., Stefansson, S., Handeland, S., Terjesen, BF., 2013. Effects of salinity and exercise on performance and physiology of Atlantic salmon postsmolts reared in RAS, Abstracts Aquaculture Europe 2013. European Aquaculture Society, Trondheim, 465.

CtrlAQUA PARTICLE project

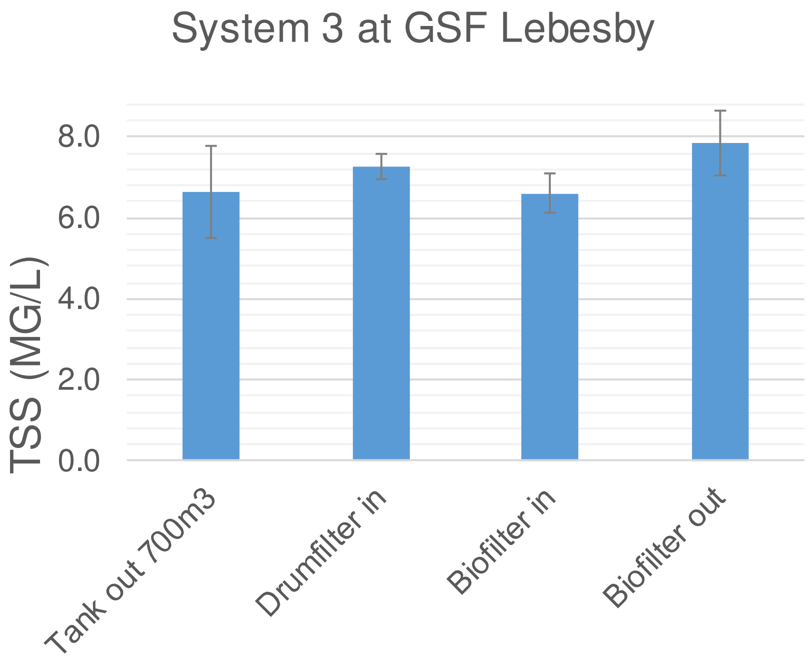
PL: Astrid Buran Holan

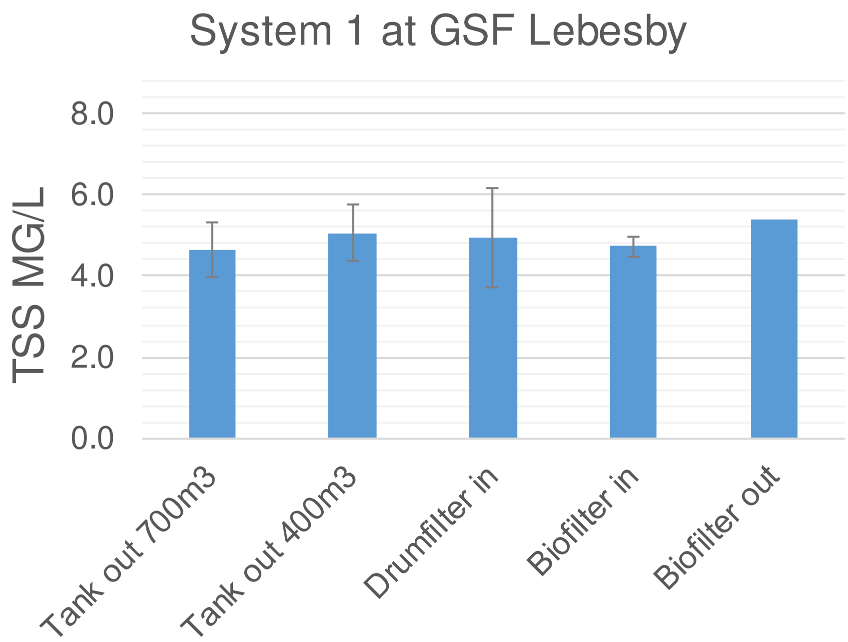
- Knowledge exists about the effect of particles on water treatment processes
- Lack of experimental evidence on effects of typical RAS particles on salmon post-smolt welfare, health and performance
- If no detectable need to keep small particles below a certain concentration and/or size range, this can impact prod costs



Choice of experiment particle levels

- We measured TSS levels at producer sites, such as Grieg Seafood at Lebesby in Adamselv (large-scale RAS for postsmolts)
- Nofima Center for Recirculation in Aquaculture (NCRA) in Sunndalsøra mg/L





Particle concentrations varies between 4 and 8 mg TSS/L

Holan et al., unpublished

CtrlAQUA Nofima

Experimental design PARTICLE

- Five different concentrations of particles in the water
- Three replicates per treatment level (15 tanks in total)

