Bjørn Olav Rosseland: Sustainable aquaculture:

Monitoring of water quality in Norway….

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Sustainable aquaculture: Monitoring of water quality in Norway combining the documentation relevant for EUs Water Directive on pollution and fish welfare control

Bjørn Olav Rosseland
Professor, Dr. philos.

NORWEGIAN UNIVERSITY OF LIFE SCIENCES
MDCCCLIX

2111
2005

Atlantic salmon is Norway's main species of aquaculture

2005 data

150 mill. smolts

Key Questions

- What is the water quality criteria and minimum technology for a fish farmer to have an economic sustainable production of fin fish at a specific farm?
- Which production schemes/forms will increase a risk for internal water quality degradation, reduction of fish health and fish welfare and pollution of the surrounding environment?
- What will be the National Pollution Control Authorities or International (EU) criteria for production to:
  - ensure fish welfare
  - avoid disturbances to the external environment and
  - **How can they control the farms?**
- **Could a Water Quality Monitoring Program at the farm fulfil all tasks?**

EU Water Framework Directive: Three types of monitoring

- **Control monitoring;**
  - A general monitoring in all types of aquatic ecosystems
  - Regional overview
  - Repeat every 6 years, with a minimum of one annual cycle.
- **Operational monitoring**
  - In lakes/rivers dividing from a natural condition
  - Control of mitigation activities
- **Problem oriented monitoring**
  - In cases where **Control monitoring** or **Operational monitoring** failed to explain the reason for unexpected status and trends

Sampling frequency and parameter not given

Aquacultute in Norway
1990's - 2003: Intensive production of Atlantic salmon

- Few new licenses
- Increased production in existing fish farms (2-5 mill smolts)
- Increased need for water
- Acid water - Mixing zones – unstable Al-chemistry restricts farming
- Change from 1-year old smolt to a combination with 0-year "autumn-smolt" (60/40 %)
- Increased use of O_2 addition → increased CO_2 , CO_2 stripping
- Increased use of seawater
  - UV-treatment regulations - restricted UV-capacity until 1995
- **Increased mortality in sea, mainly caused by IPN**
- ***Could the increased IPN problems in sea be connected to these new ways of farming?***
  - ***Will "early life history stage" exposure in freshwater determine the success of the adult stage in sea?***
- **Water Quality Projects (WQ 1999 -)**

Water Quality Program (WQ)
NIVA, UMB and Akvaforsk

Rosseland, B.O., Salbu, B., Heier, L.S., Teien, H-C., UMB
Rosten, T., Kristensen, T., Åtland, Å., NIVA
Bæverfjord, G., Akvaforsk

- **WQ 1999-2005: Investigation of 160 fish farms**
  - **> 80% of producing farms in Norway**
  - **Some in UK**

WQ Sampling Program

	Water samples	Tissue/blood
Raw water	Spring and at Smolt release	
Production water	At smolt release	
Tank water	At smolt release 2 smolt tanks Water and CO_2 DGT	Gills from 2 smolt tanks Blood from same smolt N=5 x 2
	Water and CO_2 from fry tank	→ Deformities
Flood water	Raw water Spring or autumn	Gills from smolt or parr N=5

Chemical parameters for aquaculture

Raw water (18/24)

Analytical parameters	Unit	
Acidity, pH		
Conductivity	mS/m	
Alkalinity	mmol/l	
Turbidity at/ 860 nm	FNU	
Nitrogen, total	µg/l	N
Nitrate	µg/l	N
Carbon, organics (TOC)	mg/l	C
Chloride	mg/l	Cl
Sulphate	mg/l	S
Aluminium, total	µg/l	Al
Aluminium, reactive	µg/l	Al
Aluminium, non labile	µg/l	Al
Calcium	mg/l	Ca
Iron	µg/l	Fe
Potassium	mg/l	K
Magnesium	mg/l	Mg
Sodium	mg/l	Na

Production water

Alternative to raw water
When treatment:
pH, alkalinity,
Calcium, silicate
salinity/chloride

Tank water

Always complete raw water and "treatment parameters":

pH, alkalinity

NH_4

CO_2

Additional data

- Technical data, production data and historical data
- Data on vaccination

Data on transport from farms

Data on survival and growth (GF 3) up to 3 month in sea

All data are handled confidentially

Each farm get their specific report with scores and operational advices

All data presentations are anonymous

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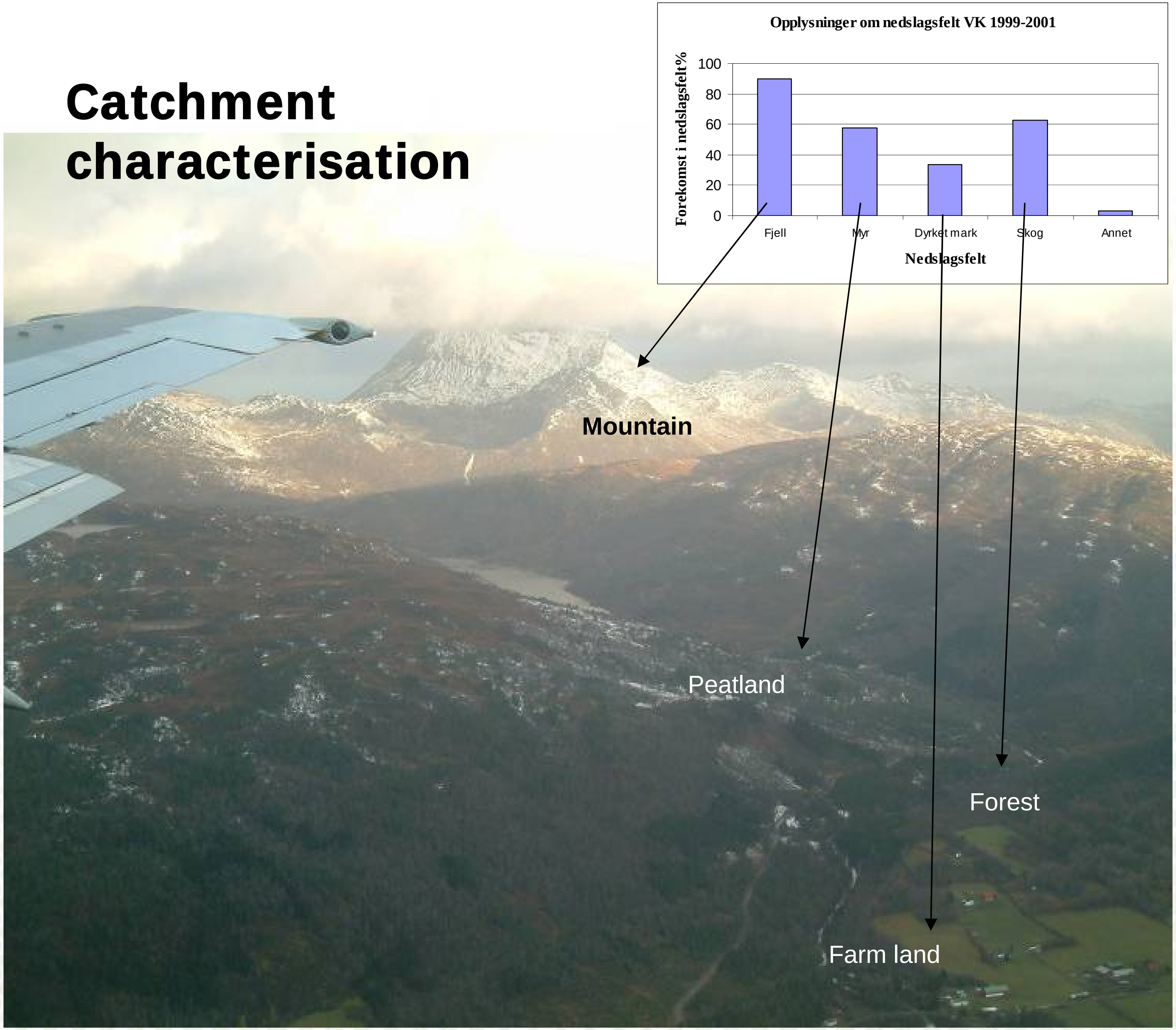
Catchment characterisation



