Water quality and gill diseases

Gardermoen, November 7, 2012

by

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http://statisk.umb.no/ina/ansatte/bjorro.php

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Fe on fish gill (scanning electron microscopy with x-ray microanalyses, UMB, Skryseth (2007)

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Vital organs in fish which can be affected by pollutants in the environment

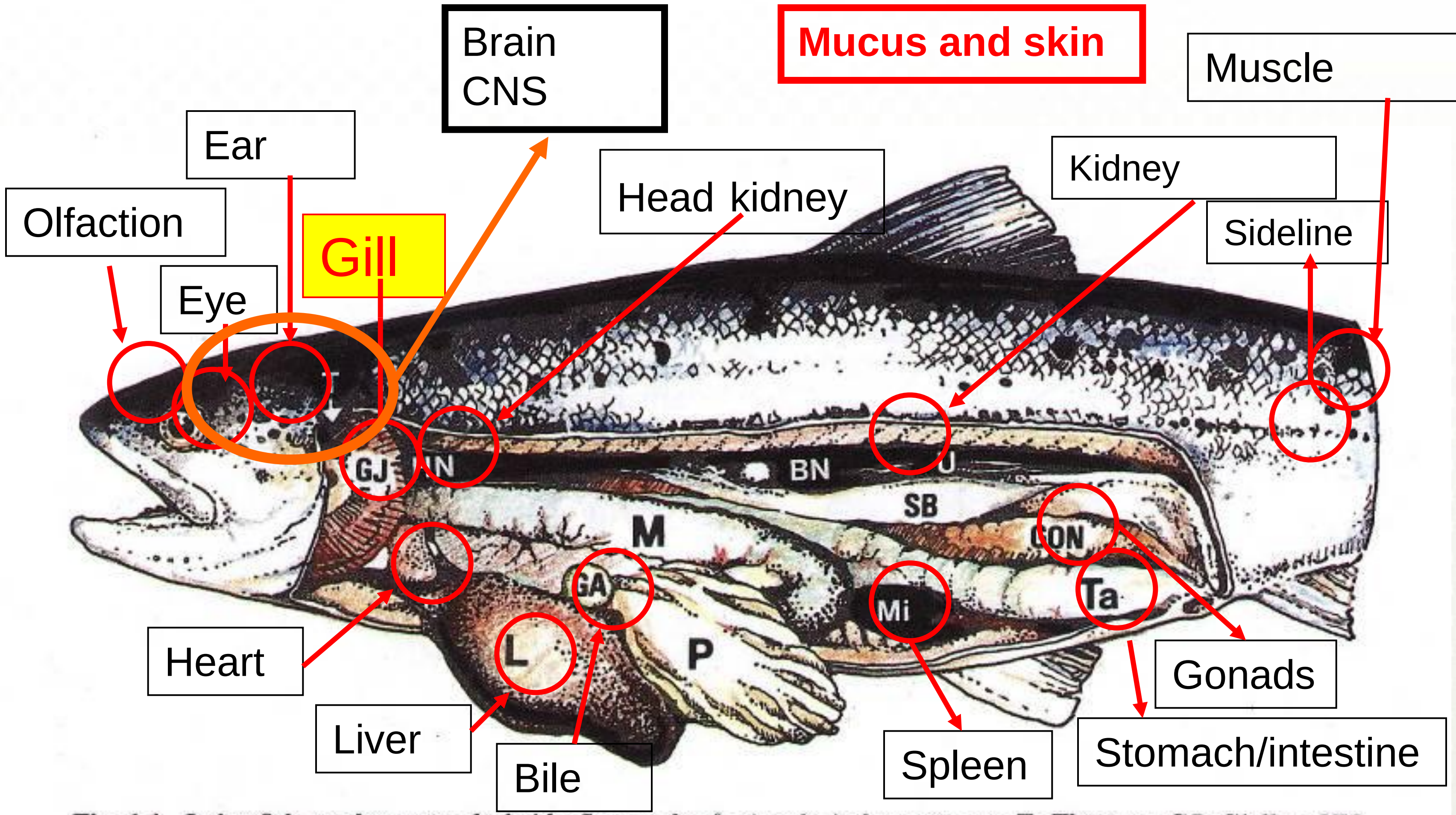

Fig. 1.4 Laksefisk med venstre bukside fjernet for å vise de indre organer. T: Thymus, GJ: Gjeller, HN: Hodenyre, BN: Baknyre, U: Urinleder, GON: Gonade, Ta: Tarm, Mi: Milt, M: Magesekk, P: Pylorusblindsekker, L: Lever, GA: Galleblære. Hjertet sees mellom lever og gjeller. Et stanniuslegeme sees foran BN i nyren.

Modified after Kryvi 1992

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What can cause adversely effects to gill surface and gill functioning other than bacteria and virus?

- Metals, mainly inorganic low molecular mass (LMM) species
- Particles with sharp edges (including silicates)
- Chemicals and gasses (NH_3, Chlorine, N_2)
- Toxins from cyanobacteria, algae, jellyfish etc.
- And probably many more causes linked to primary and secondary events (like "cold water gill disease").

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Major incidents where the gills of Atlantic salmon are "at risk"

- Presmolts through smoltification period before sea transfer (Al, Fe, free radical exposure)
- Exposure to full seawater if not seawater tolerant (increased sea lice infection and mortality)
- During transfer to sea by wellboat or car (hyperoxia, hypercapnia, high TAN/NH_3)
- Use of disinfections with free radical production
- On growth period and freshwater floods with metals
- On growth period with toxic algae, zooplankton and jellyfish

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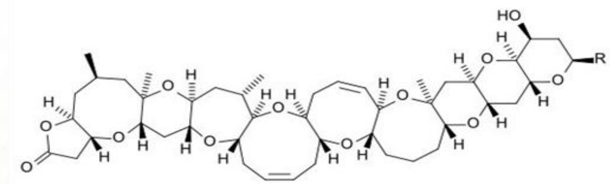
"Non virulent gill diseases"

- Harmful and toxic algae
- Harmful zooplankton (gelatinous-plankton)
- Other environmental factors



Rev Fish Biol Fisheries
DOI 10.1007/s11160-010-9182-6

REVIEWS

Non-infectious gill disorders of marine salmonid fish

Hamish D. Rodger · Louise Henry ·
Susan O. Mitchell

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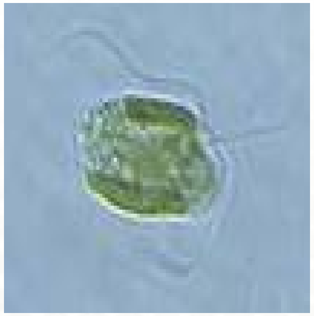
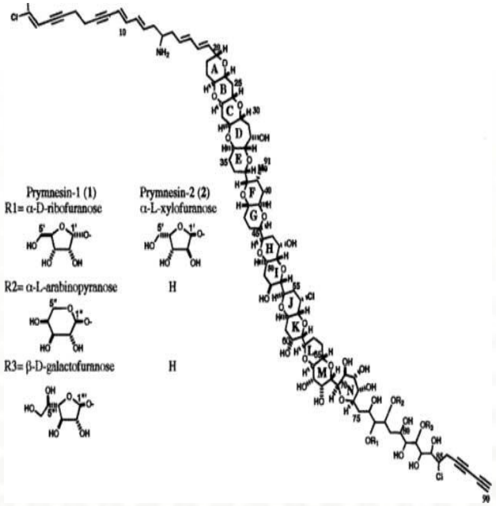
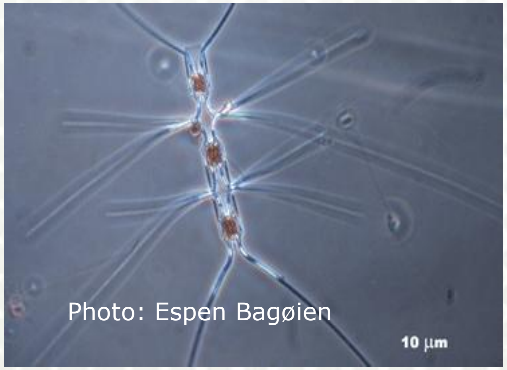
Harmful algae

There are several mechanisms by which algae can harm fish:

- Ichtyotoxins
  - Mainly marine flagellates or dinoflagellates
- Mechanical damage
  - Mainly from diatoms with silica spines/setae
- Suffocation
- High algae biomass creating hypoxia at night time and through biodegradation at the end of blooming







- «Gas-bubble trauma»
- Hyperoxia during algae blooms at daytime
- Probably a case of ”free radical” exposure

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Toxic algae

- ***Chrysochromulina polylepis***, caused a massive fish kill of caged Atlantic salmon in Southern and Western Norway in 1988.
- Affected the gills and caused osmoregulation failure (Leivestad and Serikstad 1989)

Leivestad, H. og Serikstad, B. (1989). Some observations on the effects of Chrysochromulina polylepis on the osmoregulation in fish. ICES-Workshop on the 1988 Chrysochromulina polylepis bloom, Bergen, February 28. to March 2., 1989.

- The toxin was probably like Prymnesin

Hektoen, H., Skulberg, O., Rosseland, B.O. & Kvellestad, A. 1990. Økotoksikologiske forsøk (Allelopati) med algegiftstoffer fra *Chrysochromulina polylepis* i det marine miljø. - NIVA-Akvarapport, O-88225. 19 pp.

NM STATE UNIVERSITY

Toxic Golden Algae (*Prymnesium parvum*)

Circular 647

Rossana Sallenave[1]

Cooperative Extension Service • College of Agricultural, Consumer and Environmental Sciences

This publication is scheduled to be updated and reissued 1/15.