12 ppt S clean water

Clean water

Belt filter

TSS water

12 ppt S clean water + particles from separate RAS with biomass fish

Fish biomass

Experimental tanks

0% TSS water

25% TSS water

50% TSS water

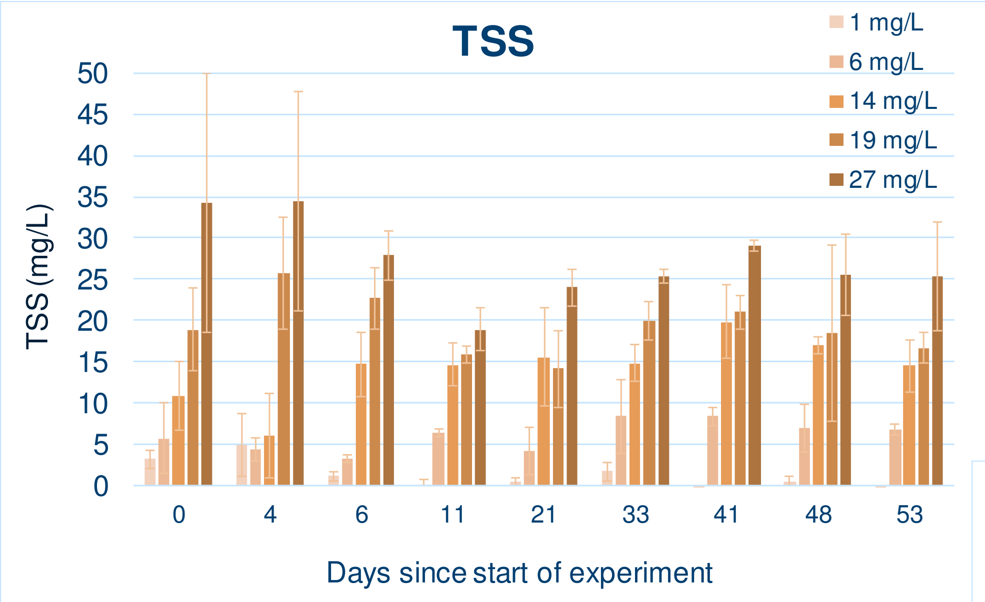
75% TSS water

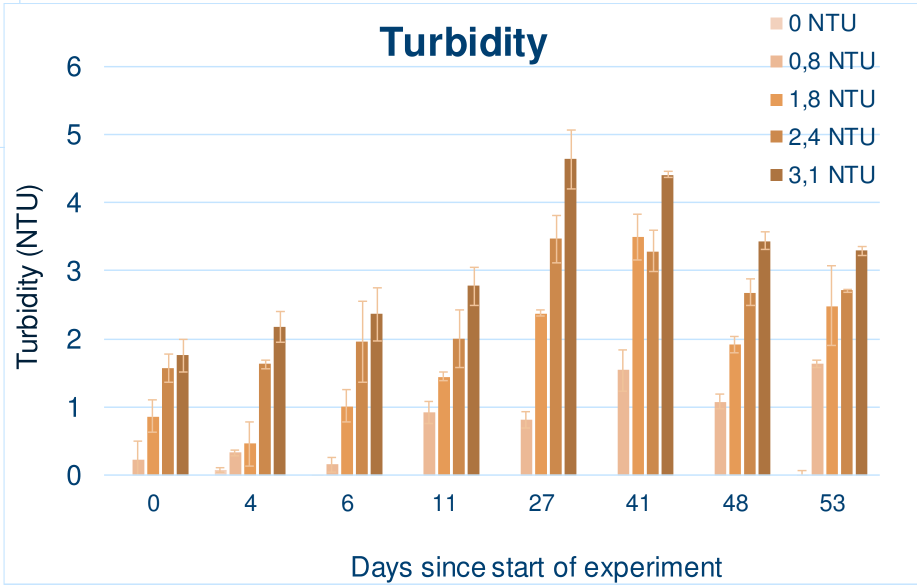
100% TSS water

Outlet water dumped, not reused in RAS

CtrlAQUA Nofima

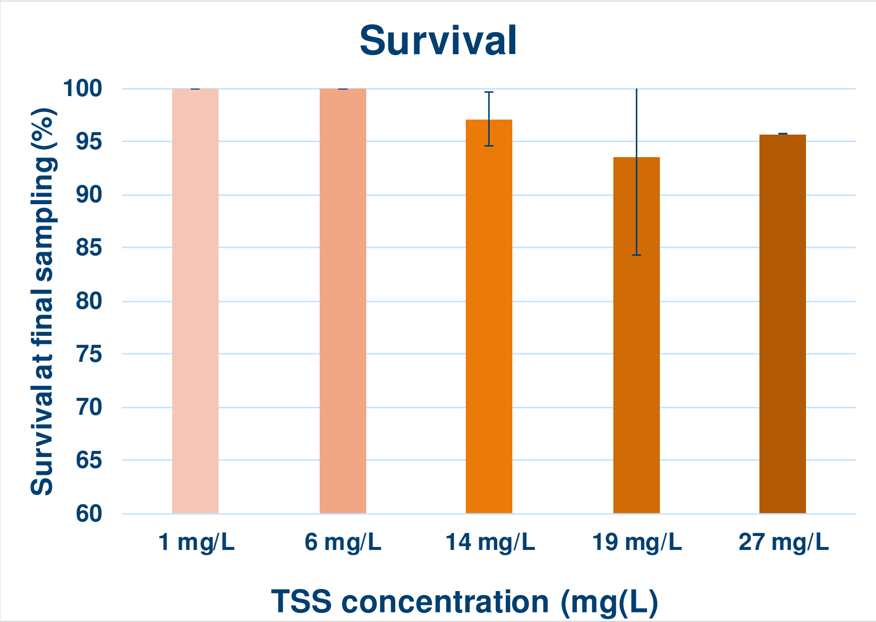
PARTICLE results – treatment levels

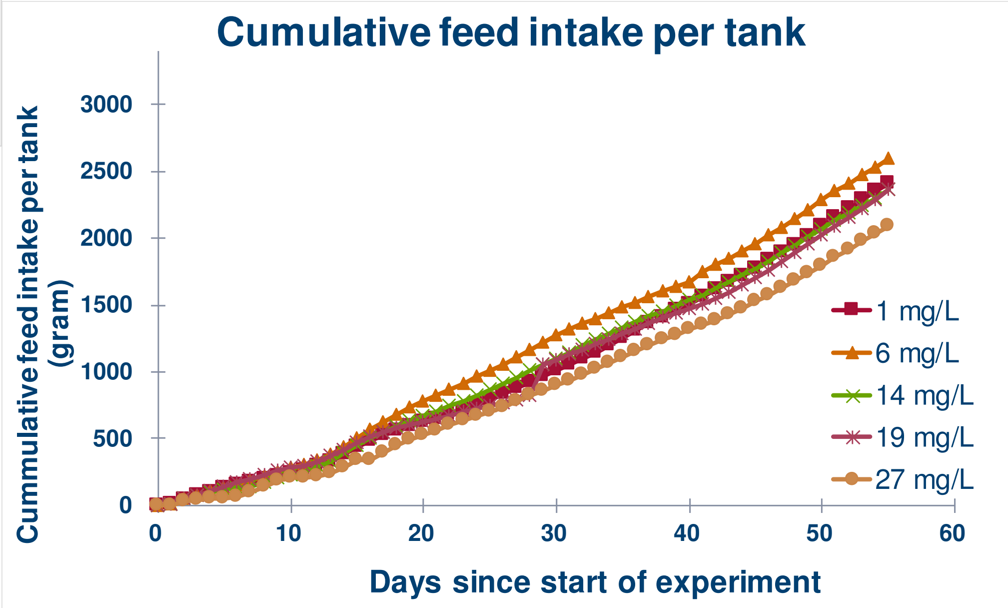