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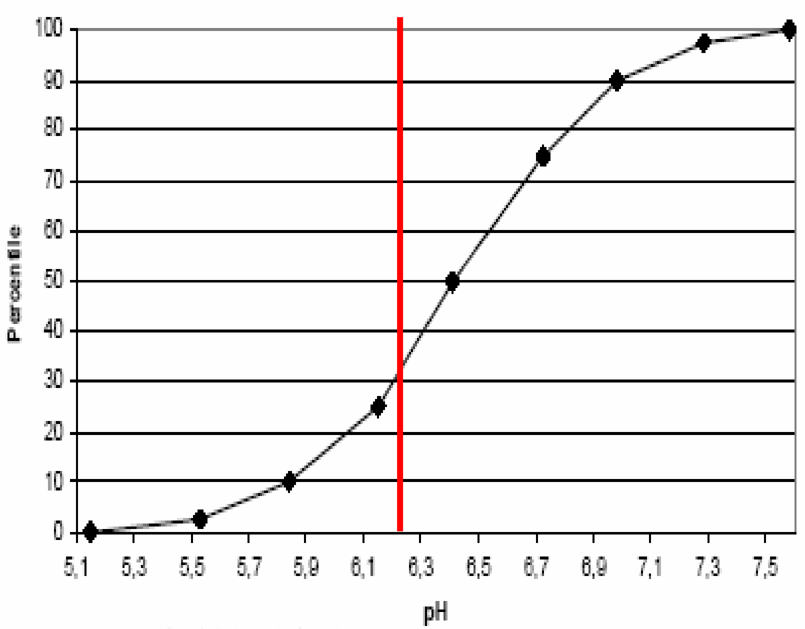
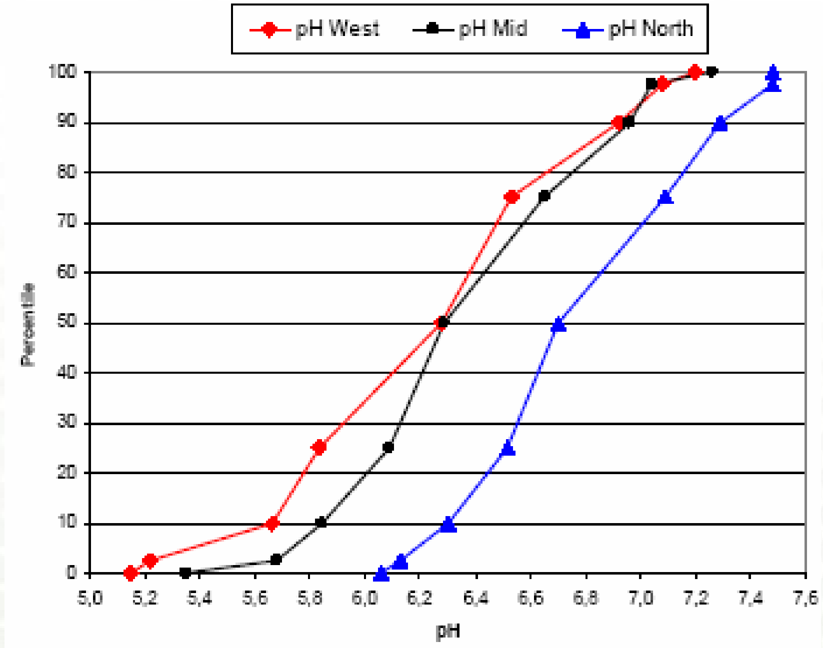
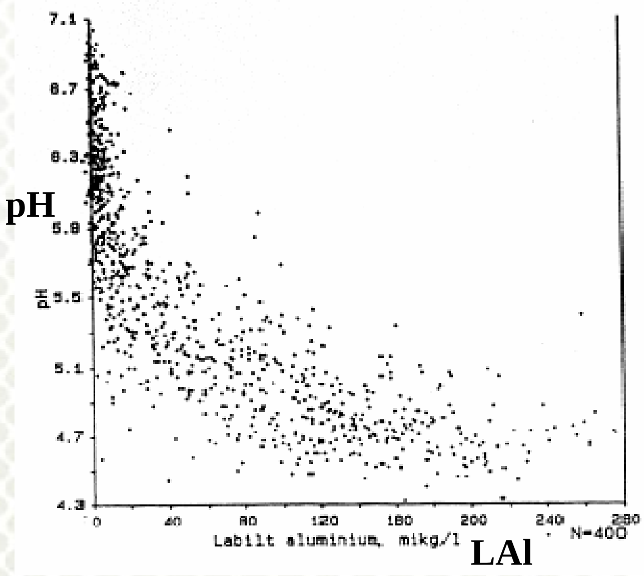
pH – WQ 1999 – 2001
Great variations





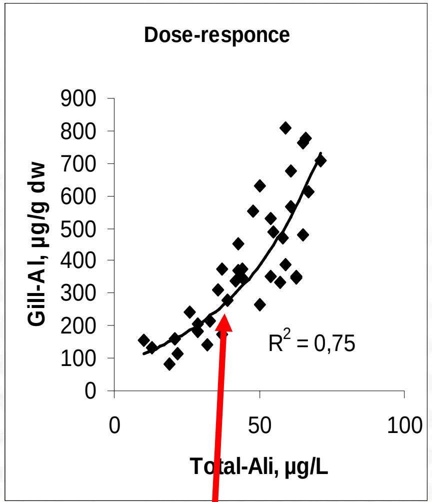


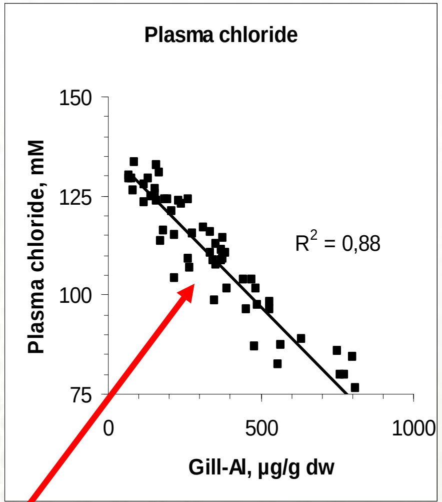
Regional differences in raw water pH

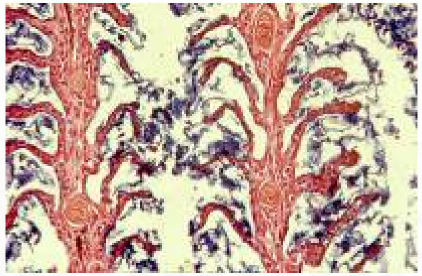
Low pH mobilise aluminium (Al)

$Al_{i\ water}$ - Al_{gills} - osmoregulation-toxicity

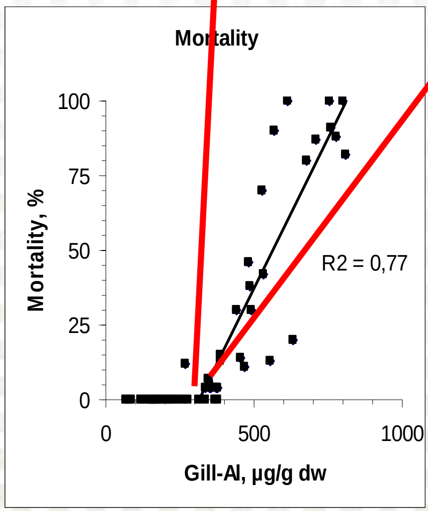
Increased inorganic Al - increased Al precipitation on gill