Photo: Photograph by Dr. John La Claire II, University of Texas at Aust

Toxin = prymnesin

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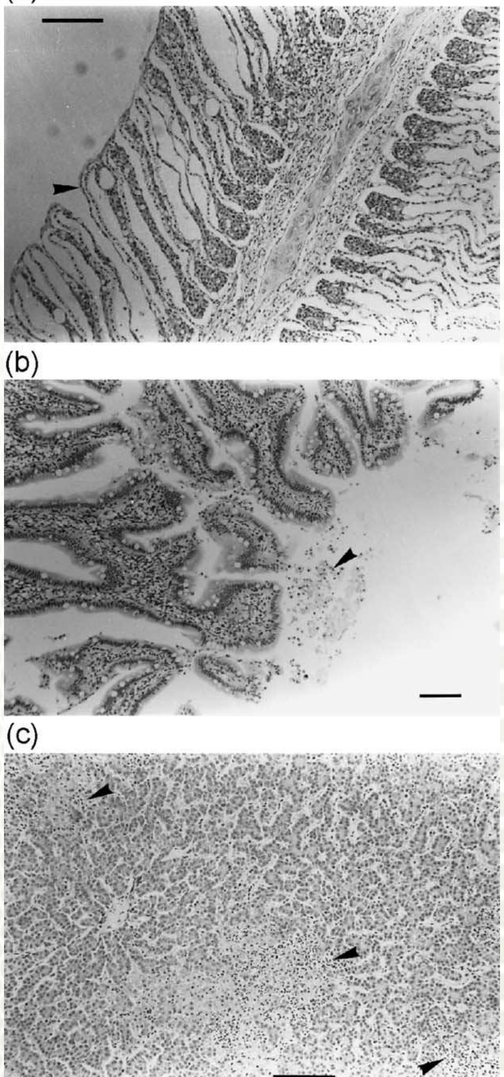
Harmful algae, Dinoflagellates – **Red Tide**

Chaetoceros wighamii (4.5 X 10^5 celler liter $^{-1}$)
dominert blomstring

(a)



Treasurer et al. 2003

Karenia mikimotoi blomstring

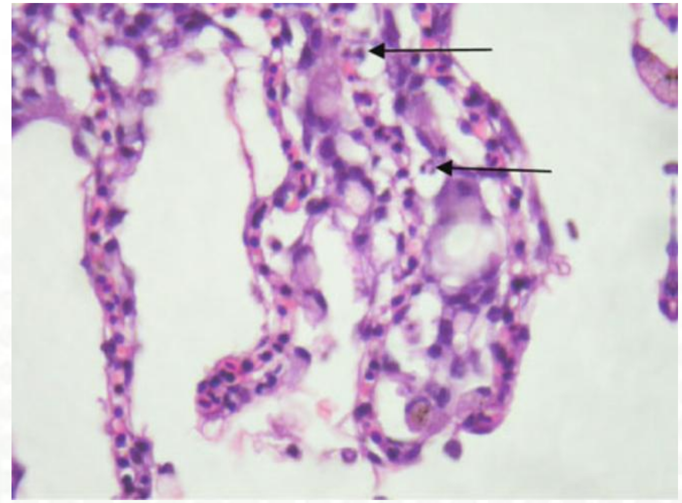


Fig. 1 Histopathological section of Atlantic salmon gills exposed to harmful phytoplankton (K. mikimotoi) exhibiting necrotic epithelial cells, irregular surface and epithelial lifting (H&E X100). Hentet fra Rodger et al. (2011)

Bull. Eur. Ass. Fish Pathol., 27(1) 2007, 39

Pathology of wild and cultured fish affected by a *Karenia mikimotoi* bloom in Ireland, 2005

S. Mitchell and H. Rodger*

2007

Fig. 2. Pathology of (a) gills, arrow indicates oedematous separation of epithelia, (b) gut, arrow shows sloughed necrotic cells, (c) liver, arrow indicates focal necrosis with haemorrhage, related to damage from a phytoplankton bloom. Scale shown as bar = 100 µm.

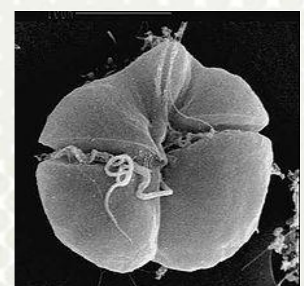
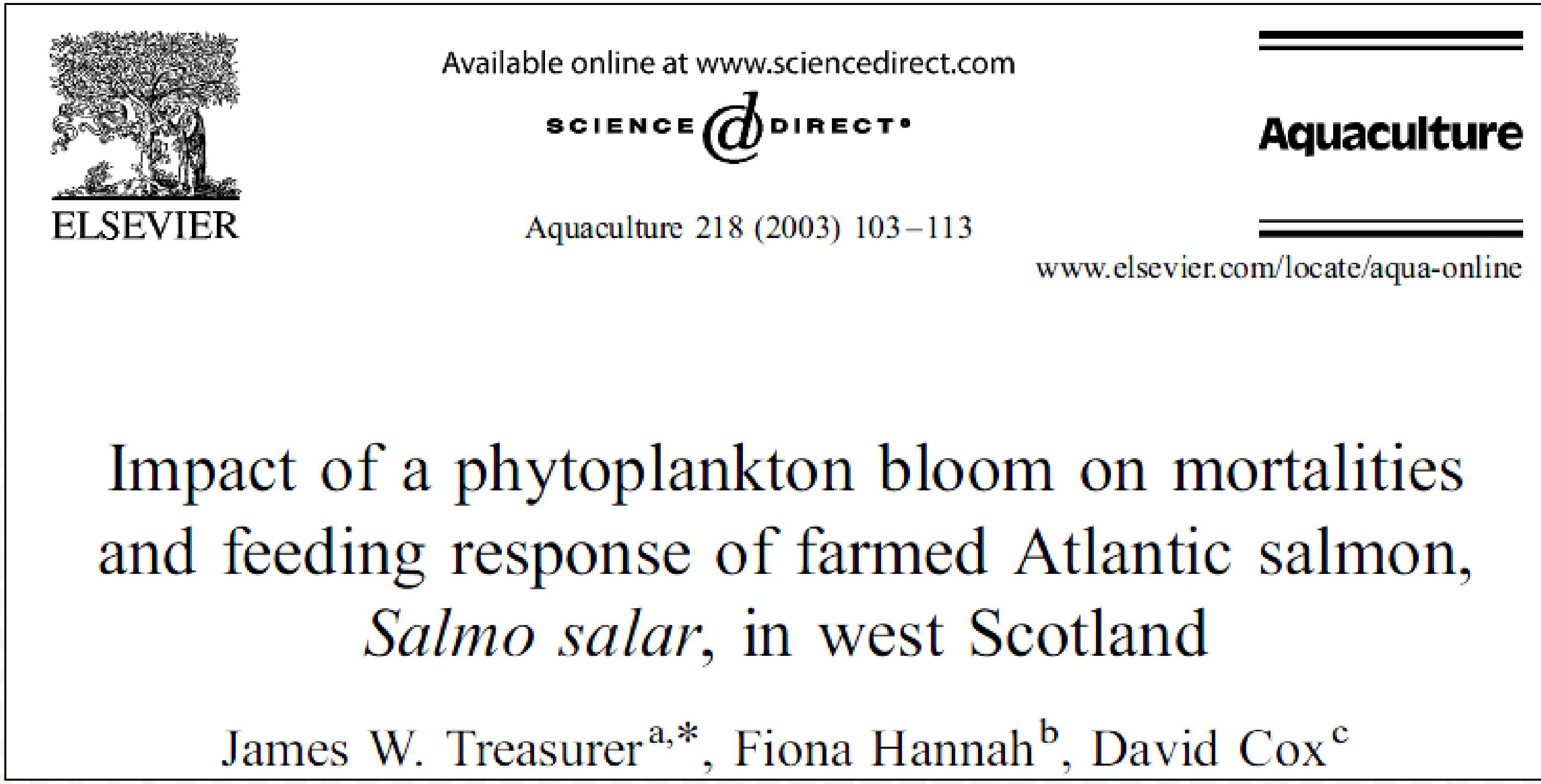


Photo: Wikipedia org.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Aquaculture 218 (2003) 103–113
Aquaculture
www.elsevier.com/locate/aqua-online

Impact of a phytoplankton bloom on mortalities and feeding response of farmed Atlantic salmon, *Salmo salar*, in west Scotland

James W. Treasurer[a,*], Fiona Hannah[b], David Cox[c]

Chaetoceros wighami

Photos: Goldenmap.com

Rosseland, B.O, Åtland, Å., Dale, T. & Powell, M. Water quality and gill diseases. Gardermoen October 6, 2012. ©

Harmful algae

Table 1 Examples of marine phytoplankton species associated with fish mortalities

Phytoplankton species	Finfish affected	Country/region	Details	References
Karenia mikimotoi	*Gadus morhua, S. salar*	Ireland	Cod hatchery juveniles killed, 500 mortalities of farmed salmon	Silke et al. (2005), Mitchell and Rodger (2007)
	S. salar	Scotland	Gill damage in farmed salmon	Jones et al. (1982), Davidson et al. (2009)
	S. salar, O. mykiss	Norway	2.6–100% mortalities farmed fish	Dahl and Tangen (1993)
Karenia brevisulcata	*Sardinops sagax*	New Zealand	0.5 tonne pilchards killed	Jones and Rhodes (1994)
Cochlodinium polykrikoides	*Various farmed species*	Korea, Japan, China		Kim et al. (1997), Yuki and Yoshimatsu (1989), Qi et al. (1993)
		Philippines	Wild reef fish	Azanza et al. (2008)
Gonyaulax excavata	*S. salar*	Faroe Islands		Mortensen (1985)
Karlodinium micrum	*Mugil cephalus, Sciaenops ocellatus*	South Carolina	Retention pond fish kill	Kempton et al. (2002)
	Morone saxatilis x chrysops	Chesapeake Bay	15,000 2–2.75 kg fish in 1 day	Deeds et al. (2002)
Gymnodinium sp	*Liza macrolepis, Acanthropagrus cuvieri*	Araban Gulf	Farmed and wild fish	Heil et al. (2001)
Chaetoceros wighami	*S. salar*	Scotland	550,000 fish died or were culled, 44 tonnes mortality	Bruno et al. (1989), Treasurer et al. (2003)
Chaetoceros convolutus	*Oncorhynchus kisutch*	British Columbia	60,000 40 g fish within 1 week	Speare et al. (1989), Albright et al. (1993)
Ceratium furca	*S. aurata, Liza klunzingeri*	Arabian Gulf	Fish kill of wild mullet and farmed bream	Glibert et al. (2002)
Ceratium furca	*Salmo salar*	Scotland (Skye)	2.69T of 4 kg fish died (670 fish)	ICES report (2005)
Ceratium fusus	*Various species*	Japan	Farmed fish	Onoue (1990)
Skeletonema sp.	*S. salar*	British Columbia	Farmed fish (4% mortality, approx. 16,000 fish, mixed bloom)	Kent et al. (1995)
Chrysochromulina polylepis	*S. salar*	Scandinavia	Farmed and wild fish	Dahl et al. (1989)
Heterosigma akashiwo	*Oncorhynchus tshawytscha*	New Zealand, Japan	Farmed fish	Chang et al. (1990), Khan et al. (1997)
Alexandrium tamarense	*S. salar*	Nova Scotia	Farmed fish	Cembella et al. (2002)
Pseudonitschia sp.	*S. salar*	British Columbia	Farmed fish	Kent et al. (1995)

Table from Rodger et al. 2011

Common species in Norway

Monitored at coastal stations by Mattilsynet (Norwegian Food Safety Authorities)

