Rearing conditions and deformities in Atlantic salmon – what have we learned so far?

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Deformities

- A persisting problem in aquaculture
  - no easy way out
- Complex problems
- Salmonids:
  - A history of organ malformations (late 1990's)
  - Predominantly skeletal deformities
  - Vertebral column, jaws, operculae
Deformities in farmed salmon

- **Skeletal deformities**
  - “Humpbacks” and “short tails”
  - Jaw deformities

- **Soft tissue malformations**
  - Missing and malformed organs
  - Most important: Missing *septum transversum*, i.e. no separation between heart and abdominal cavity
  - More recently: Small and abnormally shaped hearts
• Embryonic origin of some of the malformations was identified through experiments on salmon eggs

• Egg incubation temperature (10.4 °C vs. control groups at 7.9°C) induced a range of deformities, including those seen in practical fish farming

![Graph showing effect of egg incubation temperature on missing septum transversum]
Vertebral deformities induced by egg incubation temperature
Identified by X-ray at size 60-80g

Stable temperatures

- 8 °C
- 10 °C

%
Egg incubation temperature $> 8^\circ C$ in Atlantic salmon can induce:
Aplasia of septum transversum

Effect of temperature increase during egg incubation

(2nd experiment)

Temperature increased at:
- 110 d
- 220 d
- 330 d
- Hatching

From 8 to 10 °C
From 8 to 12 °C
Vertebral deformities

Effect of temperature increase during egg incubation

(2nd experiment)

Temperature increased at:

- 110 d°
- 220 d°
- 330 d°
- hatching

% count:

- From 8 to 10 °C
- From 8 to 12 °C
Long term experiment, 2001-2003:
Rearing temperatures 0-60g
Effects on deformities in different life stages

• Rearing experiment, freshwater
  - First feeding Feb 2001
  - Sea water transfer Apr 2002
  - Harvest June 2003

• Fish reared at 12, 14, 16 and 18°C
  from first feeding and to 60g size

Supported by the Norwegian Research Council
Deformed vertebrae in parr at 60g size

Effect of rearing temperature 0-60g

% of fish with deformed vertebrae

Average number of deformed vertebrae per affected fish
Seawater transfer, Smolts 80-100g

Harvest, 3-5kg
Temperature induced vertebral pathology
Development of vertebrae in seawater

• 200 fish with PIT-tags were X-rayed in April 2002, at size 80-120g, just before seawater transfer
• Same individuals X-rayed again in November 2002, at average size 1,2 kg
• ...... and were X-rayed again at harvest, in June 2003, mean weight 2,5 kg

X-rays were taken by Norwegian School of Veterinary Science
April 2002
163g
Kfakt 1,32

Nov 2002
1920g
Kfakt 1,54
Nutritional aspects of vertebral deformities

• No limit to the number of potential nutritional factors
• In commercial diets, mineral supply may be a limiting factor
• Phosphorus deficiency impaires bone formation
• Mineral supply (dietary level X bioavailability) is a challenge in fast growing animals
• Unpredictable dietary supply in formulated diets
  - Vegetable ingredients impairs absorption
  - Unforeseen variation in availability in fish meal
2002–2005:
Deformities of vertebral column and jaw in Atlantic salmon.
Effects of genetic susceptibility, mineral nutrition and production temperature

• Funded by Fiskeri- og Havbruksnæringens Forskningsfond (FHF), the industry research foundation
  - AquaGen: Supplied egg groups selected for genetic disposition
  - Ewos Innovation: Experimental feeds
The study was based on previous results, which demonstrated that:

- ... there is **genetic variation** (among family groups) in susceptibility to vertebral deformities (Gjerde et al., 2005)

- ... margins may be too narrow for some **minerals** in commercial diets (**contents x bioavailability**), and impaired mineralisation is suspected to contribute to development of vertebral deformities.

- ... **high rearing temperatures** induces vertebral pathology in Atlantic salmon juveniles

- ... **high growth rates** is known to induce inferior bone quality in poultry and swine. Maximum growth rate in Atlantic salmon at 15-16°C
Observations at 60g size:
Radiography, 20g size:

Control diet

Diet with 1% P and 70 ppm Zn
Water quality in freshwater production

- Increased production of smolts (higher numbers, bigger smolts) at fewer sites
- Available water resources do not increase correspondingly
- Water flow (l/kg/min) is decreased
- Oxygen is added
- CO$_2$-accumulation and low pH in tank water

- ...any effects on skeletal deformities?
Production exp. # 1
Low density, unlimited water supply, compared to
High density, low water supply, oxygen added

O$_2$ saturation (% inlet water)

pH outlet water (= in tank)

CO$_2$ outlet (in tank)
**Production exp. #2**
Low density, unlimited water supply, compared to High density, low water supply, oxygen added, in fish given diets with different levels of available phosphorus.
Downgrading of fish at harvest in tanks with unstable conditions 22%

These tanks were characterized by

- Rearing temperature 3-60g: 16°C
- Fluctuating O₂-saturation, periods with supersaturation (>100%)
- Periods with high levels of CO₂ (>30mg/l)
- Periods with low pH (<5.8)
- A near death experience with stop in water supply and hypoxia

Unstable conditions, fluctuations, stress
• In particular, increase in fish with **platyspondyly**
• Vertebrae not fused, just flattened (?)
• Platyspondyly only in caudal region
• Seen only in seawater, no early signs have been detected yet
Project “Water quality- smolt quality”

$O_2$-supersaturation in freshwater: Effects on health condition and seawater performance

AKVAFORSK, NIVA, UMB, NIFES, UiB

• Limited water supply, oxygen added
• What happens if fish are reared in hyperoxic conditions, i.e. with $O_2$ saturation $> 100\%$?

• Exposure in two periods
  - From 40 to 80g size, growth under continuous light
  - From 80g to smolt, through smoltification,
    6 weeks of 12D:12L, 6 weeks of continuous light
• Examination of fish after 16 weeks of communal rearing in seawater
Exposure levels:

• First period
  Inlet  Outlet
  100   75
  150   105
  175   130

• Second period
  Inlet  Outlet
  100   85
  170   125

Corresponding to $O_2$ saturation in tanks
Vertebral pathology

Effect of oxygen supersaturation prior to seawater transfer
Radiography after 16 weeks in seawater

Exposure first period:

Exposure second period:

$O_2$ saturation in tank water
“Irregular vertebrae”
Effect of oxygen supersaturation prior to seawater transfer
Radiography after 16 weeks in seawater

- Exposure first period:
  - 75
  - 105
  - 130

- Exposure second period:

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<thead>
<tr>
<th>O₂ saturation in tank water</th>
<th>%</th>
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<td>85</td>
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VK2004- Vannkvalitetsundersøkelsen 2004

• Benchmarking program for water quality in Norwegian hatcheries
  • Since 1999
  • NIVA, UMB and AKVAFORSK (from 2004)

• Skeletal deformities (2004 >)
• Fish from 21 hatcheries
• 30 juveniles per hatchery
• Radiographic examination
Different forms of vertebral pathology
All fish

VK2004
Normal vertebrae

Single deviant vertebrae, small and dense

Fusion
Normal tail

"Ring vertebrae"
Summary, March 2005:

- Temperature is an important ethiological factor
  - In embryos
  - In juveniles

- Temperature induced changes continue to develop well into seawater rearing

- Dietary mineral supply may be a critical factor, especially when growth rates are high

- Water quality may have an impact, but the pathogenesis seems to be complex

- Vertebral deformities can be induced any time during freshwater rearing, most likely also in seawater