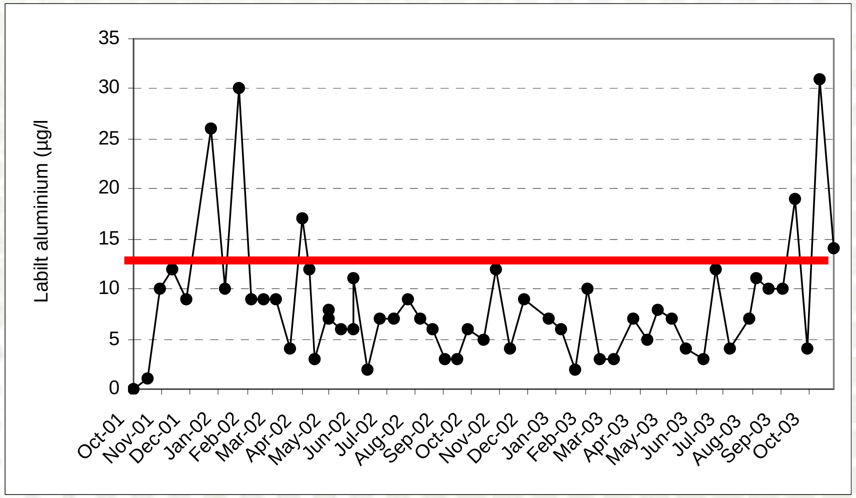






LAl





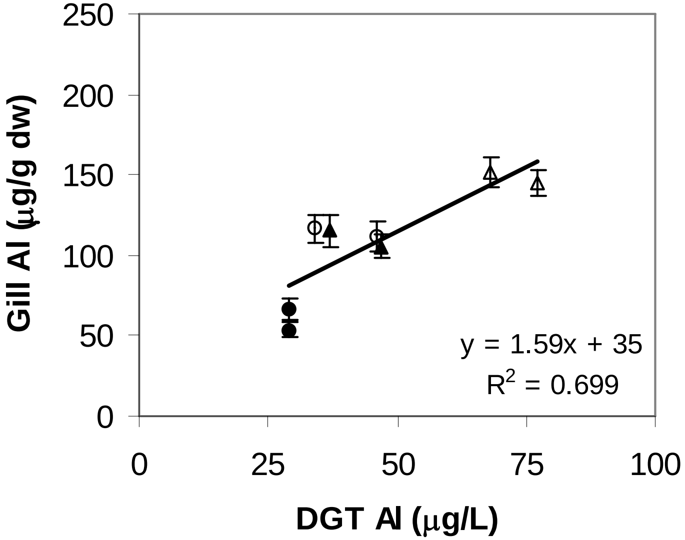
Kroglund et al. 1998, 2001

FW

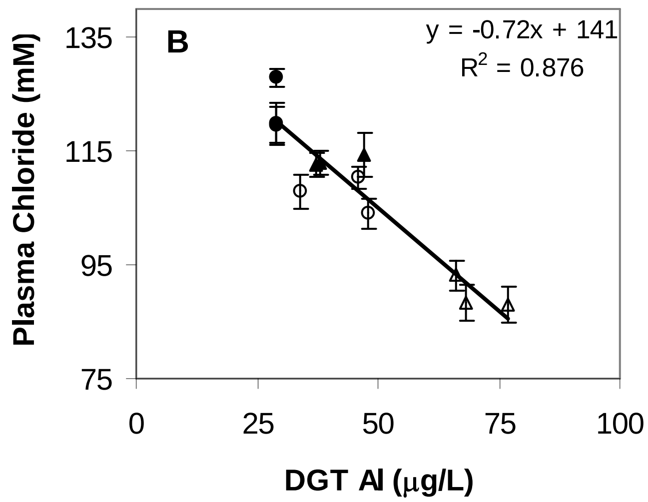
Can "New technology" be used as BIOMARKERS?

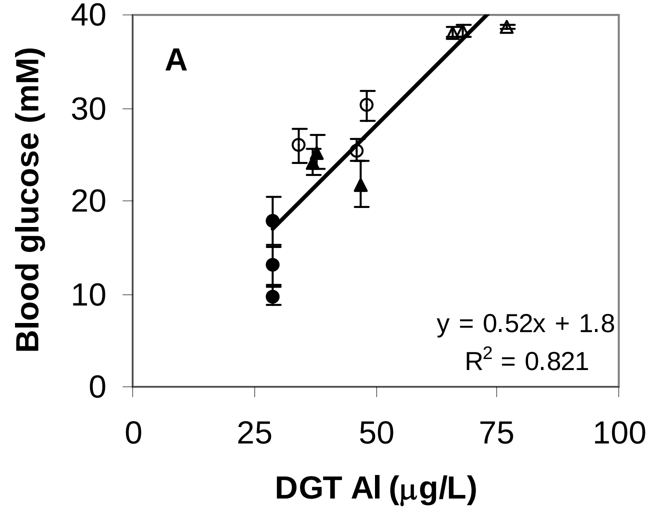
DGT – "Diffusion Gradient Thin Films"

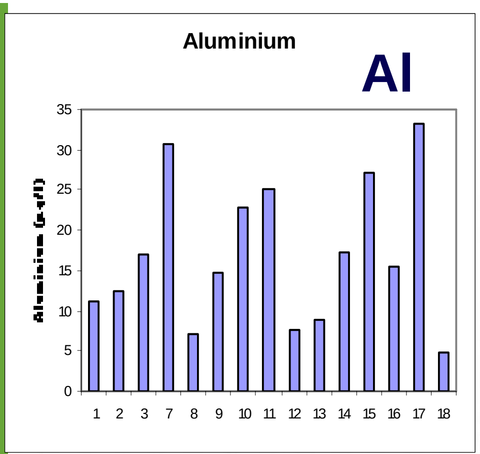
DGT "simulate" gill- and physiology responses

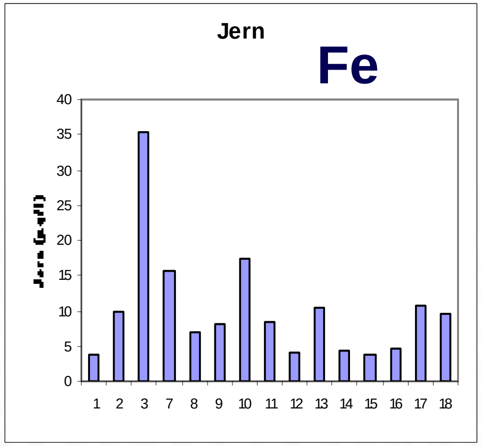


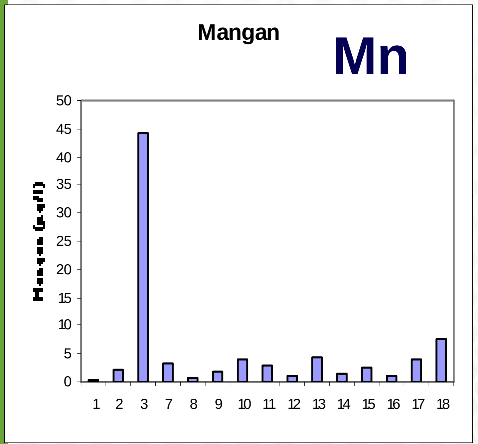
Røyset *et al.* 2005

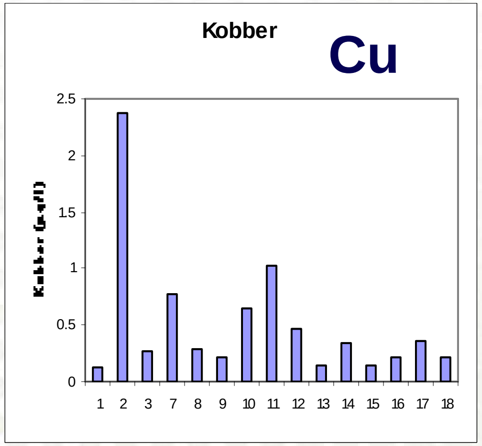


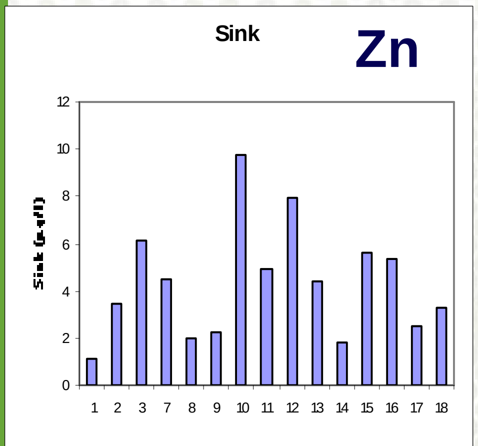


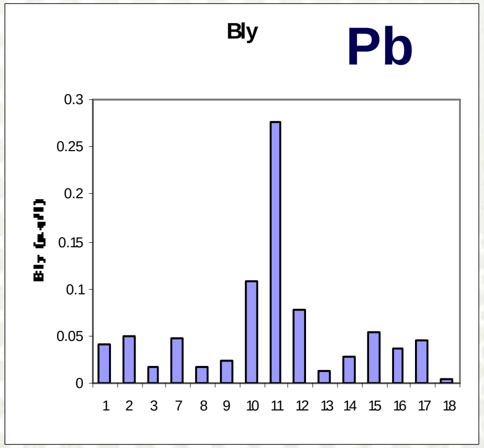












WQ-2002

DGT based mean concentration of metals in fish tanks

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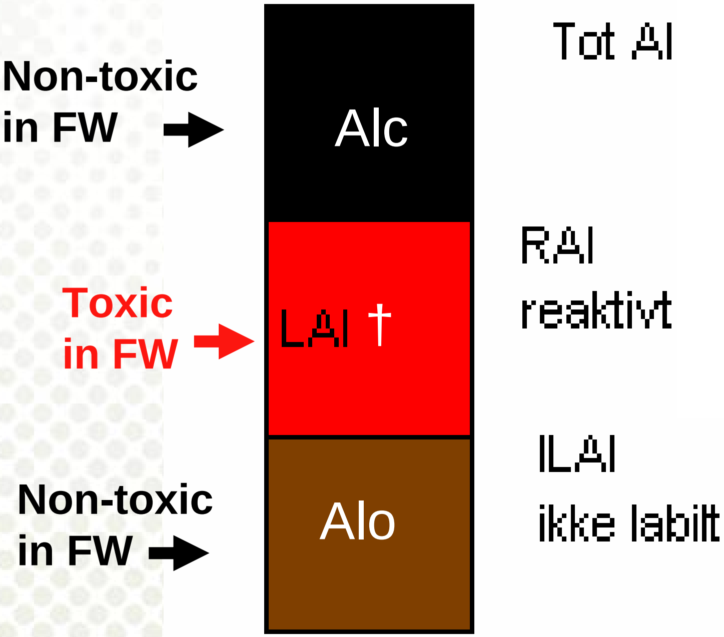
We have underestimated the toxic potential of Al!