Several other freshwater species are harmful

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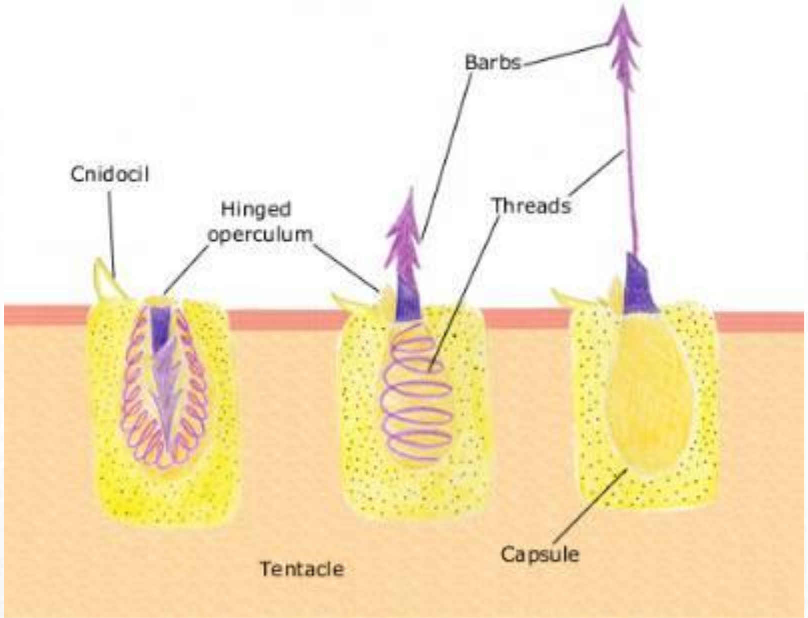
Harmful zooplankton (gelatinous-plankton)

- Harm from zooplankton are quite similar to harm from phytoplankton
- Physical damage to skin, mucus and gills
  - Many with nettle (nematocycsts) cells with hooks
- Toxins
  - Different compounds, often proteins with paralyzing or necrotic properties
- Suffocation
  - Clogging of gills



Harmful zooplankton (gelatinous-plankton)

Table 2 Examples of gelatinous zooplankton associated with mortalities in farmed salmonids

Zooplankton species	Fish affected	Country/region	Details	References
Aurelia aurita (Scyphozoan)	*S. salar*	Norway	Farmed salmon	Bamstedt et al. (1998)
		Shetland	Farmed salmon	Bruno and Poppe 1996
		Ireland	Farmed salmon	Mitchell (personal observation)
Pelagia noctiluca (Scyphozoan)	*S. salar*	Northern Ireland	Approx. 250,000 fish killed	Doyle et al. (2008)
	S. salar	Ireland, Scotland	O'Connor (2002), Hay and Murray (2008)	
	S. salar	France	Significant mortalities in farmed fish	Merceron et al. (1995)
Muggiaea atlantica (Siphonphore)	*S. salar*	West coast of Norway	>100,000 farmed salmon, 2000 siphonophores/m^3	Fossa et al. (2003), Hellberg et al. (2003)
	S. salar	Scotland	Mortalities in farmed fish	Sourd (pers. comm)
Phialella quadrata (Leptomedusa)	*S. salar*	Shetland	1,500 fish died	Bruno and Ellis (1985)
		Norway		Bamstedt et al. (1998)
Cyanea capillata (Scyphozoan)	*S. salar*	Scotland, Ireland	Farmed salmon (90,000 mortalities in Ireland in 2004)	Bruno and Ellis (1985),
				Rodger (personal observation)
Solmaris corona (Narcomedusa)	*S. salar*	Scotland	Farmed salmon (650,000 mortalities in 2 days in 2002)	Sourd (pers. comm.)
				Bamstedt et al. (1998)
				Hay and Murray (2008)
Apolemia uvaria (Siphonophore)	*S. salar*	Sweden, Norway	Farmed salmon	Bamstedt et al. (1998)
				Rodger (personal observation)
Bolinopsis infundibulum (Ctenophore)	*S. salar*	Norway	Farmed salmon	Bamstedt et al. (1998)
Vellella vellella (Athecata)	*S. salar*	Ireland	Skin and gill pathology observed	Rodger (personal observation)

Table from Rodger et al. 2011

Marked species are common in Norwegian fauna, often linked to fish kills

NIVA or other institutions **are not** involved in **monitoring** of these species along the Norwegian coast

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Jellyfish

OPEN ACCESS Freely available online

PLoS one

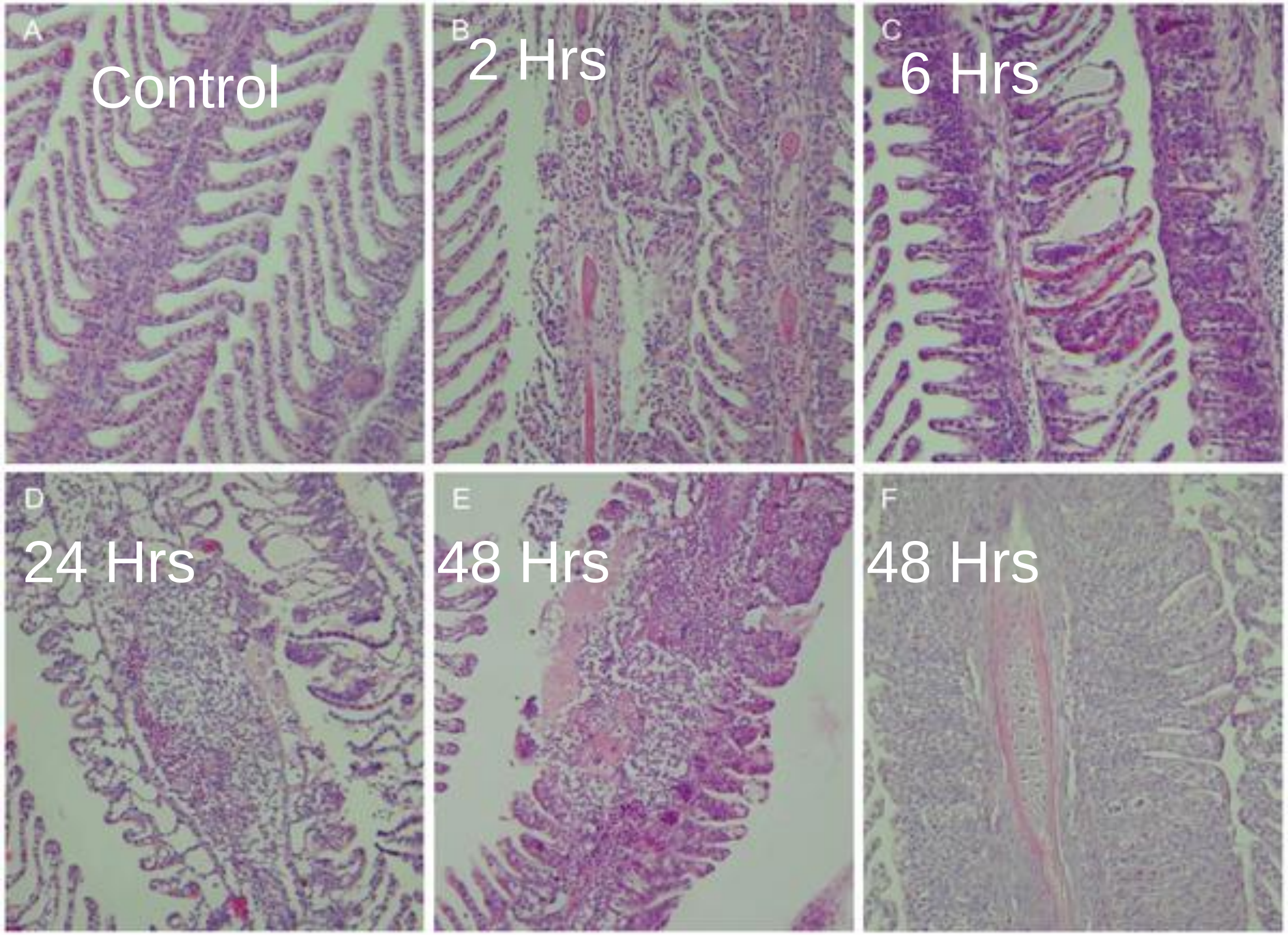
Gill Damage to Atlantic Salmon (*Salmo salar*) Caused by the Common Jellyfish (*Aurelia aurita*) under Experimental Challenge

Emily J. Baxter[1,2,3]*, Michael M. Sturt[2], Neil M. Ruane[4], Thomas K. Doyle[1], Rob McAllen[2], Luke Harman[2], Hamish D. Rodger[5]

Photo: Marinbi.com

2011

Photographic time series of gill lesions in fish exposed to *Aurelia aurita* under experimental challenge.



Baxter EJ, Sturt MM, Ruane NM, Doyle TK, et al. (2011) Gill Damage to Atlantic Salmon (Salmo salar) Caused by the Common Jellyfish (Aurelia aurita) under Experimental Challenge. PLoS ONE 6(4): e18529. doi:10.1371/journal.pone.0018529
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0018529

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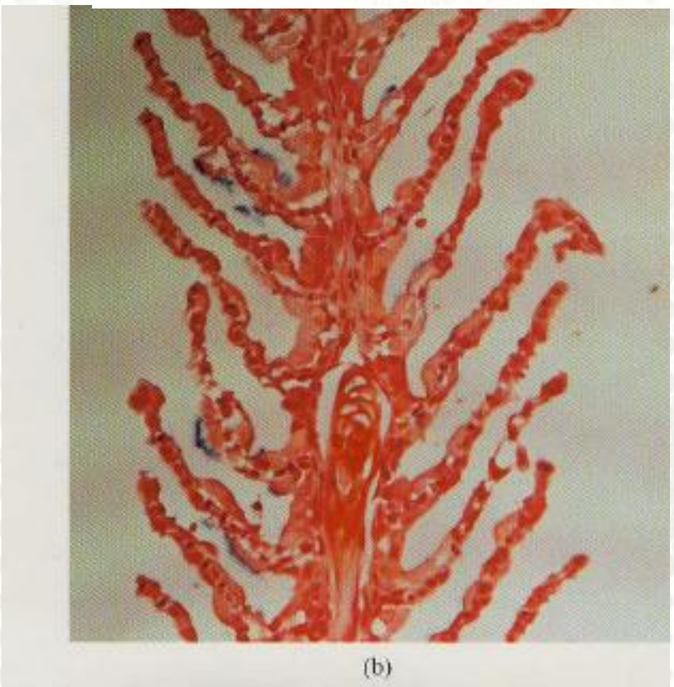
The fish gill has become our most important single biomarker for metal toxicity!

