Chemical Inputs from Salmon Aquaculture

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Aquaculture

Atlantic Canada's first salmon farm, Lords Cove, Deer Island (c. 1978)

La première installation de salmoniculture de la région de l'Atlantique, Lords Cove, Île Deer (vers 1978)

Nature of chemical inputs from salmon aquaculture activities

- Antibiotics
- Anti-sea louse drugs/pesticides
- Antifoulants
- Disinfectants
- Anaesthetics

Everything is toxic

The dose makes the Poison

The products we are talking about are all built to kill something!

Biological effects

EC50: The concentration of a chemical that, when in the environment of a test organism, is estimated to be affect 50% of those organisms under the stated conditions.

Biological effects

Chemical(s)

Species

Time

Regardless of use, each chemical is different

- Water solubility
- Affinity for sediments or tissue
- Persistence

These characteristics dictate where a chemical may go and how long it will stay there.

Species

- What species has been tested.
  - Is it important in the area of question? (Lobster)
- Is the chemical available to the animal?
- Does the animal have a choice? (Water vs. food vs. faeces vs. sediment)
- Concentration vs. Dose. The concentration remains constant the dose does not.

Physical and chemical characteristics of the receiving environment

- Water depth
- pH
- Suspended matter
- Currents

These characteristics also dictate where a chemical may go and how long it will stay there and affect bioavailability.

Hazards are Determined

Risks are Assessed

(possibility vs. probability)

Courtesy of the BC Salmon Farmers Association

Importance of Chemicals in Aquaculture

- Essential part of normal practices in finfish aquaculture
- Scientific Debate: C.E. Nash NOAA (2001) and Fish. Res. (2003): Risk and Uncertainty in the Pacific Northwest
  - Aquaculture/environment issues which carry most risk:
    - Impact of bio-deposits
    - Impact on benthic communities of the accumulation of metals
    - Impact on non-target organisms of the use of therapeutants
- Public domain – Scientific and opinion papers published showing how contentious this issue is.

We assume that Salmon Aquaculture is here to stay

Then fish farmers must have access to medications to combat disease and infestations of parasites

GOOD NEWS

- Regulations dictating what chemicals can be used are in place in all jurisdictions.
- These regulations are based on available science and risk assessments. So there is already considerable information about the potential environmental effects of these compounds

Despite regulations, determining how many and how much of these chemicals are being used is difficult at best in some jurisdictions.

Key recommendation:

That regulatory agencies in all jurisdictions require yearly reporting of the quantities of antibiotics, antifoulants, parasiticides, disinfectants and anaesthetics used by salmon farms. If reporting is already required, that these data be made available to the public. The model used by the Scottish Environmental Protection Agency is a good example.

These data are important for purposes of regulatory accountability but also for research. For example, these data can be used to identify problems with over prescription, to identify trends regarding the presence and prevalence of disease, to correlate with analytical information on environmental concentration and can be a useful in identifying onset of resistance in local populations.

Crucial Research gap:

Cumulative effects of chemicals and of interactions between chemicals and between chemicals and the marine environment are largely unknown. Studies must be designed and carried out to address this need both in the near site and far-field environment.

Caveat

- Old data - 2003
- Total use of compounds per year include those applied to all age classes.
- The reported numbers are normalized to market fish, therefore making rate of use look higher than it may actually be.
- It’s the best information we have.

Country	Production (Metric Ton)	Therapeutant Type	Kg (active ingredient) used 2003	Kg Therapeutant/ Metric Ton produced
Norway	*509544*	*Antibiotics*	*805*	*0.0016*
		Anti-louse	*98*	*0.0002*
		Anaesthetics	*1201*	*0.0023*
Chile	*280,481 (486837)*	*Antibiotics*	*133800*	*0.477 (0.274)*
		Anti-louse	*27942*	*0.099 (0.057)*
		Anaesthetics	*3530*	*0.013 (0.007)*
UK	*145609*	*Antibiotics*	*662*	*0.0045*
		Anti-louse	*110*	*0.0007*
		Anaesthetics	*191*	*0.0013*
		Disinfectants	*1848*	*0.013*
British Columbia	*65411*	*Antibiotics*	*21781*	*0.333*
		Anti-louse	*5.2*	*0.00007*