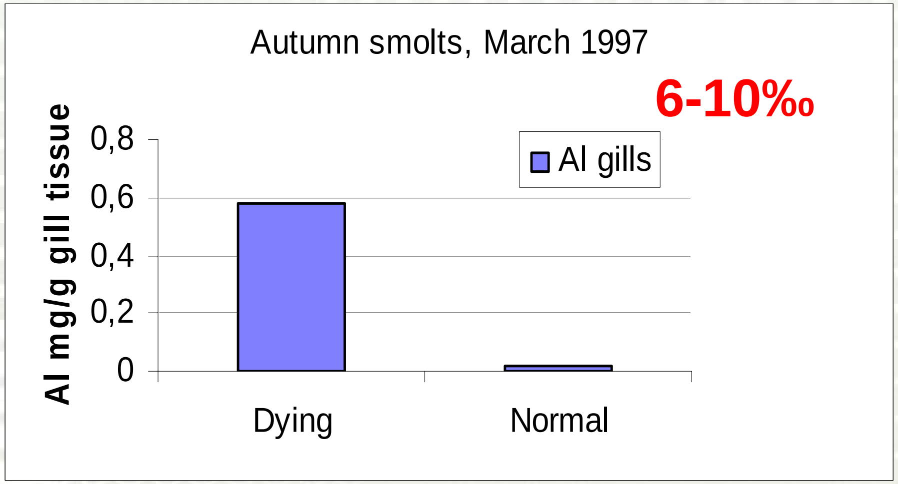
Today's aquaculture practises creates Al problems in new areas!



bilisation of
xic Al by:
Seawater
Production
Intensity or
Water
treatment

Al from freshwater can kill salmon in seawater!
Estuarine mixing zones - aquaculture

Aluminium from acid or humic rivers can kill salmon in net pens in fjords during high flow



Bjerknes et al. 1998

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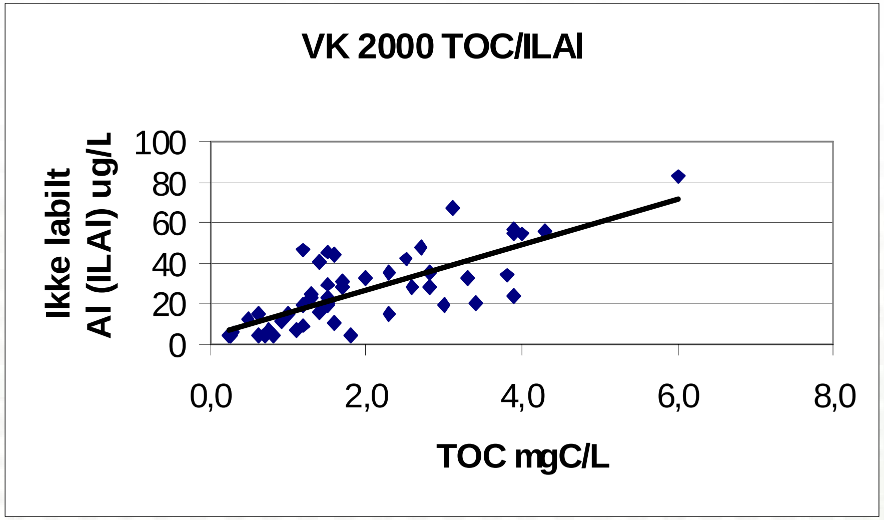
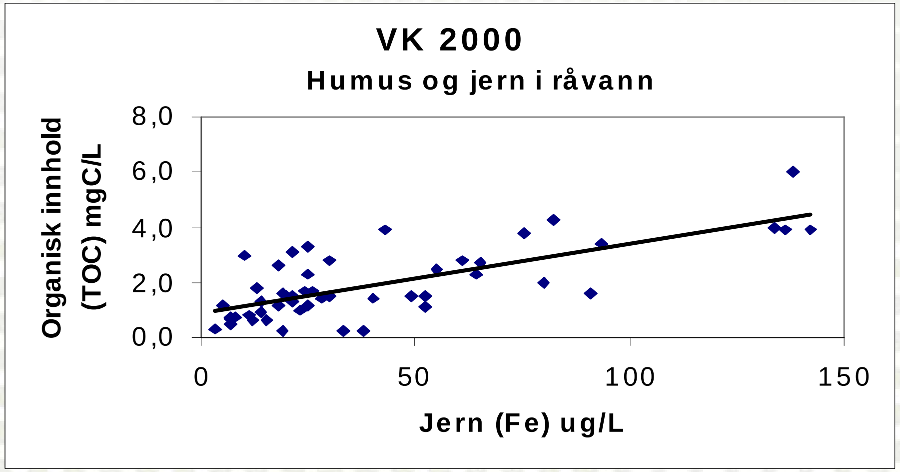
Humics (Total Organic Carbon) as a source for metal problems



Increased TOC = increased Al & Fe

"Organic bound" aluminium, Alo (ILAl)