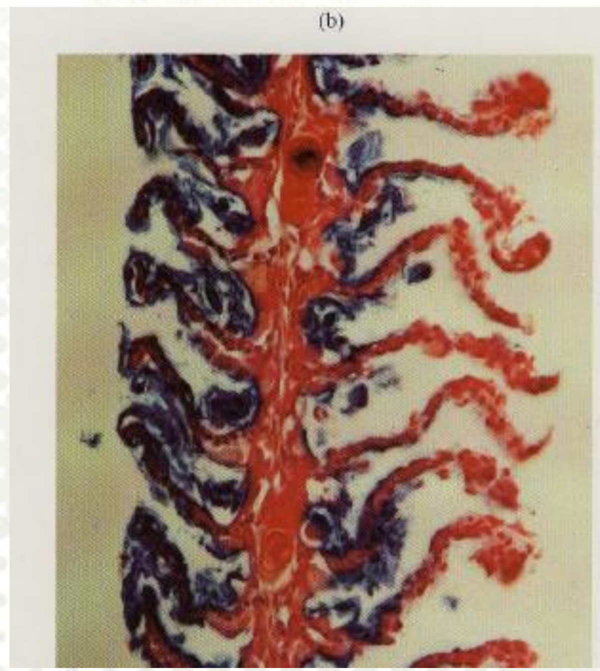
Environmental Pollution 78 (1992) 3–8

Rosseland et al. 1992

The mixing zone between limed and acidic river waters: complex aluminium chemistry and extreme toxicity for salmonids

B. O. Rosseland,[a] I. A. Blakar,[b] A. Bulger,[c] F. Kroglund,[a] A. Kvellstad,[d] E. Lydersen,[e] D. H. Oughton,[f] B. Salbu,[g] M. Staurnes[h] & R. Vogt[i]





"Blue" = Al

Photos: D. Oughton

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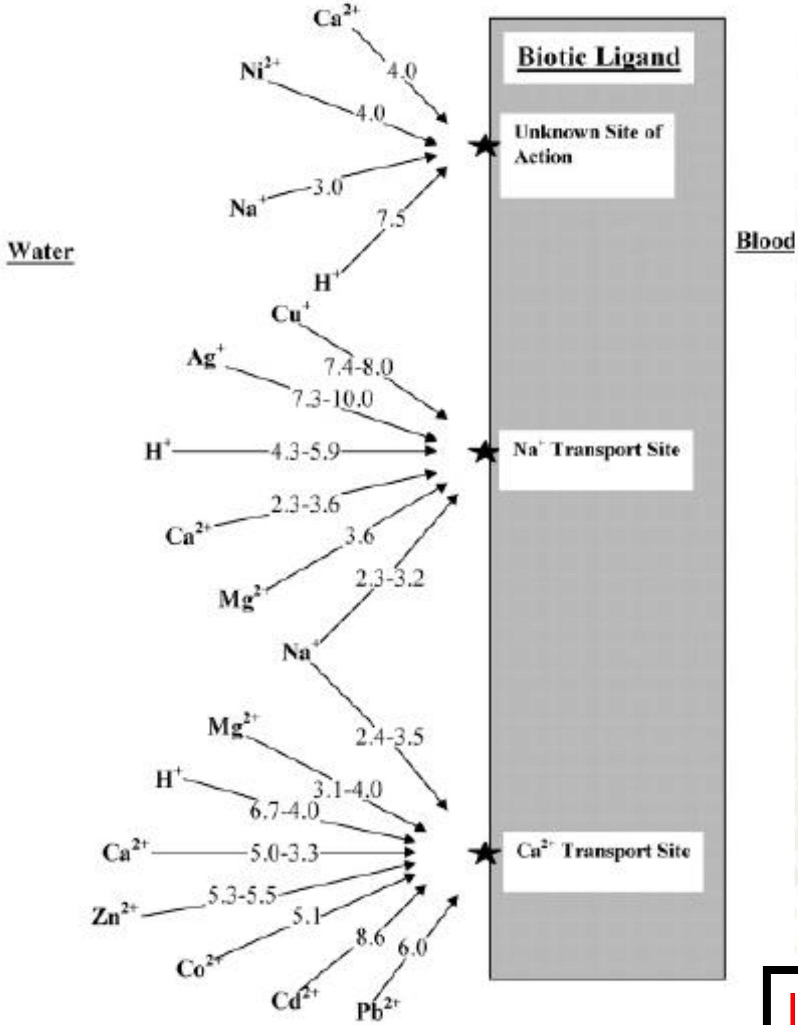
Biotic Ligand Model (BLM)

Binding affinities (log K) of "free ions" onto gills



Biotic Ligand Model, a Flexible Tool for Developing Site-Specific Water Quality Guidelines for Metals

SOUMYA NIYOGI AND CHRIS M. WOOD*

6178 ■ ENVIRONMENTAL SCIENCE & TECHNOLOGY / VOL. 38, NO. 23, 2004

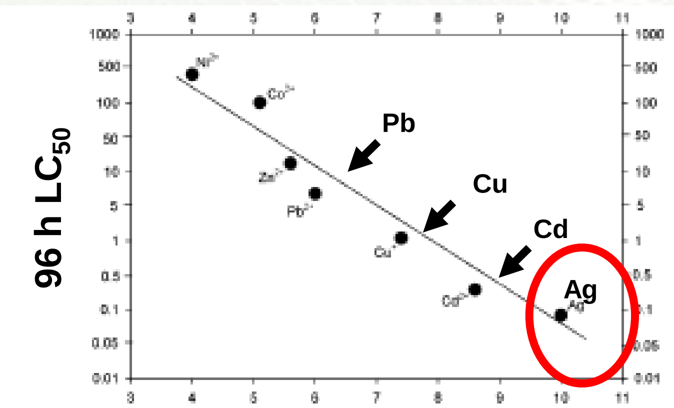


FIGURE ... the ... Lake ... Pb^{2+}, ... , 60, 60, 174, 72, 62, and 162, respectively. The 96 h LC_{50} data for the same metals are taken from the cited literature: refs 13, 75, 73, 173, 77, 176, and 160, respectively. The Y-axis of the plot is in log scale.

Increased affinity = increased toxicity

Niyogi and Wood (2004).

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Aquatic Toxicology 108 (2012) 78–84

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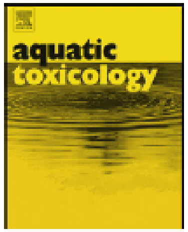
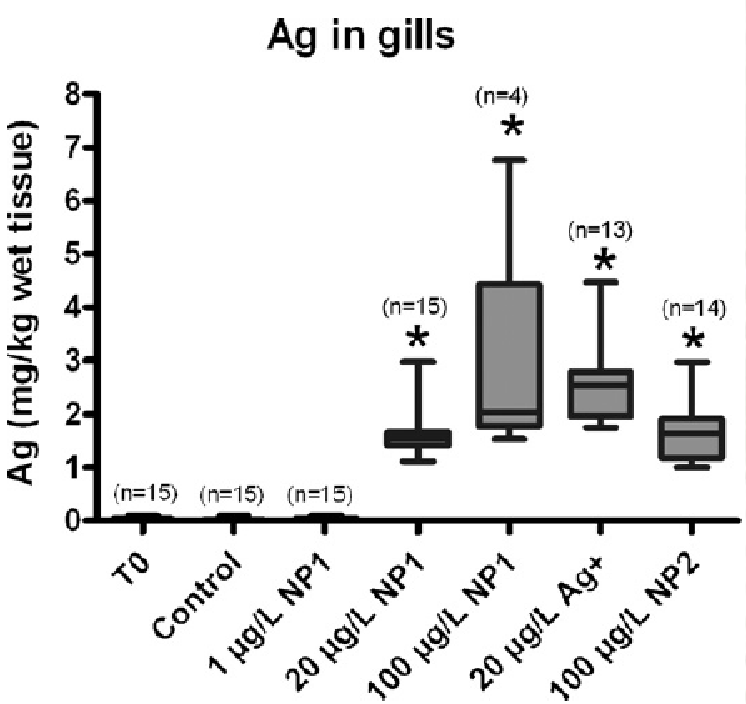


Acute and sub-lethal effects in juvenile Atlantic salmon exposed to low µg/L concentrations of Ag nanoparticles

E. Farmen[a,b,*], H.N. Mikkelsen[a], Ø. Evensen[c], J. Einset[a], L.S. Heier[a], B.O. Rosseland[a], B. Salbu[a], K.E. Tollefsen[a,b], D.H. Oughton[a]



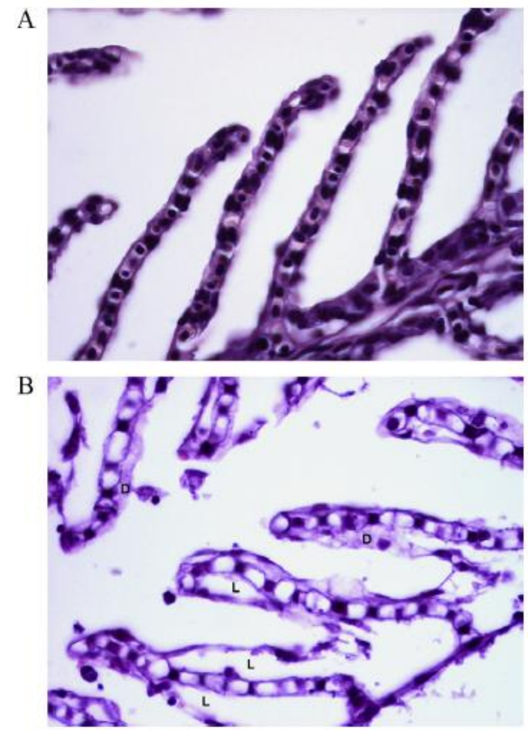


Fig. 3. Gill histology showing (A) normal secondary gill lamellae. In fish exposed to 100 µg/L of the commercial Ag NP (NP1) (B) the epithelial lining of the secondary