Holan et al., unpublished

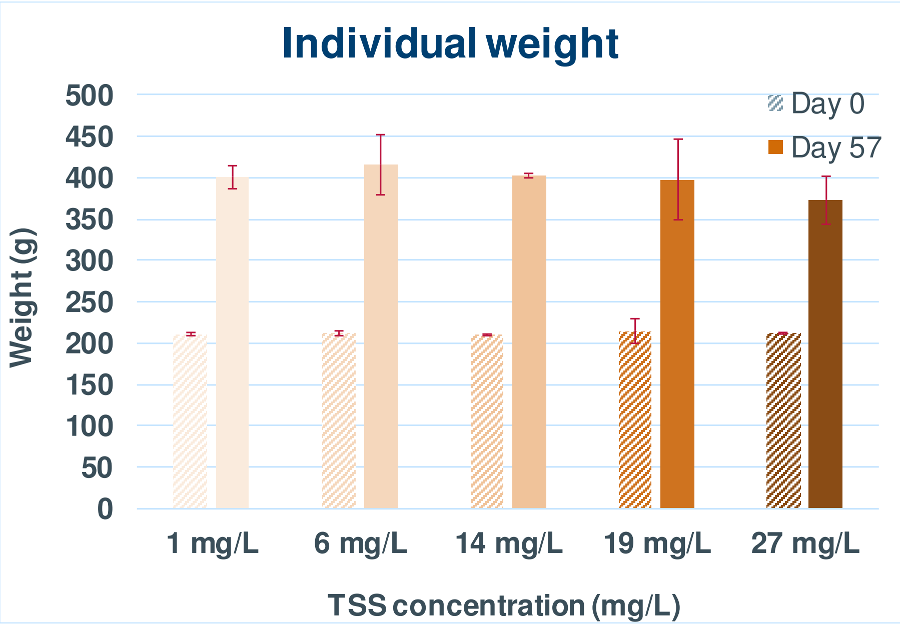
PARTICLE results: fish performance

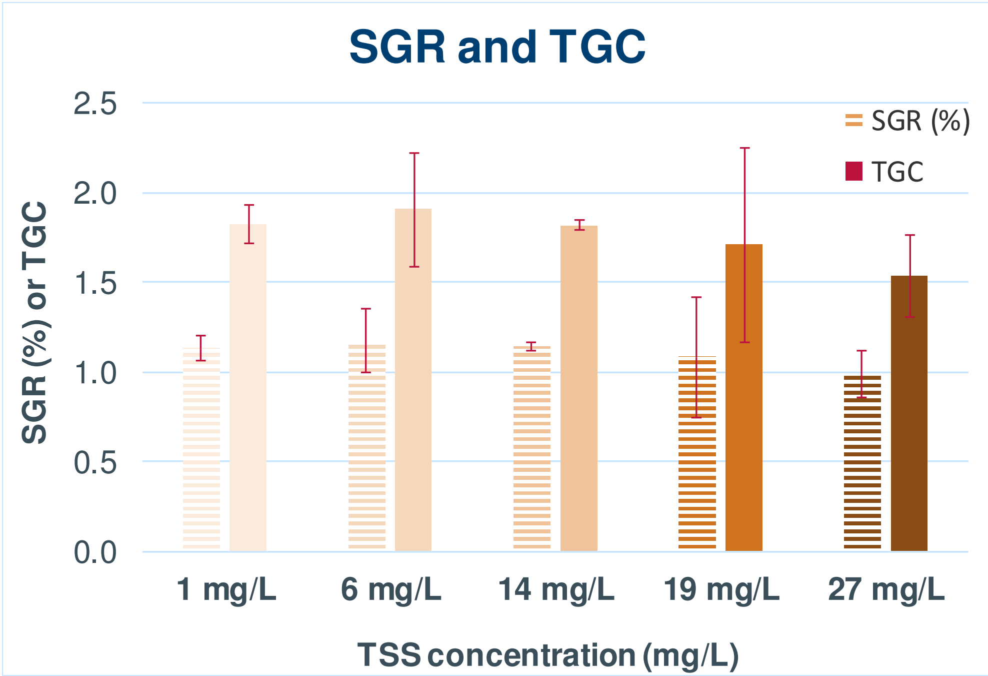




Holan et al., unpublished

PARTICLE results: weight and growth rates

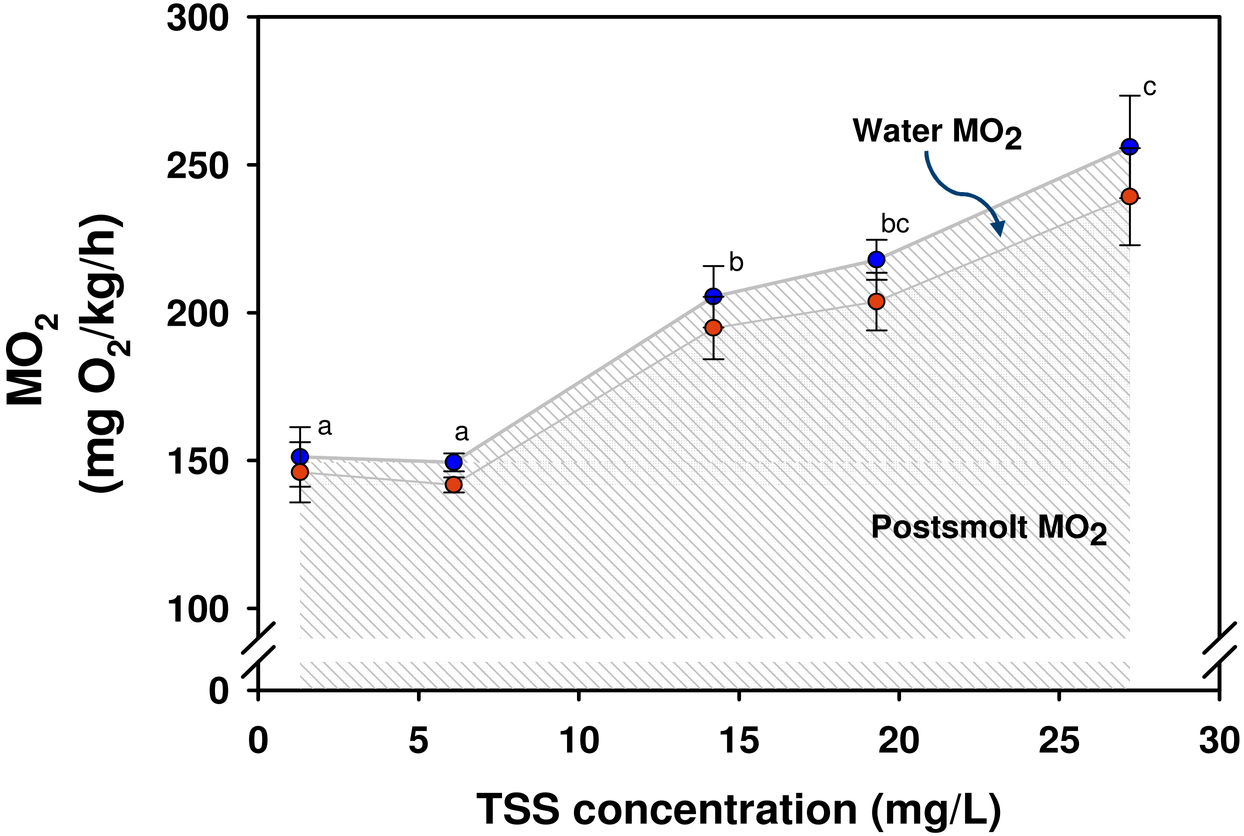




Holan et al., unpublished

PARTICLE results: Oxygen consumption - end of trial

- MO_2 of the treatment water (1, 14, 27 mg/l TSS) measured over 120 min (mg/l/min)
