CURRENT CHALLENGES AND FUTURE OPPORTUNITIES FOR EXPOSED SALMON FARMING IN NORWAY

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Director of the EXPOSED Aquaculture Operations Centre
SFI EXPOSED - The coast of Norway offers great opportunities

Significant parts of the Norwegian coast is today unavailable to industrial fish farming due to remoteness and exposure to harsh wind, wave, current and ice conditions. Regular as well as infrequent operations are challenging.

The Exposed Aquaculture Operations Centre will draw upon Norway's strong position in the aquaculture, maritime and offshore sectors to enable safe and sustainable seafood production in exposed coastal and ocean areas.

The centre is funded by the Norwegian Research Council and the 22 centre partners, has a planned duration of 8 years, starting in 2015 and a total budget of 210 MNOK (≈ 22 M USD) and 15-25 PhDs.
Current exposed salmon sites in Norway

Typical high capacity Norwegian fish-farms
- 15,000 metric tonnes salmon per cycle
- 10 – 16 cages Ø 50 meter
- 40,000 m³ volume per cage and max. 200,000 fish per cage
- 1,000-1,500 metric tonnes/man year
- Exposed but not offshore/open ocean

Photo: SINTEF/ACE
5 Current challenges

1. Operations
2. Management
3. Fish welfare
4. Escapees
5. Safety and working conditions
Challenge 1

More demanding operations

- Vessels must come alongside – Large relative motions
- Fish is crowded toward the surface
- Unpredictable environment – Delays or interrupted operations
Demanding management and daily operations

- Unpredictable weather and sea states leads to postponed de-licing and longer periods of starvation
- Routine operations and inspections become challenging in bad weather
- Some farms have prolonged periods with ocean swell
- Examples of farms that have been abandoned
Fish welfare under rough conditions

- Treating fish under rough environmental conditions inflict additional stress, with a potential for higher mortality
  - Short weather windows
  - Crowding towards surface with large relative movements, waves and cold air/water
- Extreme conditions have caused mass mortality
- A need for robust fish and adapting stocking strategies
What is the capacity of the fish?
Challenge 3 continues

What is the capacity of the fish?

**Figur 1.** Den kritiske svømmehastigheten for ulike størrelser av atlantisk laks. Figuren er basert på målinger av 270 fisk og temperatur var 13-14 °C. Den blå linje viser gjennomsnittet, mens den røde linje i grafen viser de svakeste svømmerne. I eksponert oppdrett må man ta hensyn til den naturlige variasjonen i svømmeevne hos laks, og den røde linje representerer da en anbefalt grenseverdi for vannstrøm.

**Figur 2.** Den kritiske svømmehastigheten for atlantisk laks ved ulike temperaturer etter minimum 3 uker akklimatisering. Figuren er basert på målinger av post-smolt på 300-400 gram. Den blå linje viser gjennomsnittet, mens den røde linje viser de svakeste svømmerne. I eksponert oppdrett må man ta hensyn til den naturlige variasjonen i svømmeevne hos laks, og den røde linje representerer da en anbefalt grenseverdi for vannstrøm.

Read more in Norsk Fiskeoppdrett 12/2017
1 of 3 escaped salmon escapes under bad weather

- **Kartlegging og kategorisering** av årsaker til tidligere hendelser (2010 – 2016) from the Directorate of Fisheries and farmers. 514 reports.

- Extreme conditions can cause structural failures

- Demanding operations also increase risk of escapees

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**FHF-prosjekt: Kunnskap og metoder for å forebygge rømming**

[Link to FHF project website](http://www.fhf.no/prosjektdetaljer/?projectNumber=901295)

[Link to Wikipedia page on extreme weather in Norway](https://no.wikipedia.org/wiki/Liste_over_ekstremv%C3%A6r_i_Norge)
Barriers against escapes

The net structure is a single technical barrier

A range of functional requirements that also other net structures and materials needs to meet

- Double nets
- Metal nets

Too early to assess the effect of closed cages
Challenge 5

Fish farming already pose a demanding working environment – this is amplified by harsh conditions

- The other challenges of exposed farming demands attention, and result in stress, demanding working conditions and occupational hazards

- A need for coordinated efforts to reduce risks in aquaculture, involving industry and government
  - Escapes (The Directorate of Fisheries)
  - Fish welfare (The Food Safety Authority)
  - Safety and working conditions (The Labour Inspection Authority and the Norwegian Maritime Directorate)

NFR-prosjekt: Safer operations and workplaces in fish farming
https://www.sintef.no/siste-nytt/ny-undersokelse-viser-hoy-trivsel-i-havbruk/
6 Research areas

**Technological innovation**

**AREA 1** Autonomous systems and technologies for remote operations
**AREA 2** Monitoring and operational decision support
**AREA 3** Structures for exposed locations
**AREA 4** Vessel design for exposed operations

**Requirements for sustainable production**

**AREA 5** Safety and risk management
**AREA 6** Fish behaviour and welfare
Future opportunities
A very special period, with a rare rate of innovation in Norway

Development licenses, low oil prices and high salmon prices leads to investments and a high rate of innovation

104 license applications!

Both closed, semi-closed and open systems under development

The fish farm industry is leaving familiar grounds and its experience from technology and operational procedures

Significant international potential
Will this be the future?