Antibiotics

- **Key concern lies with ability of bacteria to develop resistance to antibiotics and to rapidly pass this trait on, even to human pathogens**
- **SERIOUS IMPLICATIONS FOR:**
  - **FISH HEALTH, therefore the aquaculture industry**
  - **ENVIRONMENTAL HEALTH, therefore the aquaculture industry and the general public**
  - **HUMAN HEALTH, therefore the aquaculture industry and the general public**

Modes of action

- Designed to work on unicellular organisms.
- Antibiotics act by:
  - Disrupting cell membranes
  - Disrupting protein or DNA synthesis
  - Inhibiting enzyme activity
- Low vertebrate toxicity

Classes of compounds

- β-lactose – amoxicillin
  - 80-160 mg/Kg 10 days;
  - 40-150 deg day withdrawal Scotland
- Phenicols – florfenicol
  - 10 mg/kg 10 days
  - 12 days Canada, 150 deg days Scotland, 30 days Norway
  - Not generally considered a problem for persistence or resistance

Classes of compounds

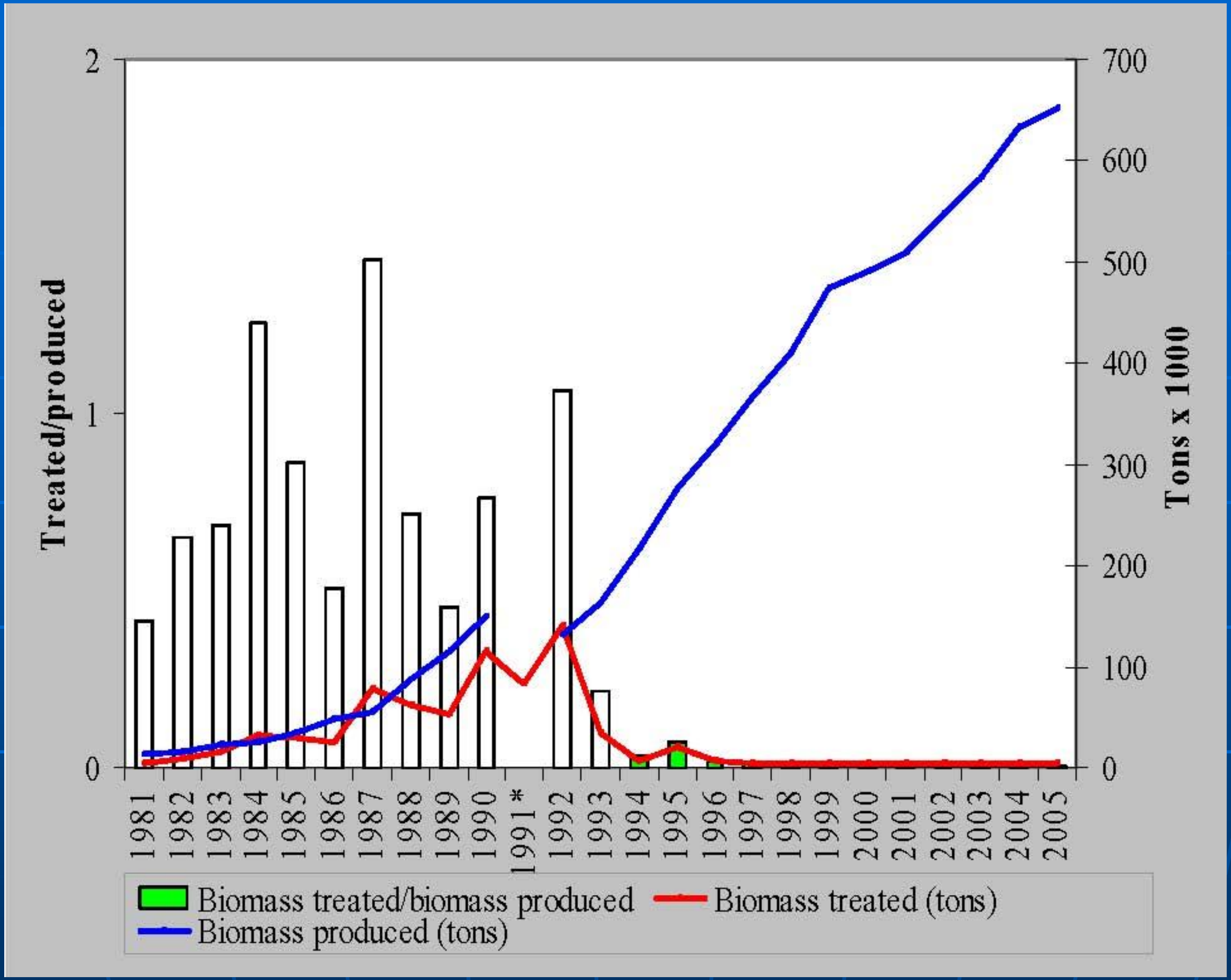
- 4-quinilones – oxolinic acid, flumequin
  - 500 deg day withdrawal Scotland, 40-80 days Norway
  - High efficacy, low toxicity, but persistent
- Sulphonomides – tribrissen
  - 30-75 mg/Kg 5-10 days
  - 350-500 deg day withdrawal Scotland, 40-90 days Norway.
  - Environmental impacts unknown
- Tetracyclines – terramycin
  - 50-125 mg/Kg 4-10 days
  - 400-500 deg days withdrawal Scotland, 60-180 days Norway
  - Persistent and concern for antibiotic resistance