- MO_2 of fish from total MO_2 of tank, but subtracting the ΔO_2 with MO_2 from water itself, for one HRT of the tank
- Temp-adjusted (small increase at high TSS loads), using Q_{10} of 2.3
- Standardized to BW of control group (to adjust for lower BW at higher TSS), using mass exponent of -0.3
- Prelim statistics significant correlation between TSS treatment and MO_2



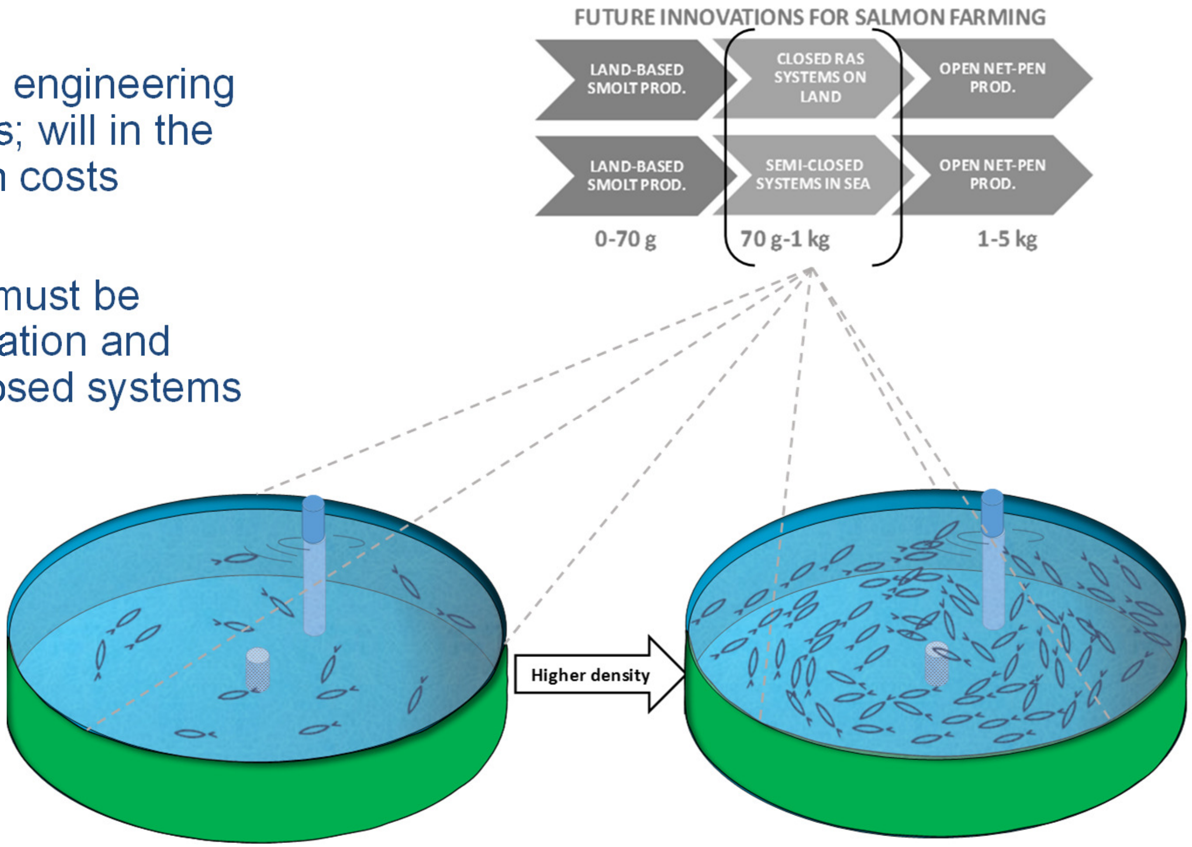
Holan et al., unpublished

CtrlAQUA BARRIER and SalmoFutura projects PL: Bendik Fyhn Terjesen & Sven Martin Jørgensen