Photo: Hauge Aqua Solutions
Or this?
Or maybe this?
... well, who knows?

Anyway, these challenges needs to be met:

1. Operations
2. Management
3. Fish welfare
4. Escapees
5. Safety and working conditions

How well will the novel concepts solve all 5?

There is still a huge knowledge need and innovation potential
6 Research areas

Technological innovation

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Requirements for sustainable production

AREA 5 Safety and risk management
AREA 6 Fish behaviour and welfare
2 requirements for designing robust, safe and efficient aquaculture structures

- Understanding the structure
- Understanding the environment
Degree of exposure and technological concepts

- Diversification – Experimentation with an aim to utilise the whole coast

<table>
<thead>
<tr>
<th>Closed (RAS)</th>
<th>Semi-closed</th>
<th>Open, flexible cage</th>
<th>Sheltered/submergible cage</th>
<th>More rigid, larger cage</th>
<th>Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current exposed salmon sites in Norway</td>
<td></td>
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</tbody>
</table>
Understanding the structure = response under varying environmental conditions + Structural integrity and failure

Current design

New concepts
- Closed systems – large mass
- Large structures
- Combination of rigid and flexible elements
- Hydroelasticity and dynamic response
- Unique designs
- Expensive to over dimension
Hydroelasticity and dynamic response
Sloshing = The importance of wave periods

FHF-prosjekt: Sjøegenskaper og forankring til flytende lukkede oppdrettsanlegg (SJØFLO) http://www.fhf.no/prosjektdetaljer/?projectNumber=901287
Understanding the environment

Coastal conditions differs from offshore conditions

Environmental loads on farms are challenging to measure adequately

- Covers large areas with significant variations and interactions
- Flexible structures with costly infrastructure

Relevant classification of exposure

- Includes extreme values, means, combinatory factors and regularity

Serviceability Limit State

- More precise criteria for operations, working environment and fish welfare needed to develop technology
Typical design parameter – 50 year storm

- Instead of measuring for 50 years – Shorter measurements combined with models
- Large variations in results, depending measurement period and statistical methods

<table>
<thead>
<tr>
<th></th>
<th>1-month maximum x 1.85</th>
<th>GEV – distribution</th>
<th>GPD – distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars 2016</td>
<td>88.89 cm/s</td>
<td>93.74 cm/s</td>
<td>69.36 cm/s</td>
</tr>
<tr>
<td>Sept. 2016</td>
<td>117.07 cm/s</td>
<td>162.52 cm/s</td>
<td>88.27 cm/s</td>
</tr>
<tr>
<td>Feb.-Oct. 2016</td>
<td>163.02 cm/s</td>
<td></td>
<td>84.0 cm/s</td>
</tr>
</tbody>
</table>
Wind wave exposure of current Norwegian farms
Langtidsstatistikk for bølger basert på SWAN

Hensikt:

- Etablering av langtidsstatistikk for bølger
  - Tidsserier for Hs og Tp for EXPOSED-lokaliteter
  - Retningsavhengighet
- Studere romlig variasjon av bølgeforhold på lokalitet
- Studere hvordan havbølger (dønning) forplanter seg til kystlokaliteter
Directional components

*H*$_S$, *T*$_p$ contours for Frohavet, dir. 10 - 55 deg

*H*$_S$, *T*$_p$ contours for Frohavet dir. 202.5 - 247.5 deg

North east

South west
Numerical study of a fishing vessel operating in partially ice covered waters

Illustration of simulation model with vessel, desired track along the crab pot string and detection regions on the starboard side.

Illustration of retrieval of a crab pot string

Snow crab fisheries vessel

Simulated ice accretion

Simulated ice impact forces

Average floe size 10m
Average floe size 20m

Ice concentration 30%
Ice concentration 50%
Ice concentration 70%

Project: Ice floe interaction with ships and waves
Fram Centre – High North Research Centre for Climate and the Environment
http://www.ifram.no/db.343156.no.html?lid=332.007a0b5247e468e198afa39c6bdb3c37
Feed barge in ice

Feed barge: 22x12x4 m

www.akvagroup.com
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Final notes
Standards for new technology and farming sites

- Challenging to find adequate standards for new technologies
- Also shortcomings for current sites and technologies
- Revisions to NS9415 and new proposed DNV GL class

Fragmented regulation

- Several governmental bodies with some overlapping or unclear responsibilities
  - Examples: worker safety, vessel-structure interaction, feed barges
- Need for coordination
Competence and project risks

- Many concepts represent **fundamental shifts** - The fish farm industry is leaving familiar grounds and its experience from technology and operational procedures
  - The central structures and technological concept must still facilitate all farm operations
  - New auxiliary systems must be developed
- Larger scale and **larger fish populations**
  - Risk management and contingency planning – how to treat 1 million fish in rough weather?
- **Highly diverse project teams and scopes**
  - How are farmers as customers of highly complex technology?
  - How will the fish welfare be safeguarded when addressing all the technological challenges?
Current technologies will be prevalent, but experimentation the next 5 – 10 years

- A huge potential for new knowledge and solutions

Not an "either or", but rather a "both"

- Combinations of sheltered and more exposed sites

Should gain more than space and increased production

- Increased investments should result in more robust, safe and efficient fish farming