Norway:

Antibiotic use in Norway 2001-2005. Quantities of active ingredient in Kg.

Antimicrobial	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Oxytetracycline	12	11	45	9	8	0
Florfenicol	109	205	154	111	202	302
Flumequin	7	5	60	4	28	7
Oxolinic acid	517	998	546	1035	977	1119

Source Jon Arne Grottum and www.fishfarmingxpert.no



Treated/produced
Tons x 1000
2
1
0
700
600
500
400
300
200
100
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991 *
1992
1993
1994
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1997
1998
1999
2000
2001
2002
2003
2004
2005
Biomass treated/biomass produced
Biomass treated (tons)
Biomass produced (tons)

Chile:

Antibiotics: **oxolinic acid, amoxicillin, enrofloxacine, erythromycin, flumequine, florfenicol, oxytetracycline, saroloxacine.**

Bravo (2005) reported 133,800 Kg of antibiotics used in aquaculture in 2003.

Antibiotic use in Scotland 2003-2006. Quantities in Kg active ingredient. Source SEPA

Antimicrobials	2003	2004	2005	2006
Oxytetracycline	662.8	38	1643	5406
Florfenicol		6	10.2	38.4
Fenbendazole	7.1	0.4	0	0
Amoxycillin				55.2

Canada

- **Antibiotics:** Oxytetracycline, trimethoprim 80%/sulphadiazine 20% (Tribrissen), sulfdimethoxine 80%/ormetoprim 20% (Romet), florfenicol (Aquafluor).
  - Tribrissen and Romet are not used primarily because of palatability problems

Canada (BC only)

Total Antibiotics

2003	21,781 Kg
2004	18,530 Kg*
2005	12,103 Kg*

* To be changed in report.