✓Need to predict and improve the tolerance of the fish to chronic and acute stress, such as high fish density

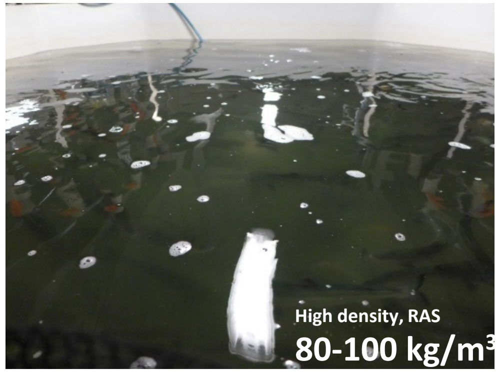
✓Important knowledge for optimal engineering of RAS and semi-closed systems; will in the long run lead to lower production costs

✓To achieve this: new indicators must be developed for welfare documentation and assessment of post-smolts in closed systems

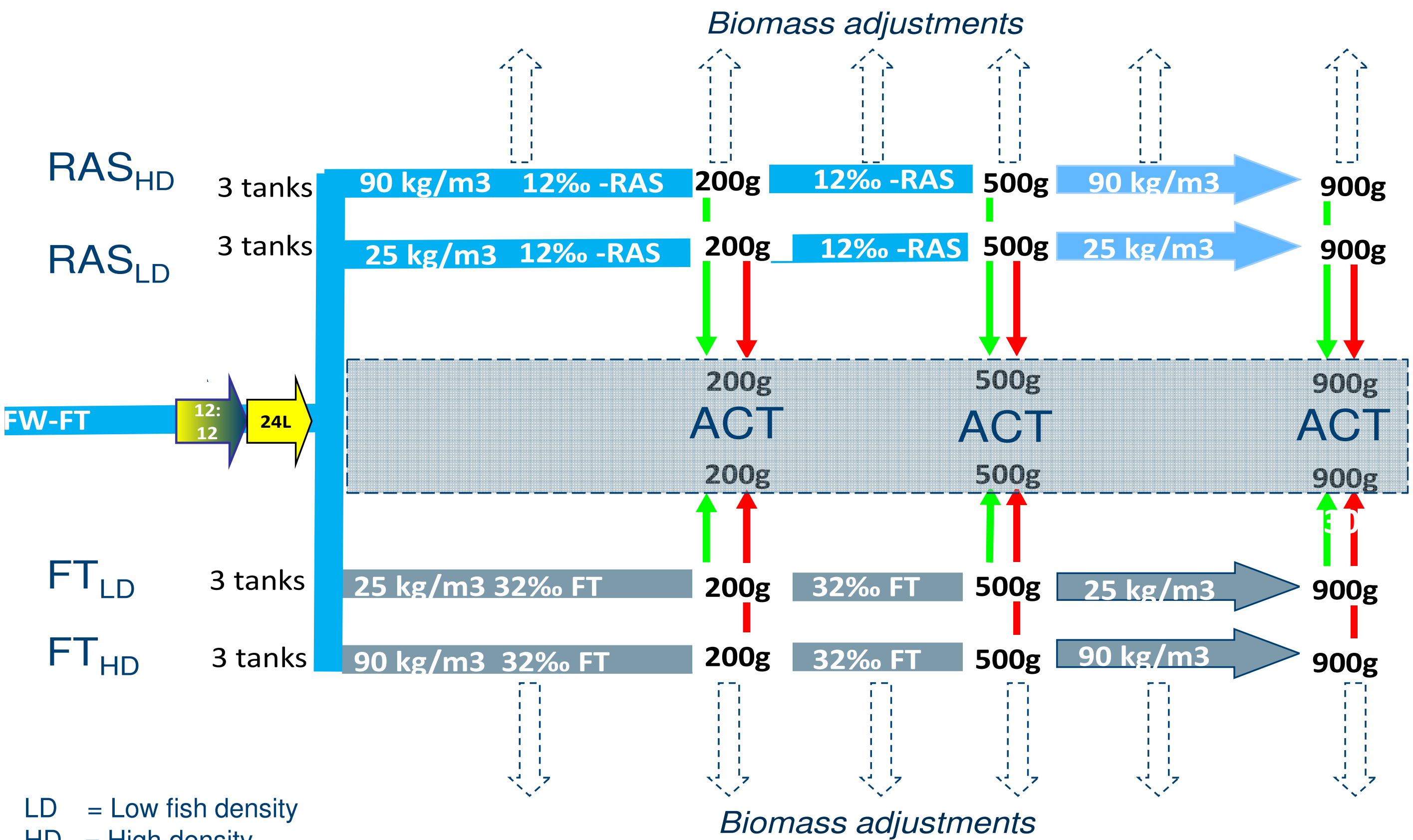


CtrlAQUA BARRIER /SalmoFutura:

Experiments to identify good response variables in post-smolts to chronic and acute stress in closed systems