Total iron, Fe

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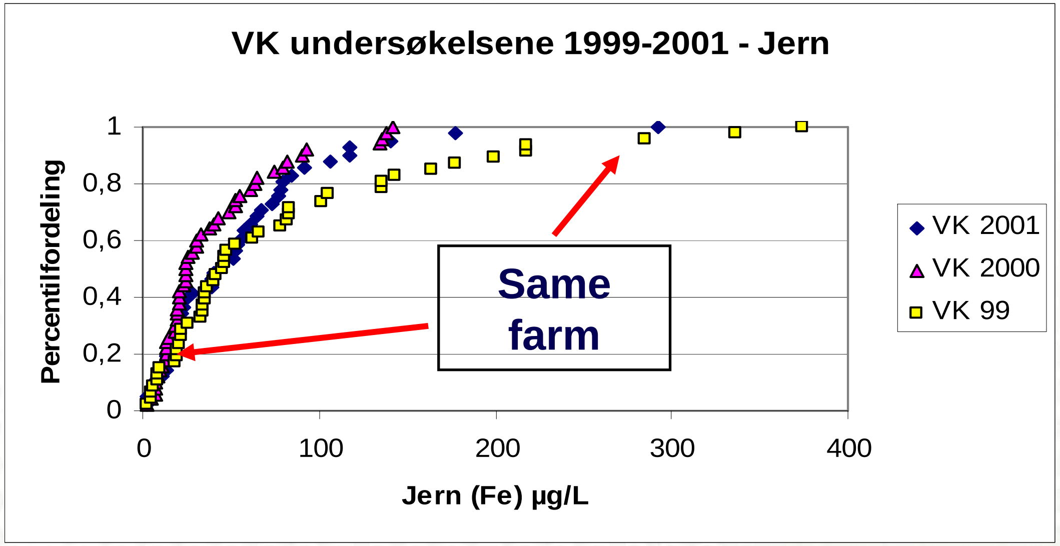
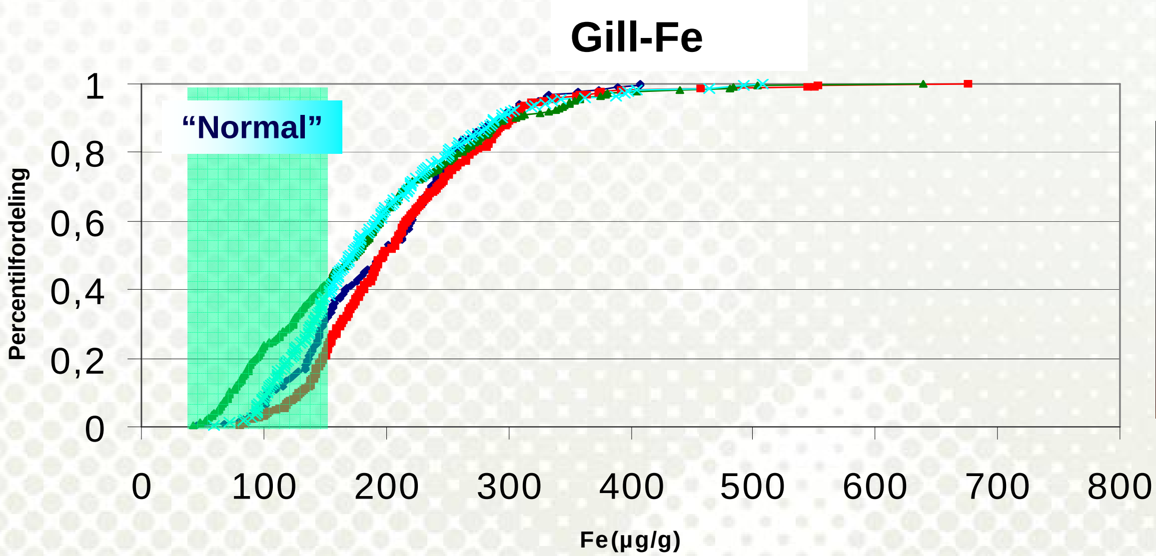
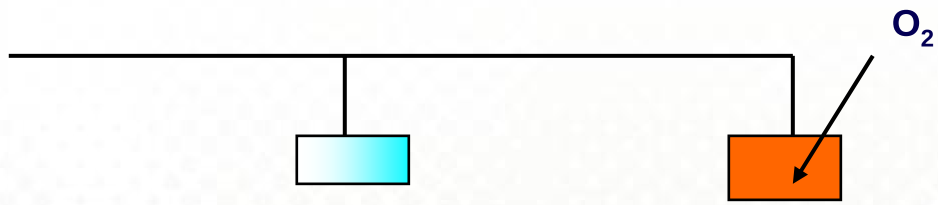
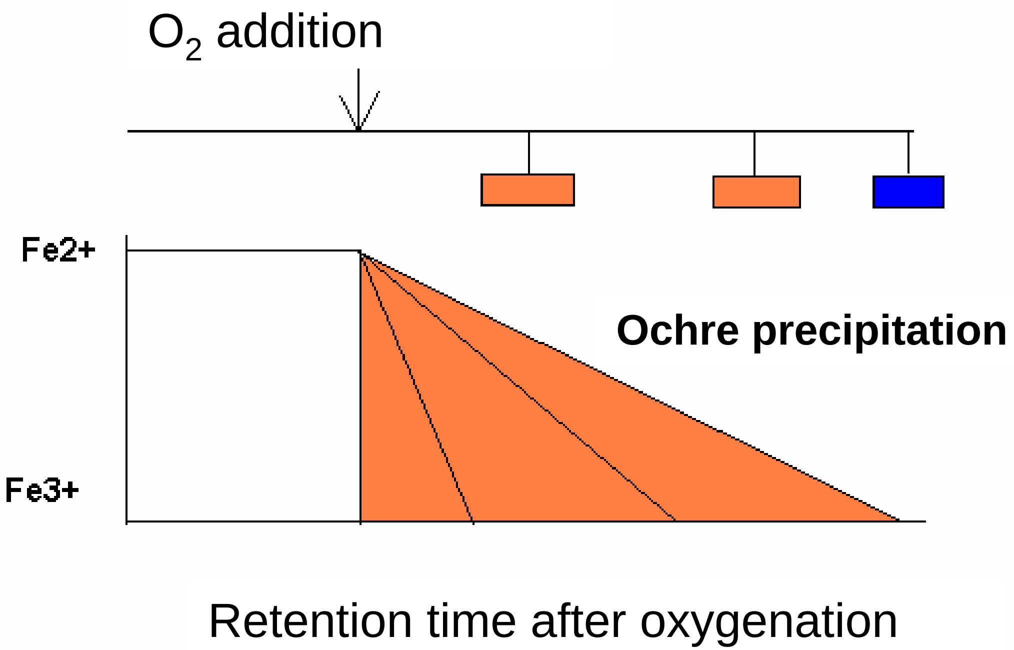
Iron, Fe





Iron and the new oxygenation methods





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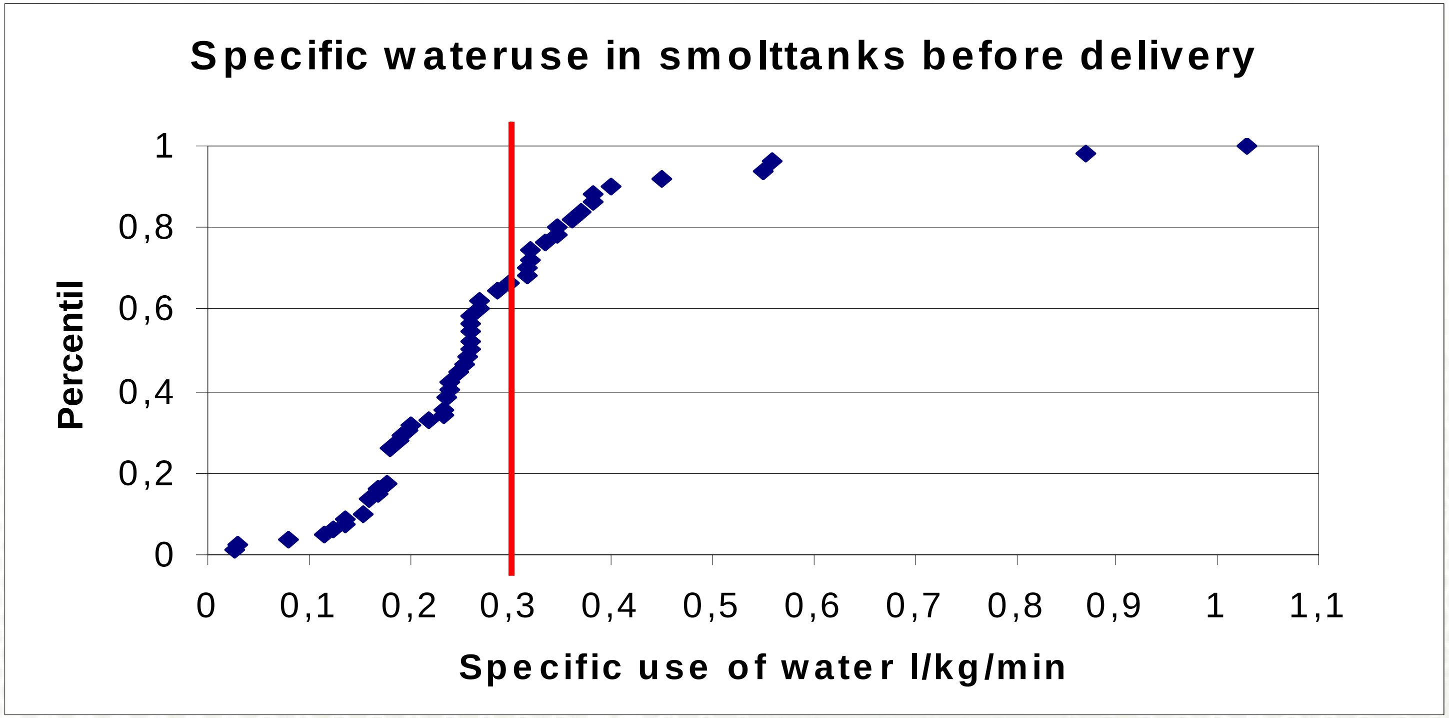
WQ 1999-2001
Intensive production - lack of water



- Planned to use 0,3 L/kg/min as a minimum flow
    - 70% used less!