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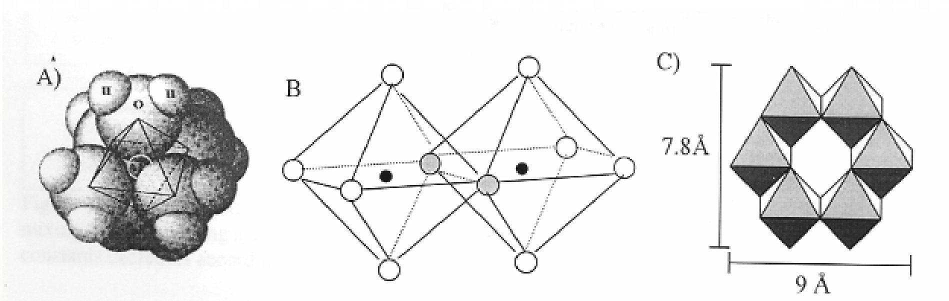
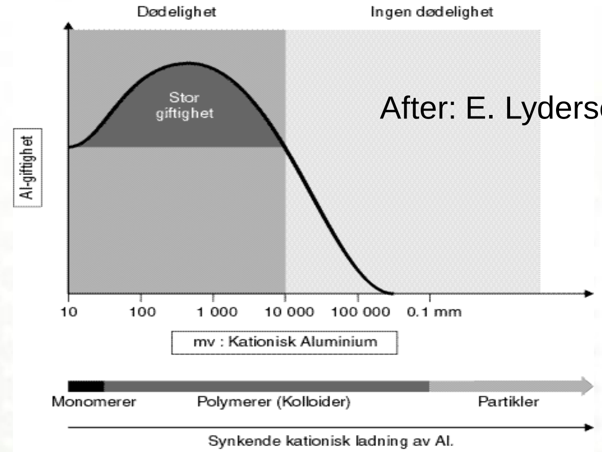
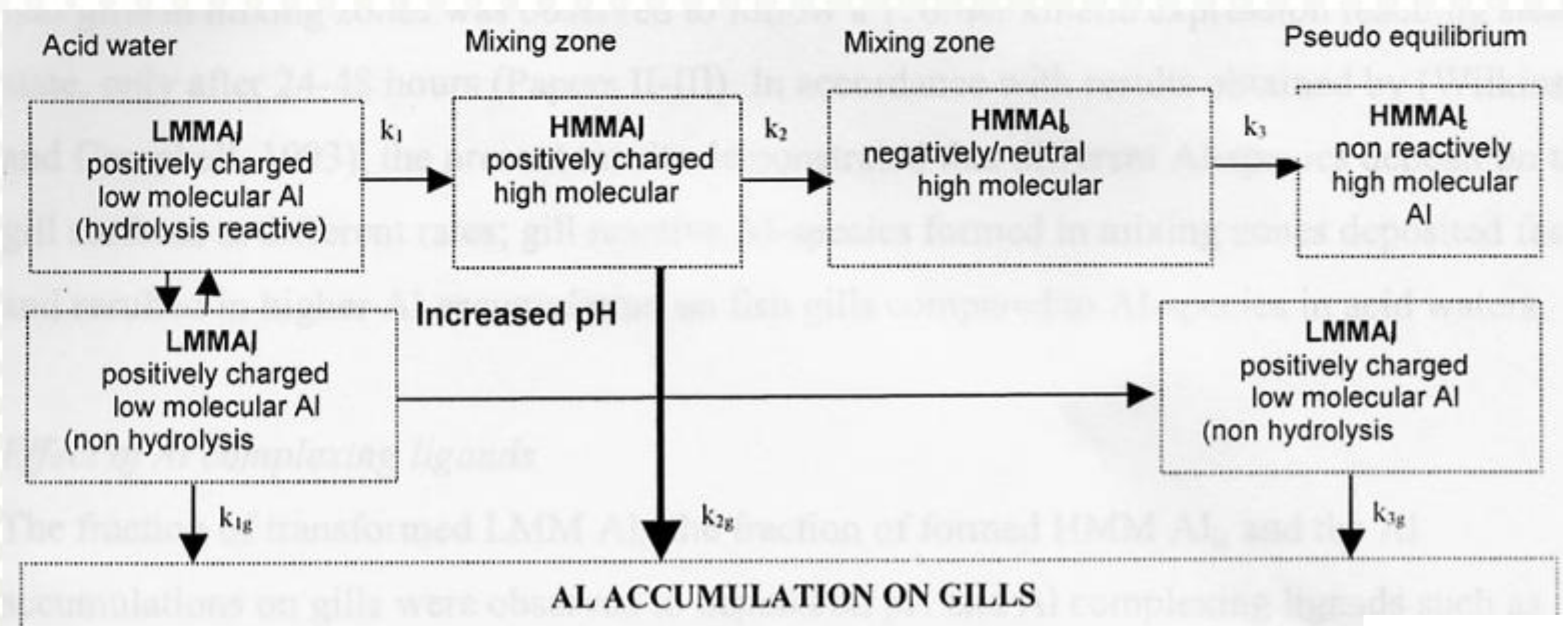
Cationic Al-species transform to transient, more “gill-reactive” Al-species during the initial step of polymerisation





After: E. Lydersen



Teien et al. 2004

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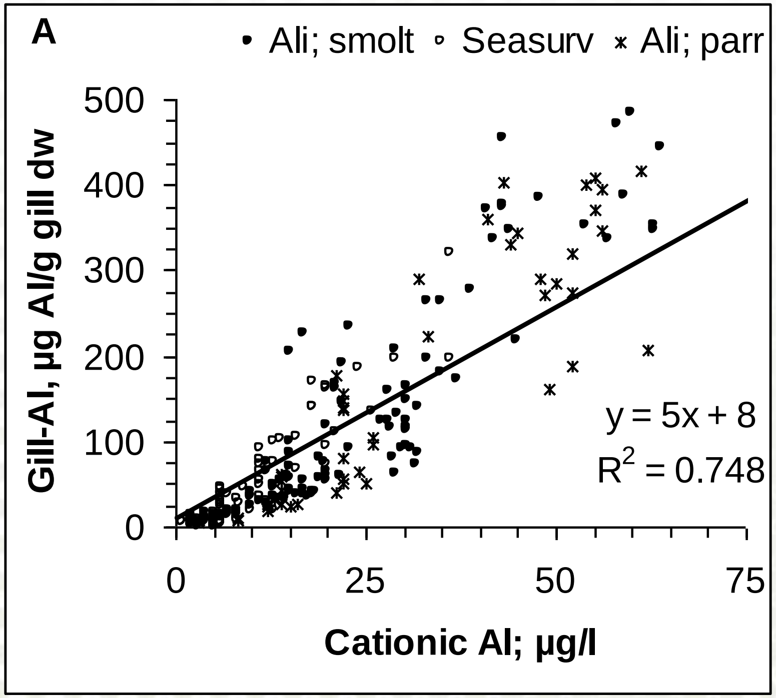
How to measure/monitor bioavailable metals

- The best way of monitoring bioavailable metals are repeated *in situ* analyses of metal species in i.e. water and relate it to content in organs of specific organisms



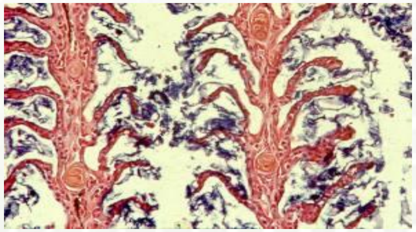
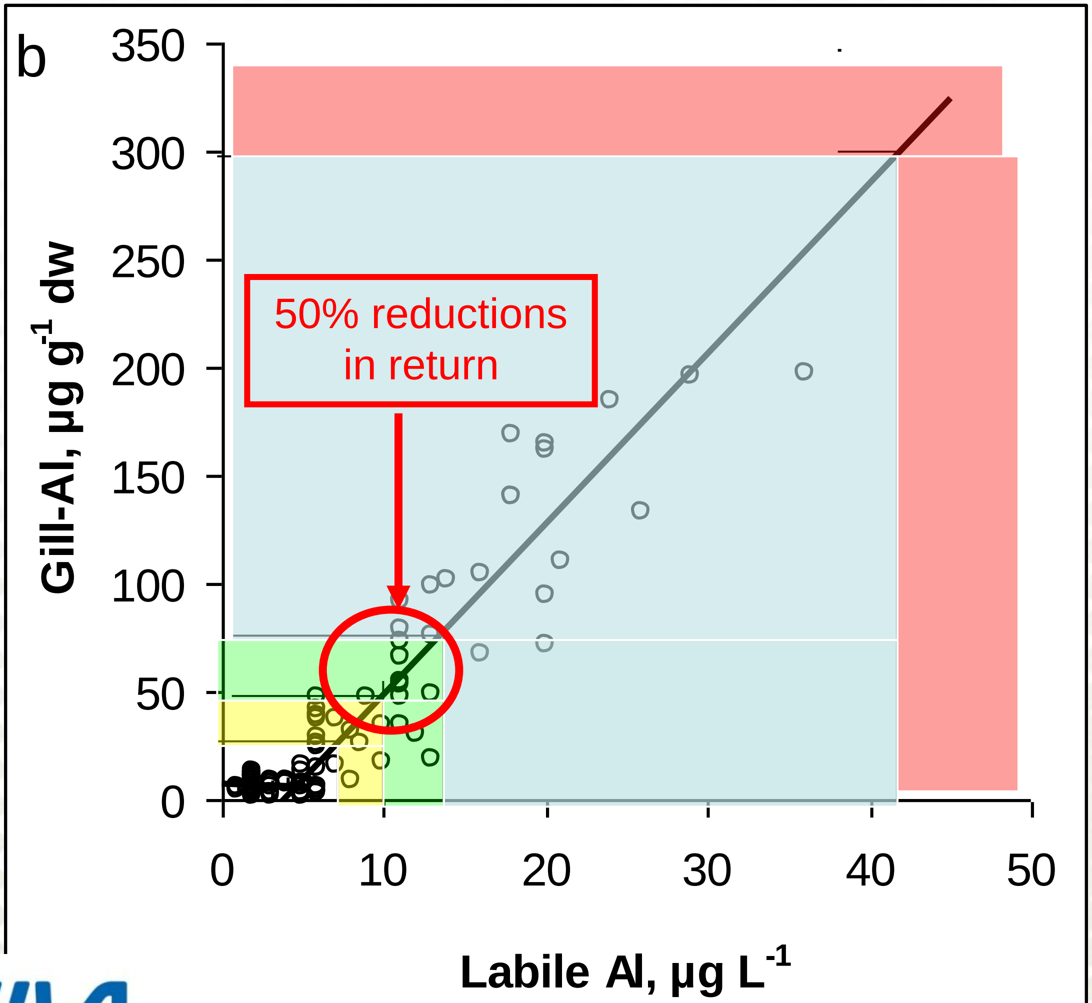


Photo. D. Oughton

Kroglund et al. 2008

- The second best way of monitoring bioavailable metals are i.e to use passive samplers, substituting organ and lake water analyses; DGT (**D**iffusive **G**radients **T**hin films)

Critical levels of Al in water and gill, relative to smolts



Mortality FW

Reduced Plasma Cl

Increased Glucose

Reduced α1b Na-K-ATPase

Kroglund et al. 2006

Aquatic Toxicology 97 (2010) 250–259

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Aquatic Toxicology

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2010

aquatic toxicology

Effects of acidic water and aluminum exposure on gill Na^+, K^+-ATPase α-subunit isoforms, enzyme activity, physiology and return rates in Atlantic salmon (*Salmo salar* L.)