Photos: Jelena Kolarevic



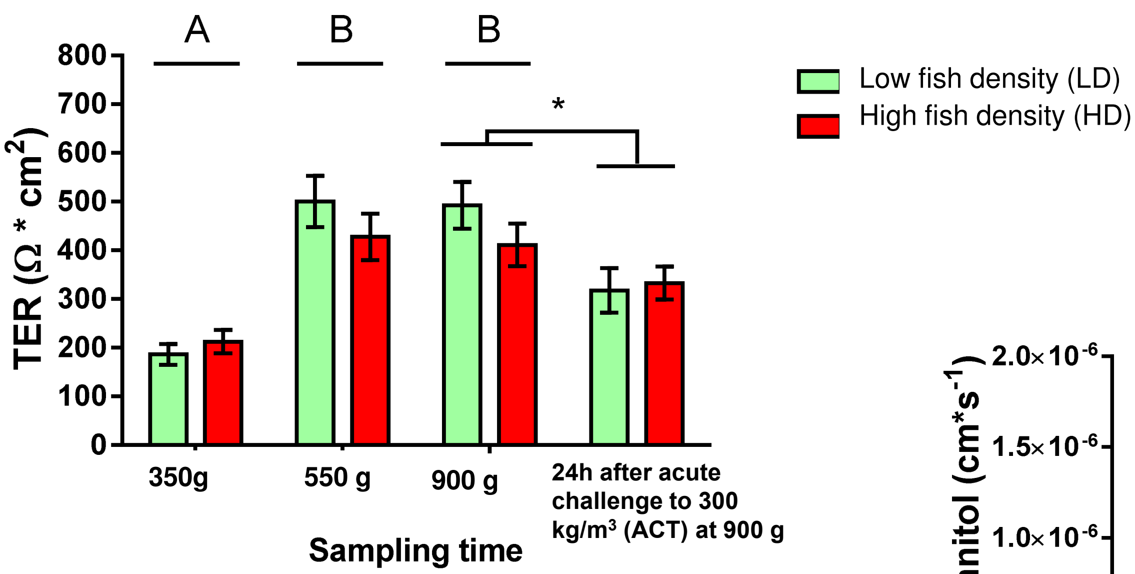
Acute challenge test at ~300 kg/m³ for 30 min at Nofima Sunndalsøra

Restitution 24 h after stress-test, in flow-through sea water, in 0.5m³ tanks, Nofima Sunndalsøra

LD = Low fish density
HD = High density
RAS = Recirculating Aquaculture Systems
FT = Flow-through systems
ACT = Acute Challenge Test

CtrlAQUA BARRIER/ Salmofutura: Effects of postsmolt size and rearing density on skin barrier-functions in RAS

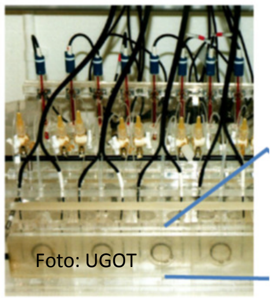
Transepithelial resistance (TER)



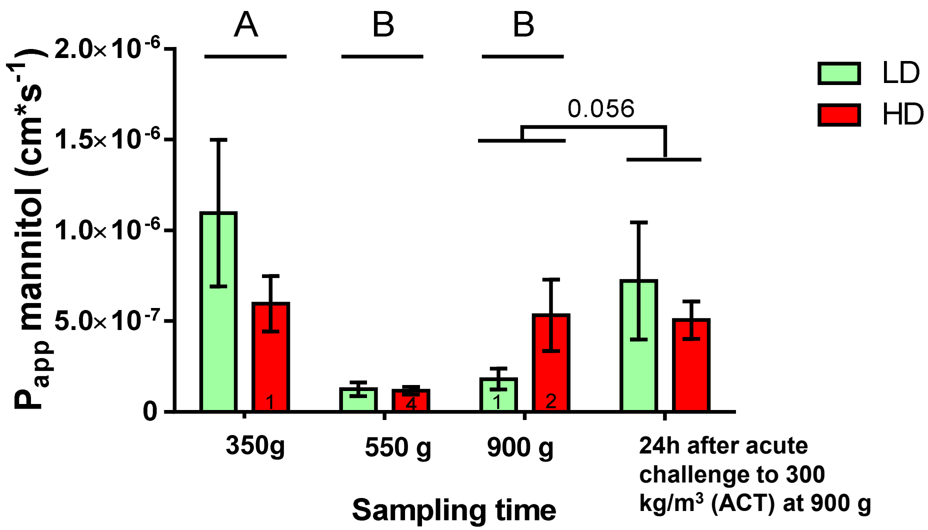
- Skin barrier in postsmolts gets tighter towards 500 g in RAS
- Chronic (80-100 kg/m³) and acute stress (300 kg/m³) tends to increase permeablity of ions through skin
- Consequence of stress: **Increased cost for ion- and osmoregulation**