Research Needs

- *In the case of Chile and Canada, where large quantities of antibiotics are used in salmon aquaculture the most important and essential research need is the assessment of the volumes and classes of antibiotics used by the industry. The effect of the application of large quantities of antibiotic sediments and the water column should also be investigated.*
- *Research must continue into the development of safe and effective vaccines against bacteria of concern and in particular P. salmonis.*
- *The presence of residual antibiotics/antibiotic residues, antibiotic resistance in marine bacteria and in fish pathogens, and effects on the diversity of phytoplankton and zooplankton in areas surrounding aquaculture sites should also be ascertained. Investigation of the presence of residual antibiotics/antibiotic residues in free-ranging (wild) fish and shellfish around aquaculture sites and in the meat of marketable salmon is necessary.*
- *The passage of antibiotic resistance determinants from bacteria in the marine environment to human and terrestrial animal pathogens should also be investigated.*

Research Needs

- *Centralized epidemiological studies of fish infections should be implemented and their results related to antibiotic usage and antibiotic resistance.*
- *As is the case in human and veterinary medicine, excessive antibiotic use is in general the result of shortcomings in hygiene and husbandry, and for this reason, the hygienic soundness of the methods and technology of salmon husbandry should be analyzed. Methods and technology should be compared to those in use in countries where antibiotic use has been drastically curtailed such as Norway. Issues such as siting, year-class separation and fallowing should be studied to determine if better management practices can be instituted.*
- *The potential for exposure of aquaculture workers to antibiotics should be determined and the potential effects of this exposure should be ascertained*

Anti-parasitics

Bath Treatments

- Pyrethroids – cypermethrin and deltamethrin
- Organophosphates – dichlorvos and azamethiphos
- Hydrogen Peroxide

In Feed Treatments

- Avermectins – emamectin benzoate
- Diflubenzuron and teflubenzuron

Concerns with anti-parasitics

- For Fish Farmers:
  - Limited options for treatment
  - Resistance
  - Under-fortified food
  - Cost
- For environment:
  - Effect(s) on non targets
  - Persistence
  - Resistance, therefore overuse

Modes of action and treatment

- Pyrethroids:
  - Nervous system action by disruption Na channels
  - Cypermethrin 5 μg/L for 60 minutes
  - Deltamethrin 2-3 μg/L for 40 minutes
  - Withdrawal 24 h Scotland, 3 days Norway
- Emamectin Benzoate
  - Nervous system action by disrupting Chloride channels
  - 50 μg/Kg/day for 7 days
  - 175 deg day withdrawal Norway, ~68 days Canada, 0 days Chile and Scotland
- Hydrogen peroxide
  - Probable mechanical paralysis – a bubble in the gut
  - 05.5 g/L for 20 minutes above 10 C
  - 0 withdrawal

Parasiticides used in Norway (Kg active ingredient).

Active Compound	2002	2003	2004	2005	2006
Cypermethrin	62	59	55	45	49
Deltamethrin	23	16	17	16	23
Emamectin Benzoate	20	23	32	39	60

Source Jon Arne Grottum and www.fishfarmingxpert.no

Products used in Chile to control sealice

- **Neguvon (1981- 1985**
- **Nuvan (1985- 2001)**
- **Ivermectin (1989-2003)**
- **Emamectin benzoate (Slice) (1999 up to date)**
- **Hydrogen peroxide (2007)**
- **Azamethiphos (Salmosan)**
- Cypermethrin (Novartis)*
- Deltamethrin (Pharmac)*
- Pyrethrum (Py-Sal)*
- Teflubenzuron (Calicide Calicide)*
- Diflubenzuron (Lepsidon)*

* Field trials only

From Bravo 2007 WAS

Parasiticides used in Chile and the quantities (Kg active ingredient) used 2001 - 2003.

Active Compound	2001	2002	2003
Cypermethrin	0	0	80
Dichlorvos	247	0	0
Emamectin benzoate	22,413	27,355	27,612
Ivermectin	1,000	250	250

Source Bravo (2005)

Parasiticides used in Scotland and the quantities (Kg active ingredient) used 2003-2006.

Active Compound	2003	2004	2005	2006
Cypermethrin	10.5	656.9	6.6	9.7
Azamethiphos	35.5	11.6	0	0
Hydrogen Peroxide	35.3	43.8	19.7	0
Emamectin benzoate	28.3	52.6	36.3	16.8
Teflubenzuron	36	0	0	0

Source SEPA

Canada

- Only Teflubenzuron and hydrogen peroxide are registered for use by Health Canada. Neither are used.
- Emamectin Benzoate is used with veterinary prescription under Health Canada's emergency drug release program.