Tom O. Nilsen[a,*], Lars O.E. Ebbesson[a], Ole G. Kverneland[a], Frode Kroglund[b], Bengt Finstad[c], Sigurd O. Stefansson[a]

Highest sensitive a few weeks before migration, due to a change from freshwater α1a NaK-ATPase to the hypersensitive seawater α1b NaK-ATPase

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Processes: Iron toxicity is related to concentration of FeII and the oxidation to FeIII in redox mixingzones

Process 1: Oxidation Fe^{II}

Reduced LMM Fe^{II}-species → Positivly charged LMM Fe^{III}-species

Oxygen

↓ Accumulation onto gills


Foto: B.O. Rosseland

Process 2: Hydrolysis and formation of Fe^{III} polymers

Positively charged LMM species → Positively charged HMM polymere → Negatively charged /neutral HMM species → Colloids /particulate species

Increased time

↓ Accumulation onto gills

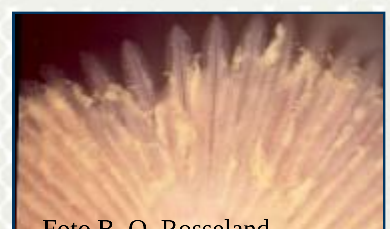
Foto B. O. Rosseland

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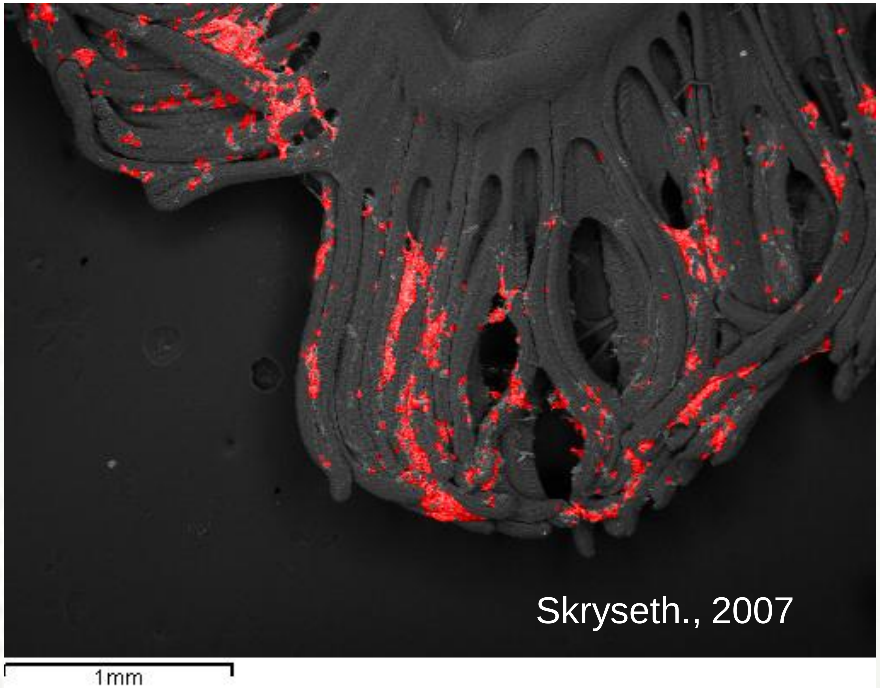
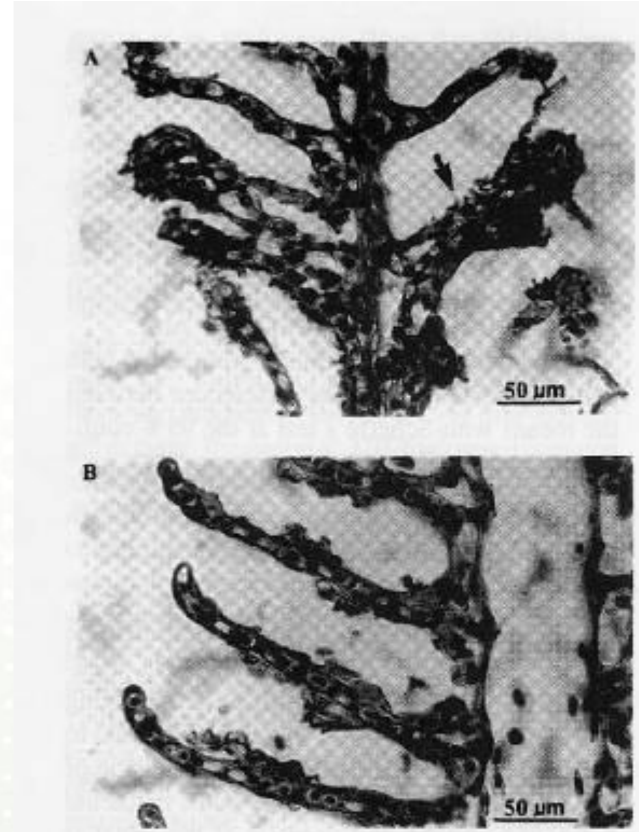
Fe accumulation on gills of fish





Peuranen et al. 2001

- The mapping of Fe (scanning electron microscopy with x-ray microanalyses) demonstrates deposition of Fe on gills after exposure of Atlantic Salmon to 200 µg Fe^{2+} /L for 120 hrs at pH 7.5. (Skryseth 2007)
- Gill damage of brown trout due to two days Fe exposure to Fe at pH 5, A) without and B) with humic acids. (Peuranen et al. 2001)

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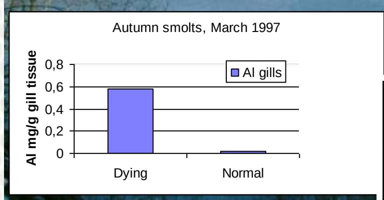
Flooding spreads pollutants to river, lakes and ocean



Rosseland, B.O, Åtland, Å., Dale, T. & Powell, M. Water quality and gill diseases. Gardermoen
October 6, 2012. ©

Simulating a river entering an estuary

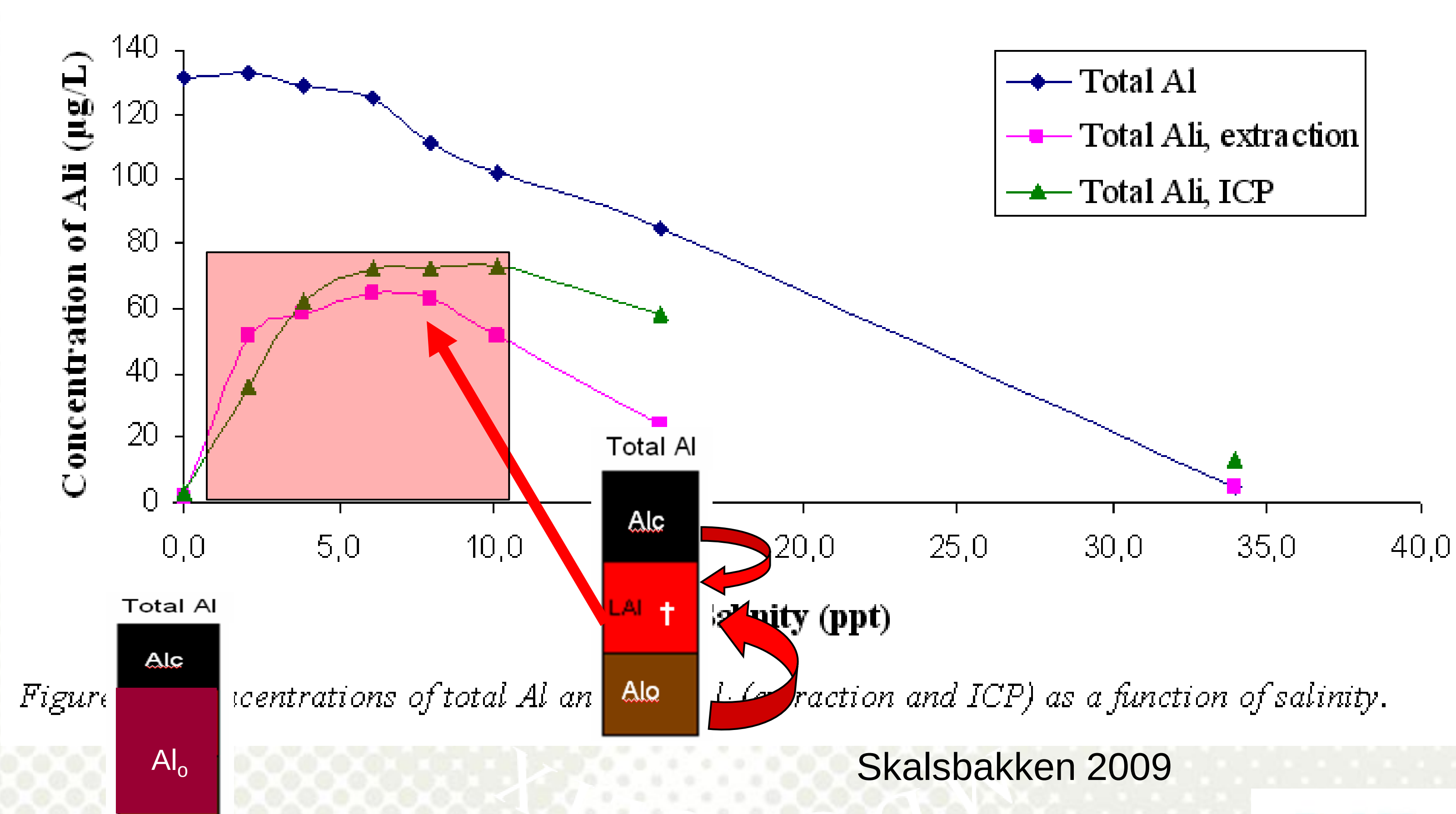
- NIVA and UMB experimental set up in River Storelva, South East Norway, testing Al speciation changes and water treatment to avoid effects on Atlantic salmon smolts

Photos: B.O. Rosseland

Estuarine Mixing Zone with Mobilization of Ali from Alo by increased ionic strength in sea

Both an acid, limed and humic river create Estuarine mixing zones!

Limed River



Skalsbakken 2009

Rosseland, B.O, Åtland, Å., Dale, T. & Powell, M. Water quality and gill diseases. Gardermoen
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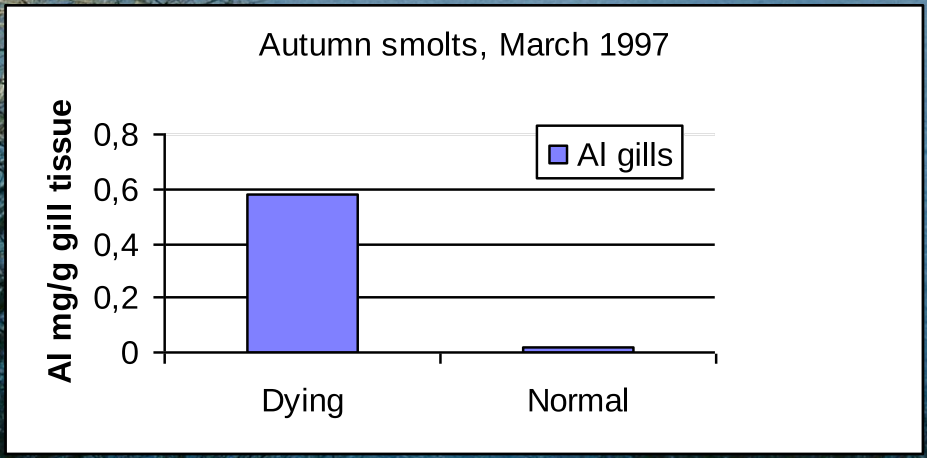
Al from rivers kill salmon in brackish areas!
Estuarine mixing zone