GÖTEBORGS UNIVERSITET

Sundh and Sundell, unpublished



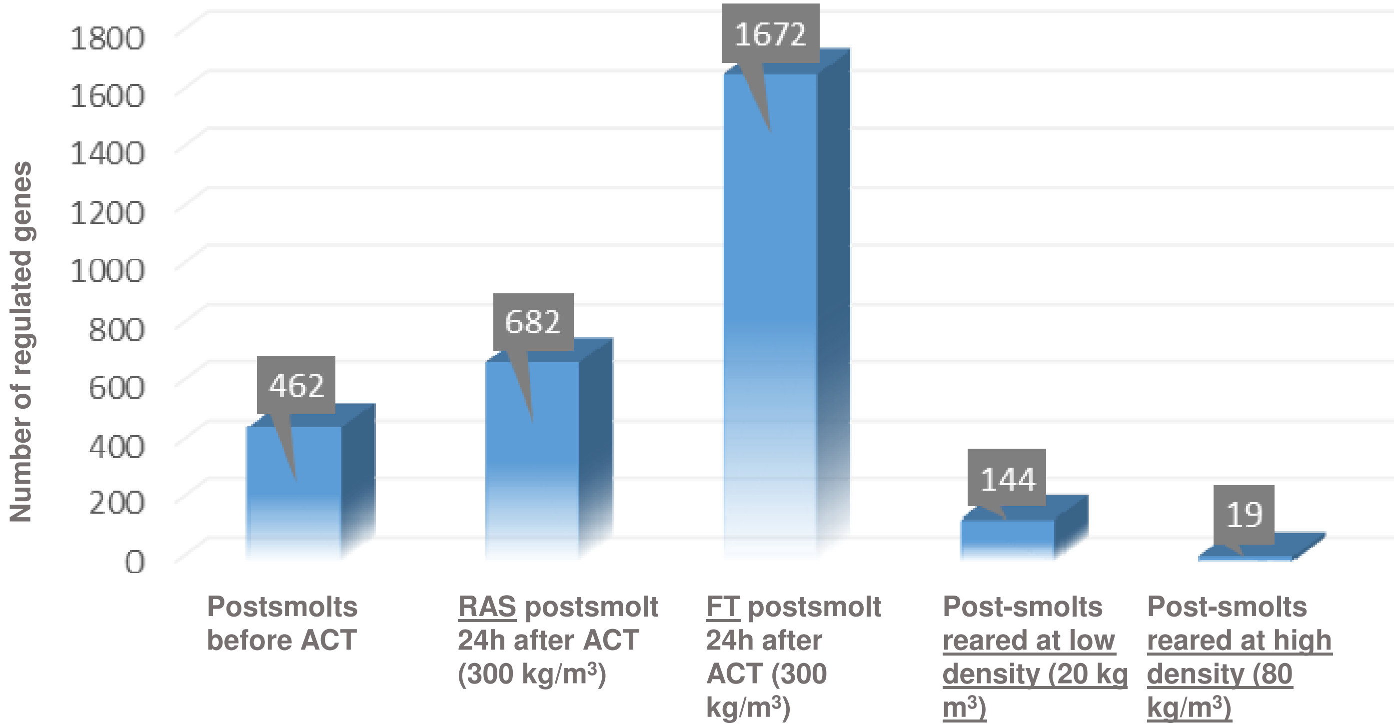
Mannitol permeability



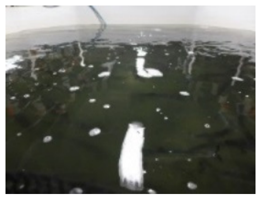
- Skin barrier in postsmolts gets tighter towards 500 g in RAS
- Chronic (80-100 kg/m³) and acute stress (300 kg/m³) tends to increase permeability of molecules through the skin
- Consequence of stress: **increased disease suceptability**

CtrlAQUA BARRIER/SalmoFutura

Effects of acute stress and rearing density on skin gene expression of postsmolts in RAS or FT, microarray



- Response to extreme density in gene transcription is greater in FT vs brackish water RAS
- Response to acute stress seen in skin of FT-fish is similar to wound healing model (Sveen et al., *in prep*), i.e. extreme density may generate small wounds?