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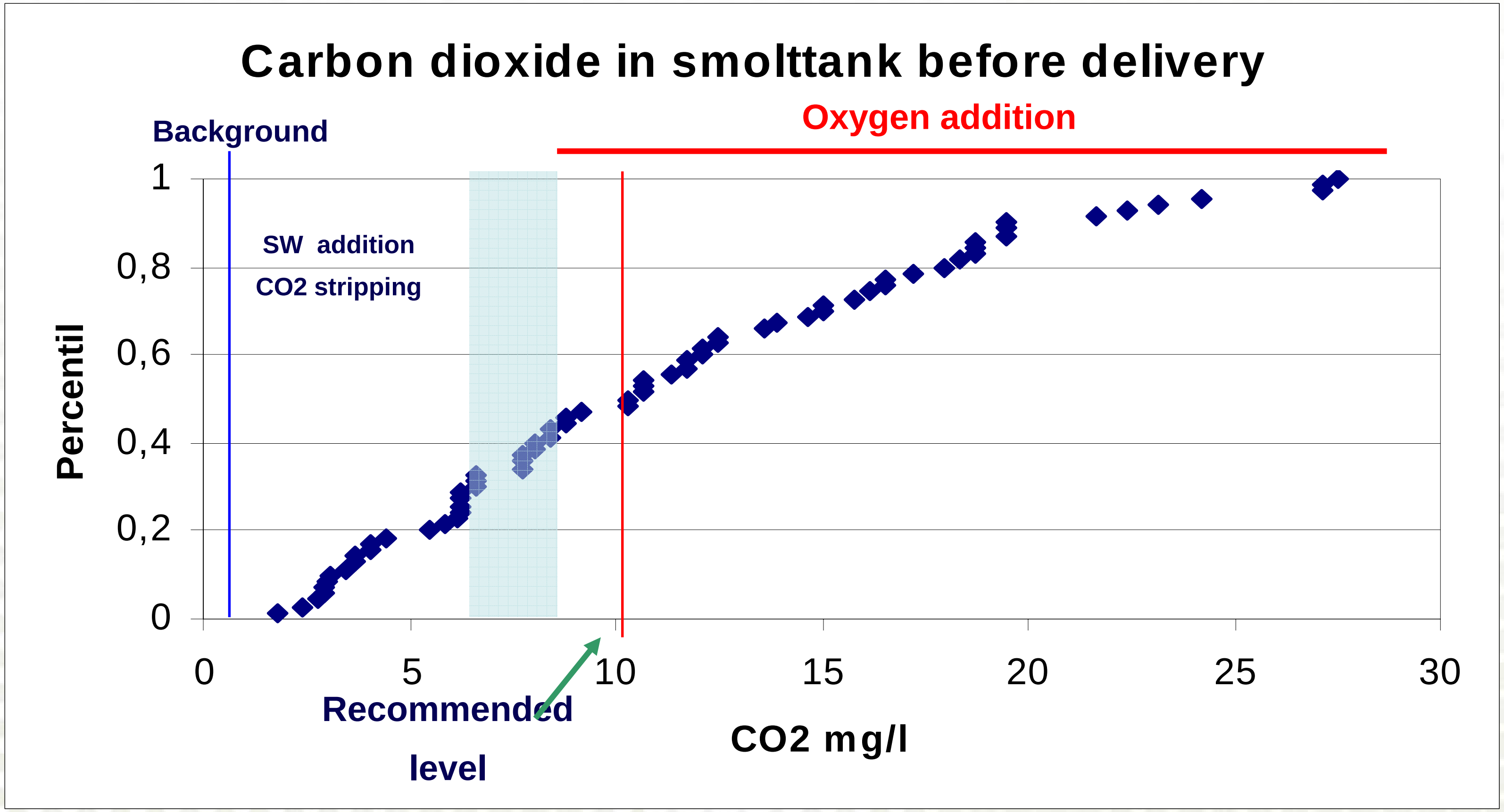
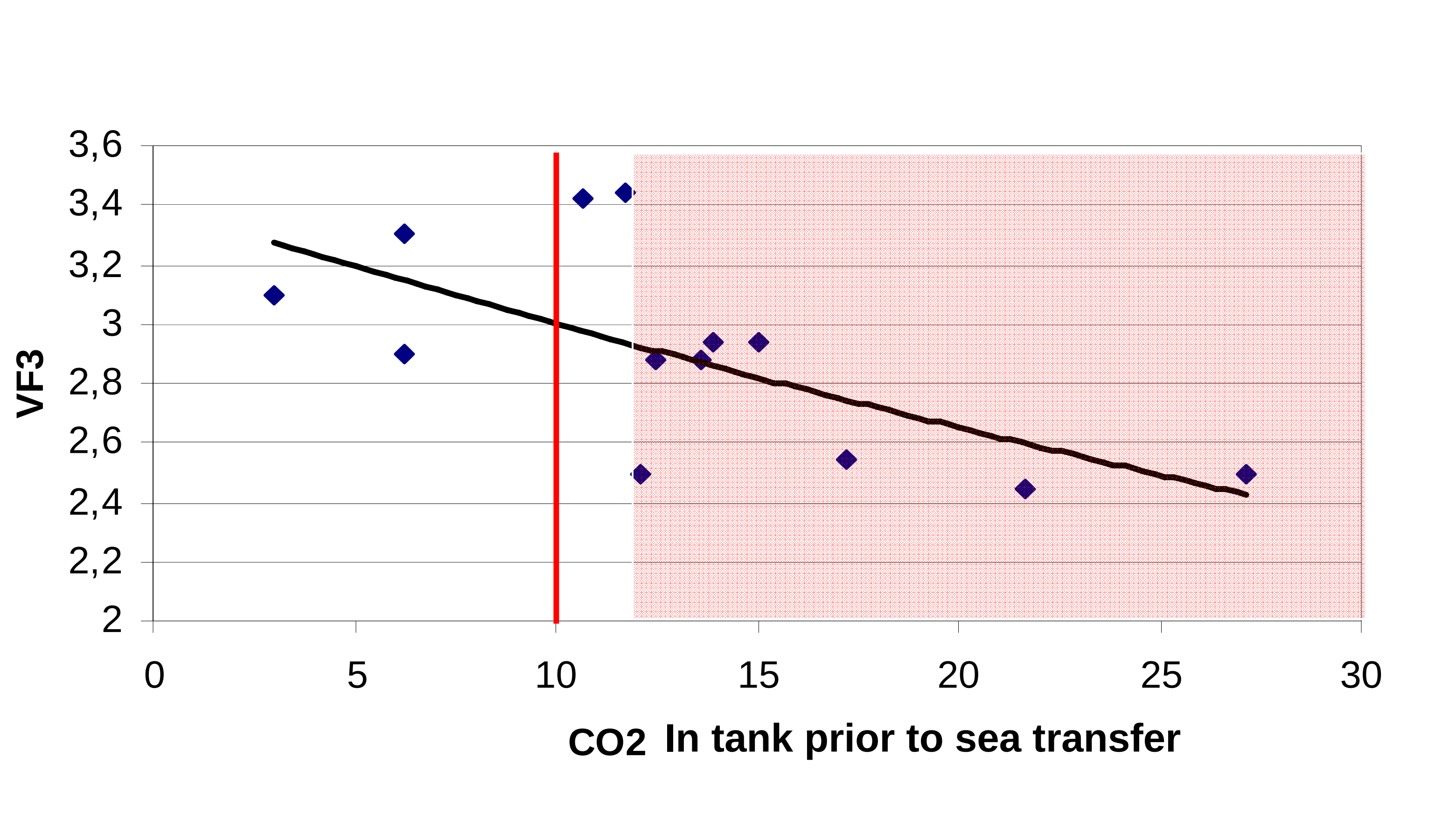
Intensive production results in high CO_2



WQ 2001 - Tankwater CO_2 and smolt. Resulting Growth Factor (GF3) after 90 days in sea



Growth factor 3

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Our main focus have been on **Oxygen** as a source for free radicals and oxidative stress

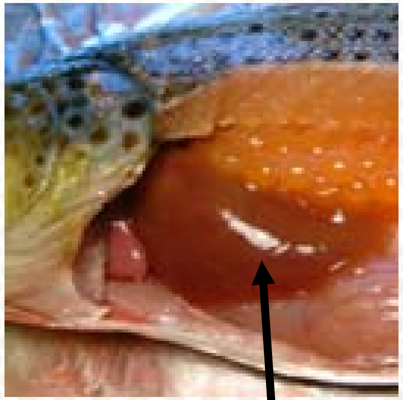
- Oxygen is reactive, and **create free radicals** hurting cell and cell function
- Will chronic super saturation of oxygen will lead to immunological problems?
- Will chronic super saturation of oxygen lead to reduced performance, including growth?

Organs for study

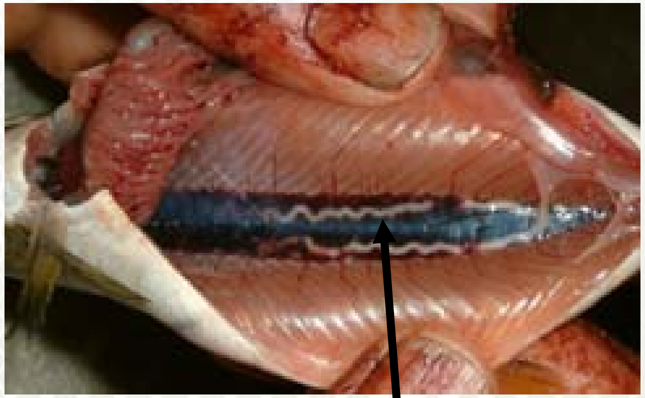
We have used several biomarkers for analyses of oxidative stress in gills, liver, kidney and blood:

Glutathione
Superoxide dismutase (SOD)
Catalase

Gill



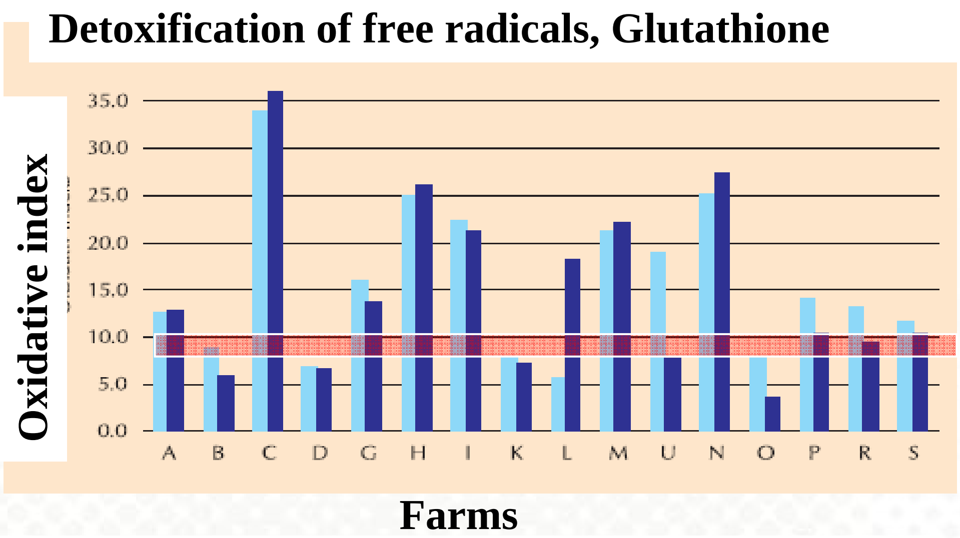
Liver



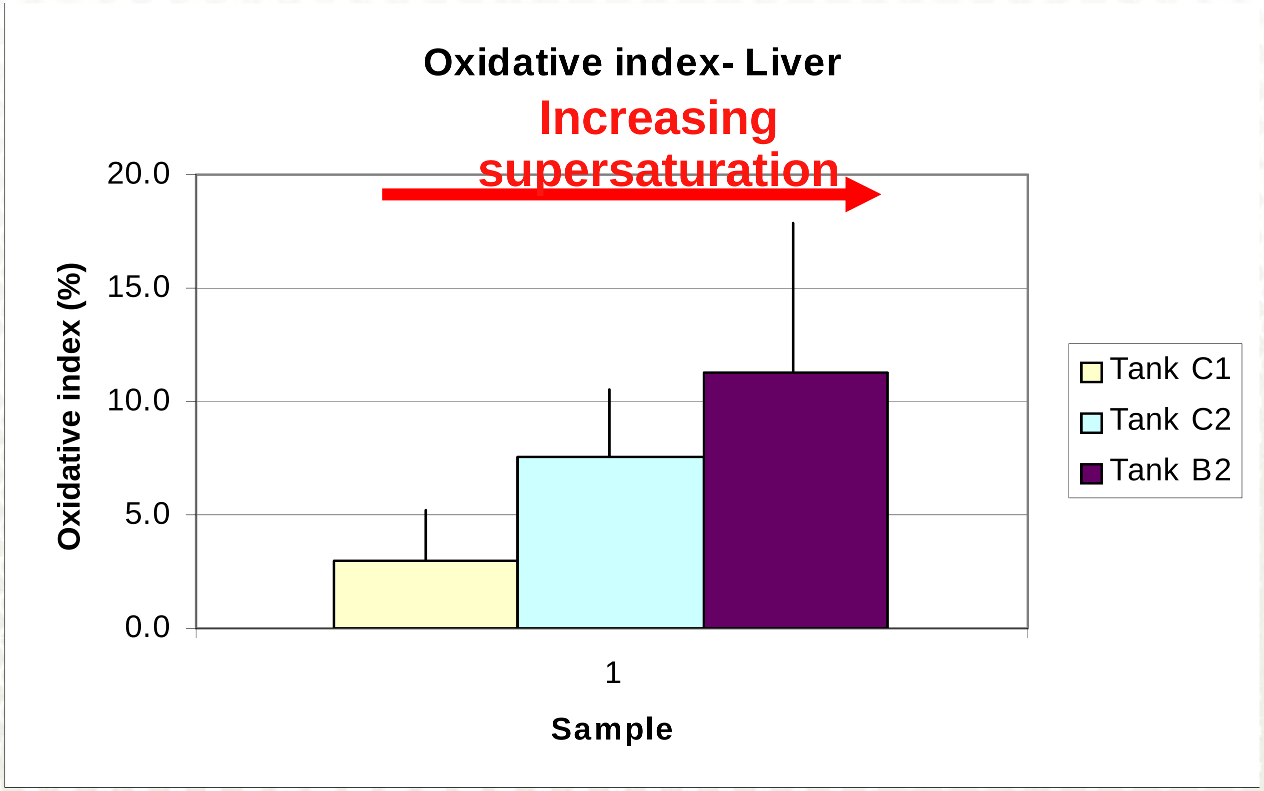
Kidney

Blood

Oxidative index, fish exposed to different oxygen pressure (hyperoxia)

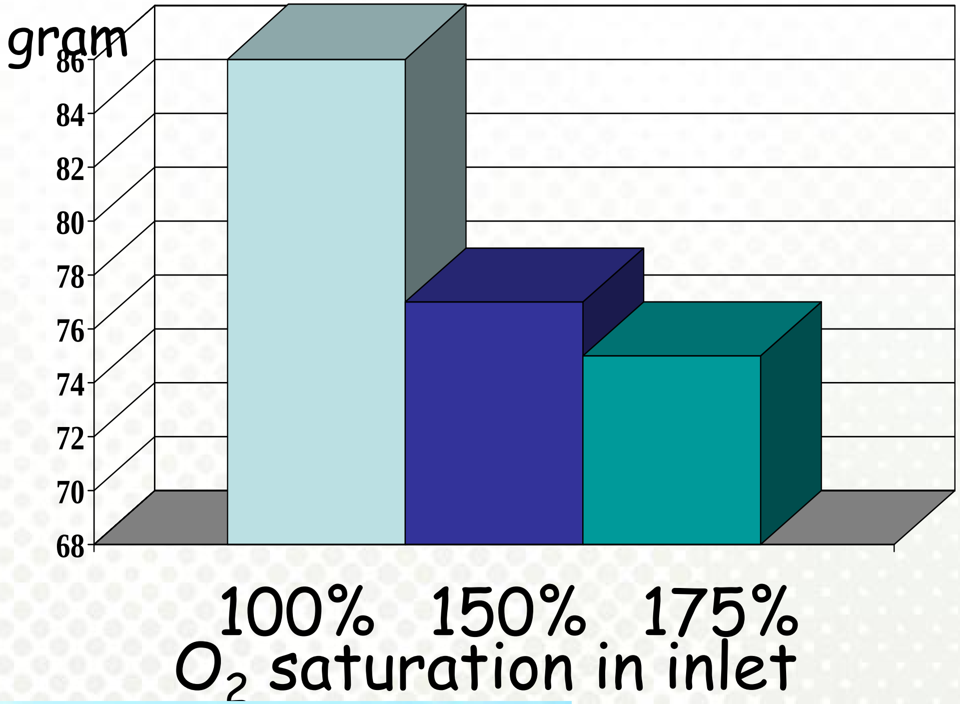


GSH/GSSH



Supersaturation in freshwater reduces growth

Weight of presmolts after an exposure period of 54 days



Reduced growth also after transfer to sea

Indication of increased deformities

Summary super-oxygenation experiments

Relative to 100% O_2 at the inlet and 70% in the outlet with CO_2 <u>< 10 mg/L</u>

O_2-saturation in freshwater >120-130 % results in:

- Reduced growth
- Increased O_2 at the same CO_2-level reduced growth even more
  - **O_2 dependent / CO_2 independent response**
- Blood chemistry changed - Hypercapnia
  - **Chloremia**
  - **Increased HCO_3**
- Ant-oxidant response indicating increased free radical formation
- Increased: IPN, fungi infection and sea lice infection

After 4 months in sea:

- High O_2-saturation in freshwater resulted in growth reduction in sea
- Indication of increased deformities

Bæverfjord et al. 2005-2006

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Main conclusion 1

- **Amount and quality of water is the major limitation for any aquaculture activity**
- **Good water quality and surplus water – Highest value!!!**
- **Water quality is highly variable due to:**
  - **Catchment characteristics and precipitation regimes**
  - **Management strategies/technology (run through/recirculation etc.)**
  - **Biotic factors (densities/ feeding regimes etc.)**
- **All farms should at least have one full year sampling (14 days frequency)**
- **Water analyses should include *in situ* techniques and/or passive sampling devices (DGT etc.)**