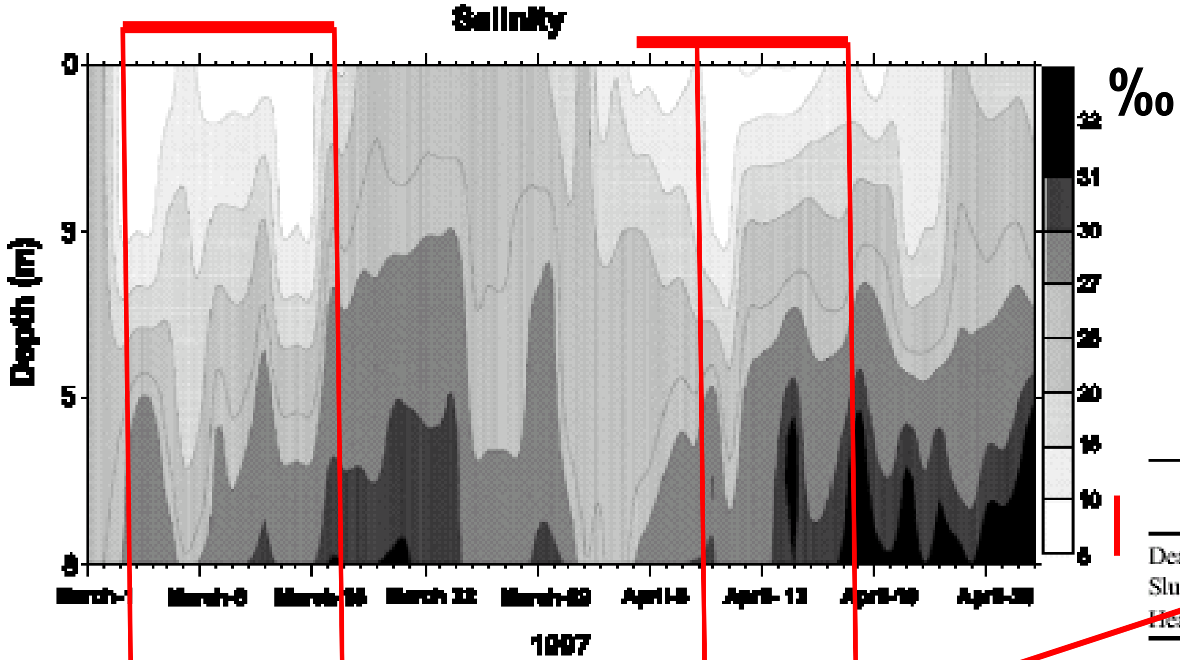
River water from snowmelting or floods create brackish surface water in fjords and kill salmon in net pens.

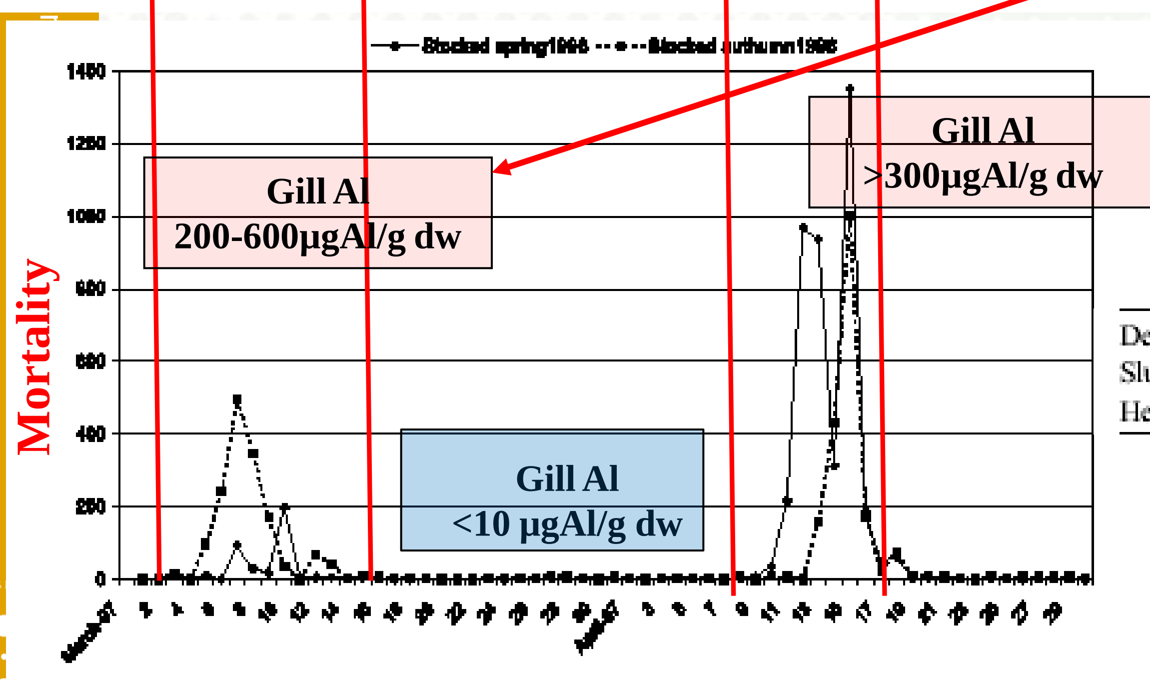


Bjerknes et al. 1998

Photos: B.O. Rosseland

Mortality at salinity < 10 ‰





Gill Al

	March 1997 (Autumn stocked)	April 1997 (Autumn stocked)
Dead	225 ± 217	307 ± 70
Sluggish	578 ± 882	
Healthy	16 ± 31	

	December 1997 (Autumn stocked)	January 1998 (Autumn stocked)
Dead		
Sluggish		
Healthy	4 ± 2	5 ± 1

Bjerknes et al. 2003

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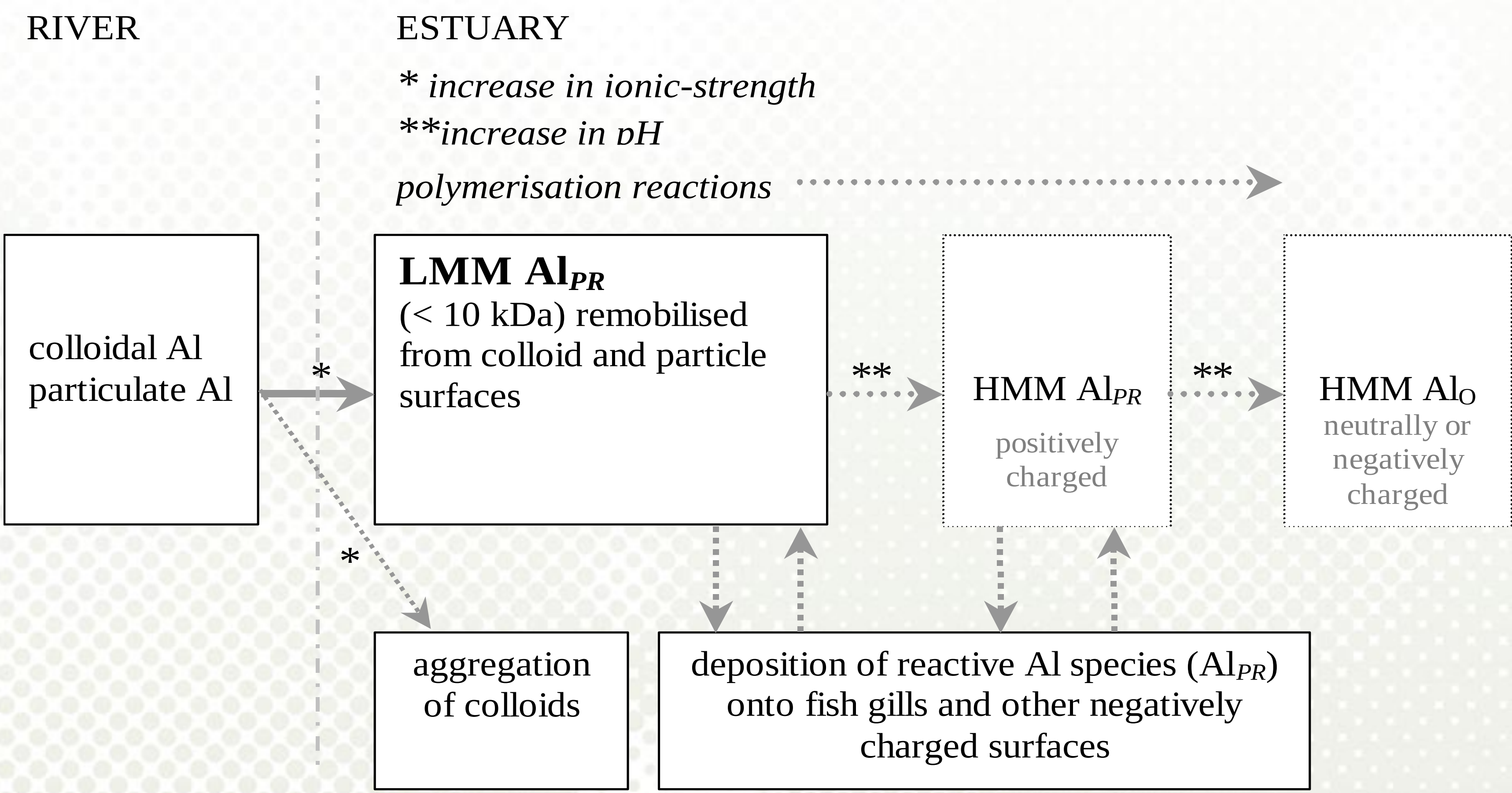
Model: Mobilisation and deposition of Al on gills in Estuarine Mixing Zones

We have the model!



Teien et al. 2005

TOC has increased up to 3X since late 1980s mainly due to reductions in acid rain.

Highest concentration in the autumn

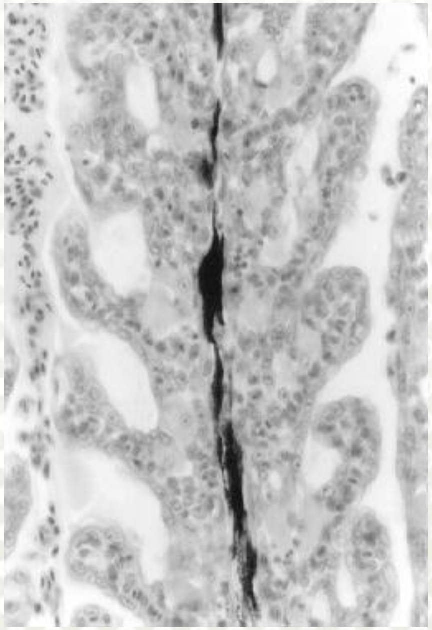
The estuarine mixing zone problems are increasing in all Atlantic salmon producing countries (except Chile)

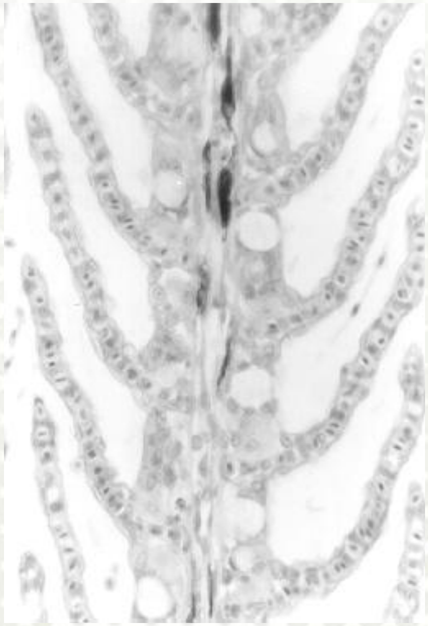
Estuarine Al problems also affects marine fish

Turbot (piggvar) is also affected by Al in estuarine mixing zones (10‰)

Gills from turbot (*Psetta maxima*)