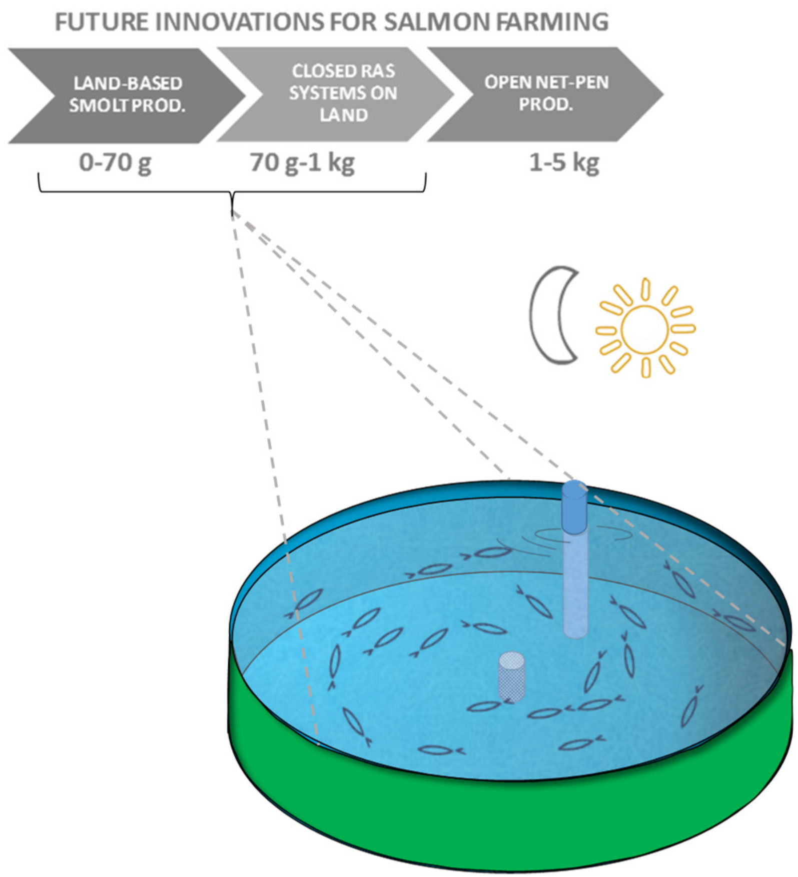
Ytteborg, Krasnov et al. unpublished

CtrlAQUA Nofima

CtrlAQUA BENCHMARK project

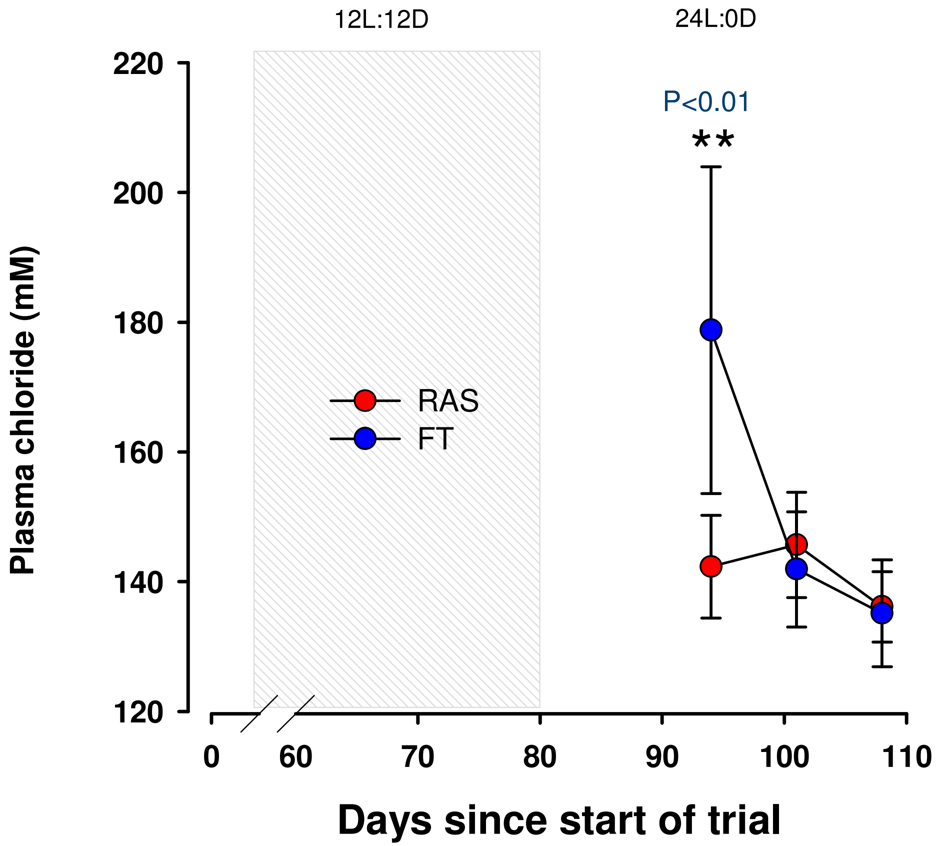
PL: Trine Ytrestøyl

- What photoperiod and salinity conditions are optimal for postsmolt production in RAS?
- Several Norwegian postsmolt producers, in RAS, do not use any light manipulation to make smolts; just 24:0
- Some use FW, some use 10-15 ppt S
- Still, ion-regulation and performance after sea transfer are reportedly good
- No controlled experiments to evaluate health and welfare
- Objective: To benchmark several different postsmolt production protocols in terms of fish performance, health and welfare

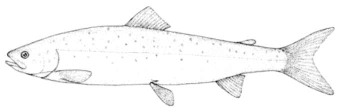


CtrlAQUA Nofima

RAS fish handle sea water earlier than fish from flow-through systems, despite similar body size



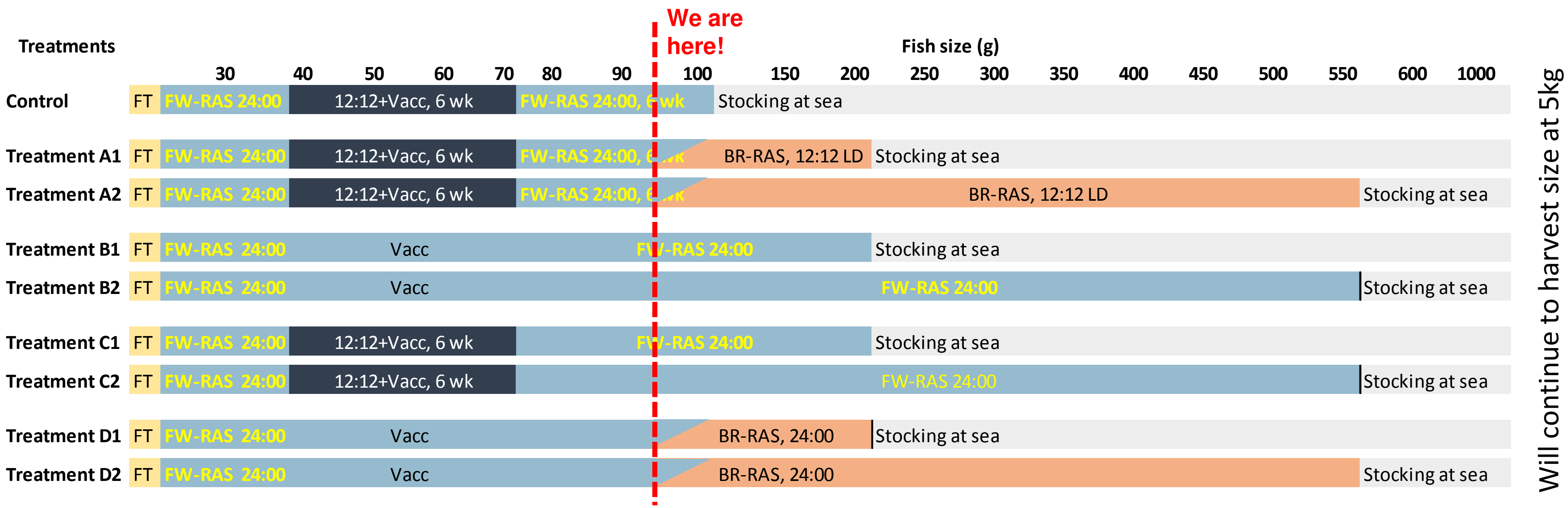
Plasma chloride in smolts previously reared in FW RAS, after 72 hours in sea water test (34 ‰ S)



Kolarevic, J., Baeverfjord, G., Takle, H., Ytteborg, E., Reiten, B.K.M., Nergård, S., Terjesen, B.F., 2014. Performance and welfare of Atlantic salmon smolt reared in recirculating or flow through aquaculture systems. Aquaculture 432, 15-25.

CtrlAQUA Nofima

CtrlAQUA BENCHMARK experimental design



Light \ Salinity	FW	12 ppt SW
12:12	FW x 12:12 (C1 and C2)	12 ppt x 12:12 (A1 and A2)
24:00	FW x 24:0 (B1 and B2)	12 ppt x 24:0 (D1 and D2)

Many thanks for the efforts by all the researchers and technicians in CtrlAQUA and associated projects

Thank you for the attention!

CtrlAQUA

Follow us on:
www.ctrlaqua.no

Funded by the Research Council of Norway and the partners

Forskningsrådet