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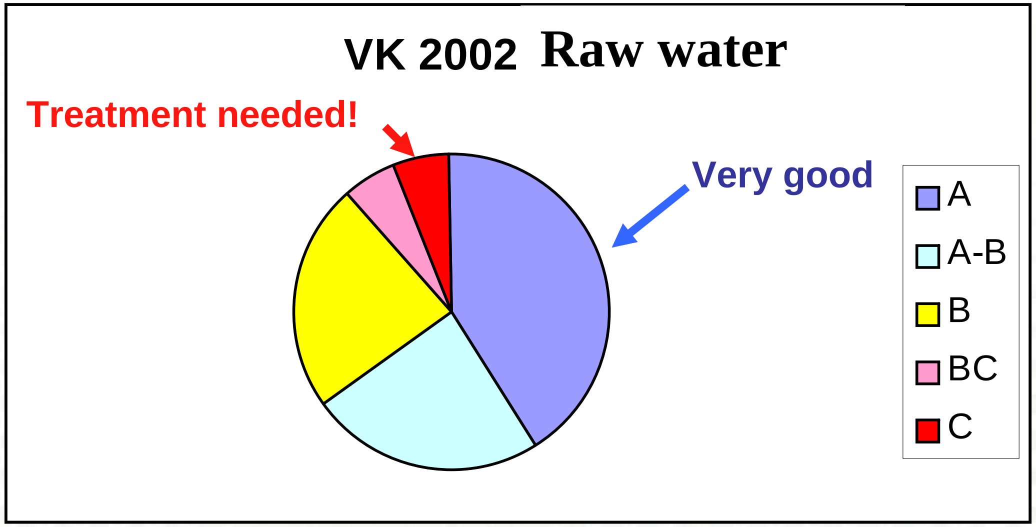
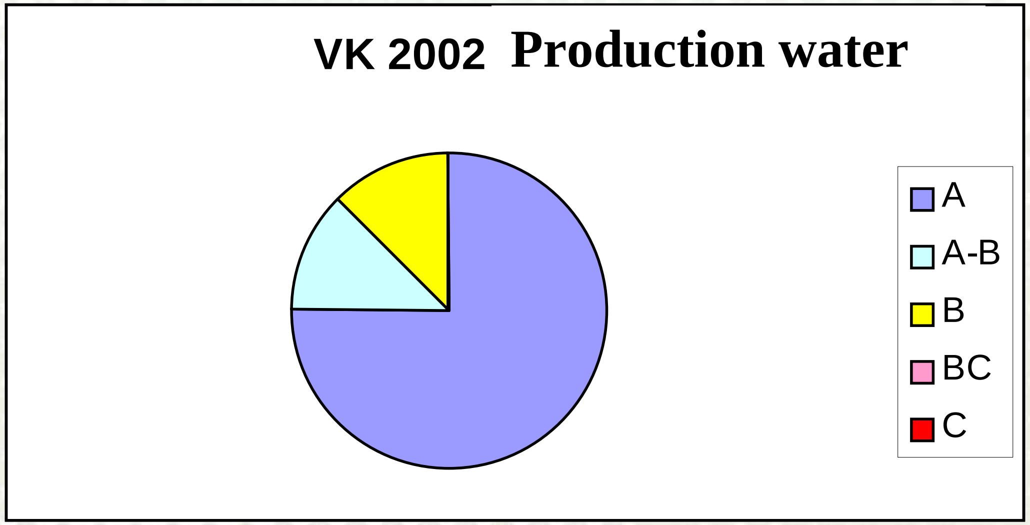
Main conclusion 2

- One cannot technically “override” basic biological limitations
- Avoid superoxygenation:
  - PaO_2 > 100 % around the fish
  - CO_2 > 12-15mg/L (?)
- Farmers having reduced their “superoxygenation strategy” have experienced increased growth, reduced mortalities and increased seawater tolerance!

Improvements in water quality after proper treatment

WQ 2002 Status Raw water and production water





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Main conclusion 3

- Monitoring programmes should include parameters relevant for:
  - Animal welfare control
  - EU Water Framework Directive (pollution control)
  - Safe food parameters (heavy metals, POPs etc.)
- Data from the WQ-Project are used to set Fish welfare and Critical Production Levels in Norway
- **Raw water quality**:
  can be used in monitoring of environmental water quality
- **Tank water quality = effluent water:**
  can be used to calculate pollution load to the environment
- **Accreditated institutions and high quality analytical laboratories trusted by the farmers and government should have a lead role**

WQ-Chile 2006 - ?

NIVA PROSJEKT fakta

WQ 1999-2006: Water Quality (WQ) in smolt production

NIVA has been responsible for the WQ project in Norway since 1999. The main goal of the project is to investigate water quality in smolt production units and to relate these findings both to production data at fish farms and to performance after transfer of the smolt to sea cages. The Norwegian University of Life Sciences (UMB) and Akvaforsk are our partners in the project. Customer reports verify that these results are vital both in terms of benchmarking and increased knowledge. To date, more than 160 farm studies have been conducted and the database covers about 80% of Norway's smolt-production units. A number of smolt farms in Scotland have also participated in the project. Globally, the WQ database is unique and has provided a useful tool for optimisation at the farms. Industry organisations and authorities concur that these data are essential to discussions of fish health and welfare issues.

What sort of data is collected in the WQ programme?

The principle of all WQ projects is to sample data from farms, fish and water one week before transfer to sea. This enables us to trace the effects of water quality in the freshwater stage on performance in the seawater stage. In addition we sample data from farms, fish and water from one tank/net with fingerlings to study the impact of intensive fry production on fish health and welfare. Smolt farms are provided with bottles, sample containers and instructions to take the following samples:

1. Untreated raw water under normal conditions and during a flooding event
2. Production water sampled after water treatment (inlet to fish tanks)
3. Tank water analysis (tank outlet), including CO_2 samples
4. Gill samples are analysed for metal concentrations. These samples are taken during a flooding event and also one week prior to sea transfer. The main focus is on aluminium and iron concentrations, because they are known to cause low performance and fish mortalities.
5. Sampling and later x-ray analysis of 50 juvenile fish to study skeletal deformities. This might be an indicator of feed deficiency or to excessive intensity in production.
6. Passive DGT (Diffusion Gradients in Thin films) samplers are used to gain information about free metal ions in the smolt tanks. These samplers are placed in the smolt tank for about a week and provide data on average concentrations for the specific period.
7. Data about vaccination types and techniques.
8. Data about key operational conditions linked to the farm and to the fish tanks, as well as to transport.
9. Mortality data during and after transport, as well as key performance indicators in the sea 2, 30 and 90 days after transfer from the smolt freshwater location.

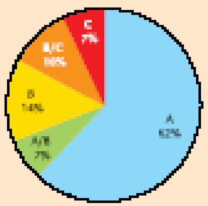

Figure 1. Classification of raw-water quality. Good water quality (blue), intermediate (yellow) and poor raw water quality (red).

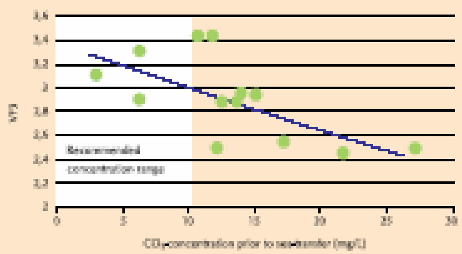

Figure 2. Correlation between CO_2 concentration in smolt tanks prior to sea-transfer and growth response (VF3) after 90 days in sea.

Smolt farm in Southern Norway. Photo: Frode Kroglund.

Smolt farms receive WQ data reports

Each farm receives a report on its own results regarding water chemistry, gill metals and skeletal status as well as operational data. Suggestions for improvements of, for example, water treatment are also included. Every year all participants meet for a one-day seminar where anonymous data from all farms are presented as well as new research findings on water quality, fish welfare and water treatment techniques.

Important findings from the WQ project

The WQ project has generated the largest database on the basis for smolt production (amount and quality of raw water (Figure 1). A negative correlation has been found between production intensity in freshwater (represented by CO_2 and total ammonia/nitrogen) and subsequent performance in the sea (Figure 2).

A key performance indicator in smolt or fingerling production in intensive land based tanks is specific use of water "SUW" (L/kg Fish/min). The water quality in the fish tanks is closely linked to this parameter, so are the production costs for smolt. A low SUW is an indicator of higher levels of metabolites as CO_2 and total ammonia nitrogen (TAN). Research projects in Norway we have shown a close link between limitation of growth and the risk for infectious pancreatic necrosis (IPN) after transfer to sea.

The Norwegian Seafood Federation (FHL-Norway) recommends the WQ project

The Norwegian Seafood Federation recommends participation in this project to its members. It is particularly interested in obtaining data on how the ongoing intensification of Norwegian smolt production affects smolt quality. Based on data form the WQ database, FHL has financed a large project on "Water quality – smolt quality" that is nearing completion.

WQ Chile

We are currently investigating the possibilities for starting up the WQ project in Chile. If you are interested in this, please contact us by e-mail or phone.

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