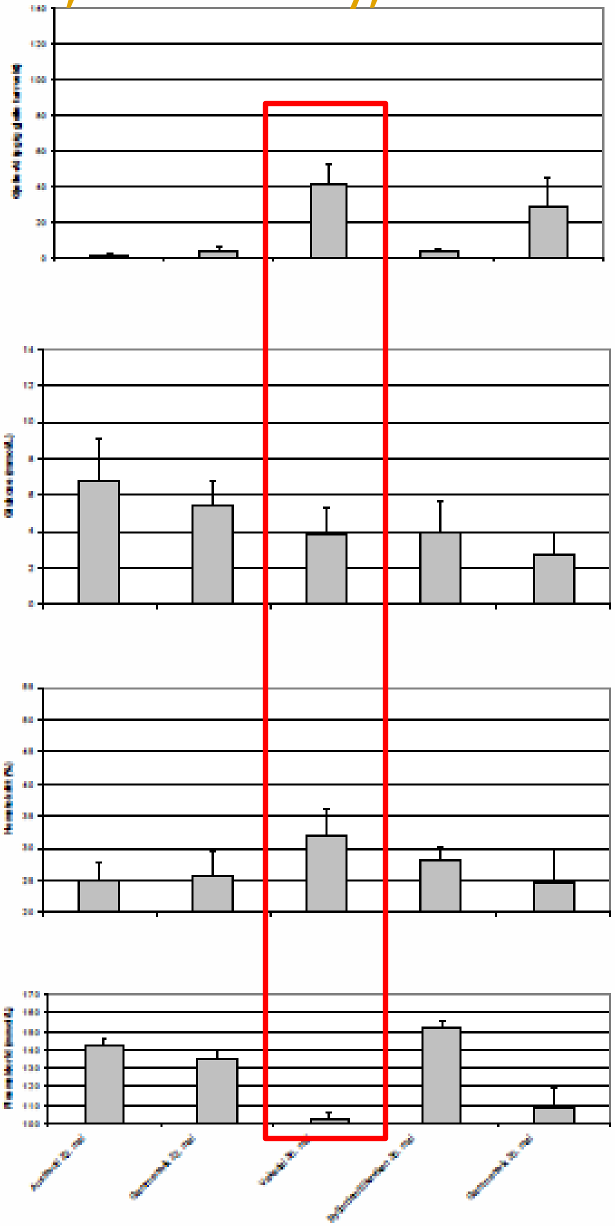
Al-exposed **Reference**





Rosseland et al. 1998

Monitoring of Atlantic cod in estuarine mixing zones in fjords, 22-30 May, 2002



Gill Al

Blood glucose

Hct

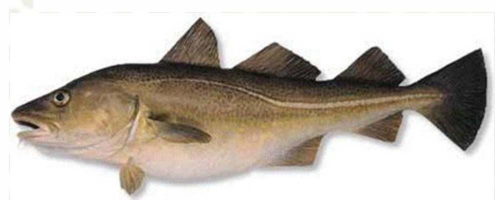
Plasma Cl

RAPPORT LNR 5032-2005

Eksponering av torsk i estuarine blandsoner

Effekter av lav salinitet og aluminium

Vilhelm Bjerknes, Åse Åtland, Torstein Kristensen, Frode Kroglund



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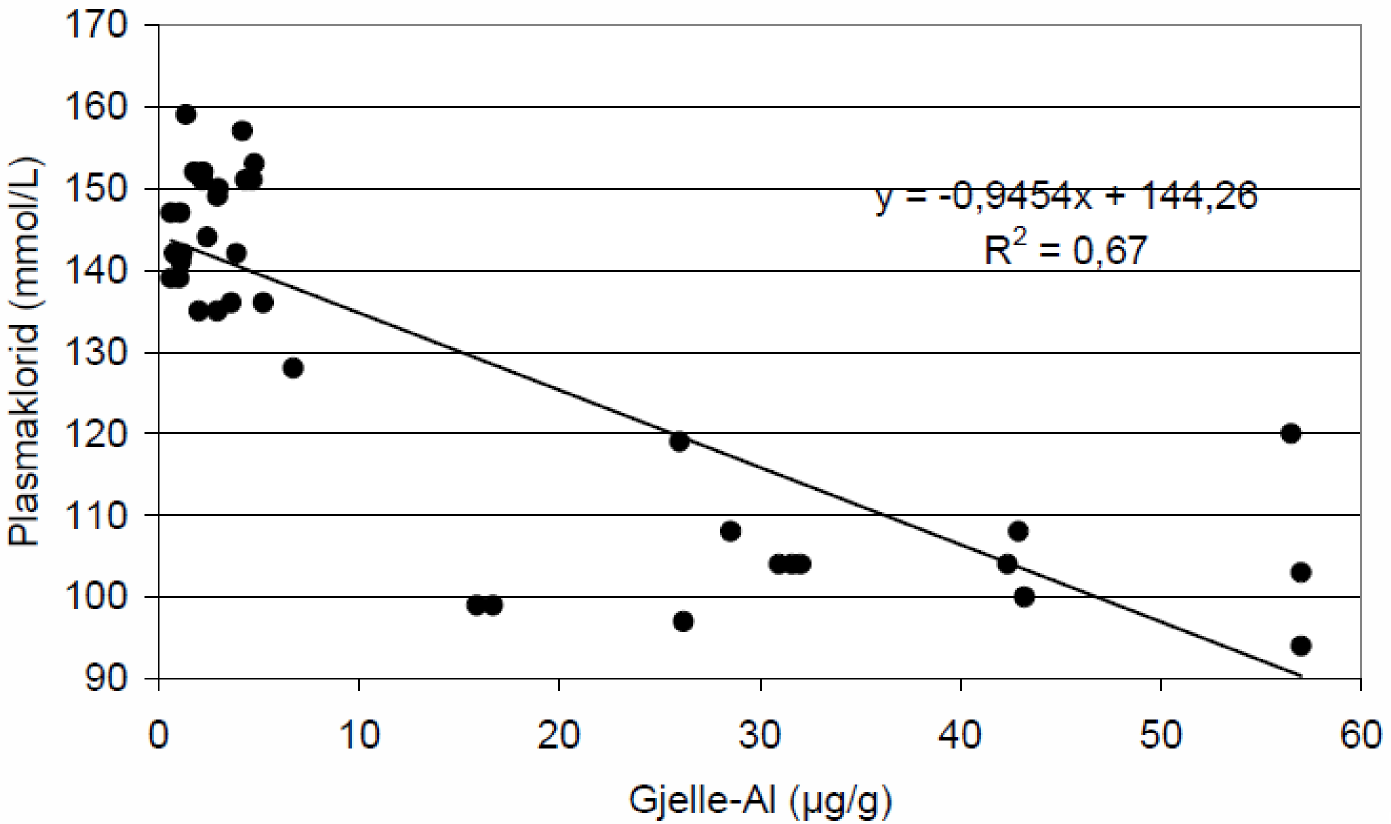
Atlantic cod – Gill Al and plasma chloride
Monitoring of estuarine mixing zones in Sørfjorden, Osterfjorden and Byfjorden

Low plasma Cl (Chloremia) is a sign of high $PaCO_2$ (Hypercapnia) = Respiratory problems.



Bjerknes et al. 2006

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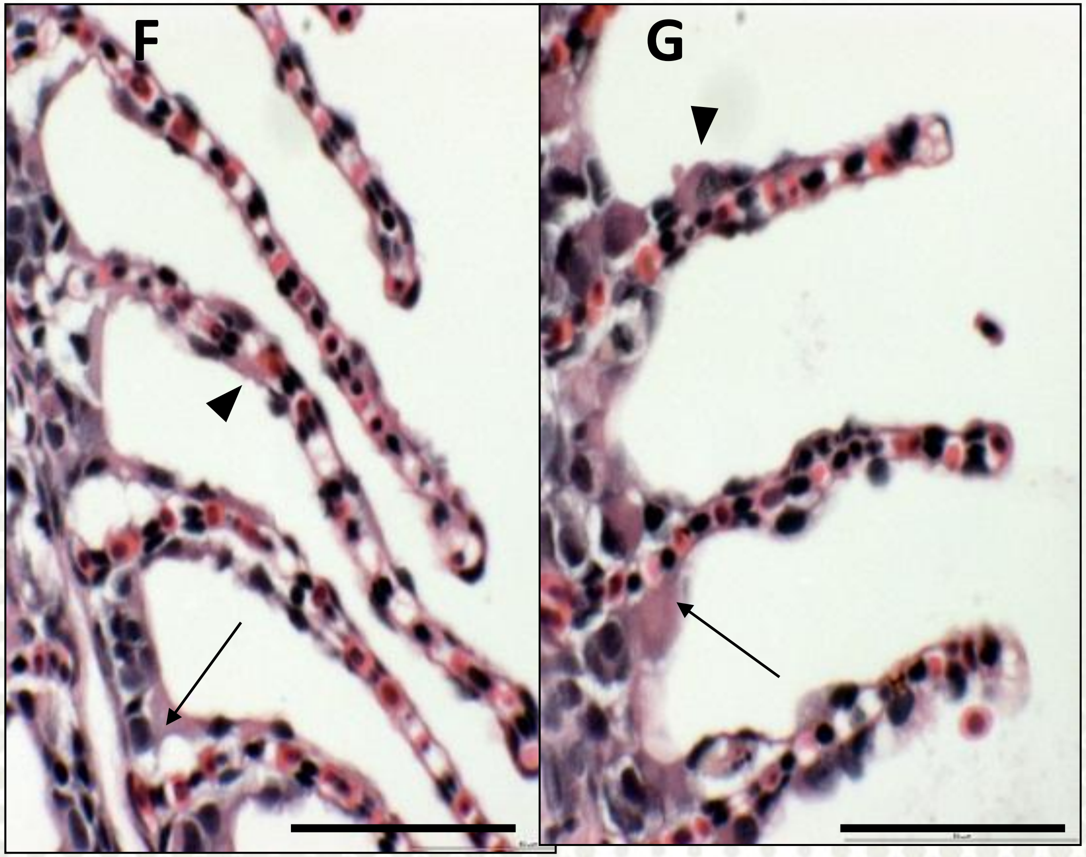
Use of disinfection with **free radical** effect and gill responses; Chloramine-T in seawater

- Osmotic imbalance
- Hypertrophic compensation to restor the osmotic/ionic imbalance.

Reference Chloramine-T



Source: Mark Powell, NIVA

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Hydrogen peroxide (H_2O_2) treatment against sea lice is a massive exposure to free radicals!
Please be aware of post treatments effects to gills, immune system etc.

Rosseland, B.O, Åtland, Å., Dale, T. & Powell, M. Water quality and gill diseases. Gardermoen October 6, 2012. ©

Conclusion

- Many abiotic water quality factors may cause directly, or indirectly gill problems
- Some of the changes in gill structure, mucus quality and quantity, membrane structure and enzyme activities may change the osmoregulation and general physiology
- Changes in homeostasis may reduce the immune responses to biotic agents, other vice not being problematic
- **One must have a holistic view, including the biotic and abiotic factors when studying "gill diseases".**