Parasiticides used in Canada (2002) or in British Columbia only (2003-2005)

Active Compound	2002	2003	2004	2005
Azamethiphos	15	0	0	0
Emamectin benzoate	25	5.23	10.5	17.8

Source Health Canada and Government of British Columbia

Research needs

- *It appears as though there are no new therapeutants in the regulatory system. In the absence of new treatment options and in support of sustainable salmon aquaculture, studies need to be conducted to identify best management practices that reduce the need to treat fish against infestations of sea lice.*
- *Risk assessment of anti-parasitics are often based on single-species, single chemical, lab-based studies. Field studies need to be conducted to determine the biological effects on non target organisms of therapeutants under operational conditions.*
- *Cumulative effects of chemicals and of interactions between chemicals and the marine environment are essentially unknown.*
- *Some of these compounds are persistent in the environment. Studies must be designed and carried out to determine fate and potential effects of these compounds in the near site and far-field environments.*

Recommendations

- *Data may exist that address some of the research gaps identified above. Where field studies have been conducted as part of the registration process, the data should be more readily available to the public.*
- *That, as it appears that all jurisdictions require some monitoring of sediment geochemistry, these sediments samples should be utilized for further (organics) analyses.*

Concerns with metals

- Fish farmers:
  - Lack of alternatives for antifouling
- Environment:
  - Persistence
  - Effects on non-targets
  - Cumulative effects

Antifoulants

- Copper-based antifoulants are universally used in the salmon aquaculture industry
- Copper in antifouling paints is most commonly as cuprous oxide
- Since the 1970s, levels of copper in marine organisms have steadily increased, indicating increasing copper in the aquatic environment. This is more than an aquaculture issue.

Scotland

Antifoulant use (Kg of copper oxide) in salmon aquaculture in Scotland from 2003 - 2006.

Copper Oxide	2003	2004	2005	2006
	18,996–26,626	11,700-29,056	34,000-84,123	35,551-86,929

Cu Bioavailability

- Cu toxicity depends on “species” of copper - chemical form
- Free ion is toxic form
- Cu may be bound to ligands, dissolved organic matter in water, or to components of the cell membrane and generally unavailable
- Salinity and pH also affects bioavailabilty of Cu.

Cu in Sediments

- Elevated around salmon farms above sediment quality guidelines
- Cu is bound to fine particles and sulfides, often in anoxic sediments. Under these conditions Cu is generally unavailable to biota except for sediment dwelling organisms and those that "work" the sediment.
- Re-suspension of sediments may make Cu available

Zn

- Zn used mostly as supplement in salmon feeds, at levels exceeding dietary requirements
- Zn pyrithione used in some antifouling paints
- Elevated in sediments around salmon cages, sometimes above effects level or sediment quality guidelines
- Less toxic than copper

Zn Bioavailability

- Like Cu, binds to fine particles and sulfides in sediments and is therefore unlikely to be bioavailable
- Disturbance of sediments could remobilize the metals
- Suggestion that feed manufacturers are using Zn in a more bioavailable form, Zn methionine, therefore reducing the quantity of Zn entering the environment from food.

Research needs

- *There is continued need to develop alternative antifoulants that are not toxic to non-target organisms, or that work through physical means and do not exert toxicity to prevent settlement of fouling organisms. (A salmon farm in Norway (Villa Laks) is developing new technology that uses non-toxic antifouling treatment)*

- *Research is needed into the fate of metals when their concentrations decrease in sediments after harvesting the fish during the remediation phase to investigate to what degree the metals are being released into the water column and available to nearby biota.*

Recommendations

That the use of anti-foulants should be made part of regulations in all jurisdictions. These regulations should include which products are used, how and where nets are treated and how nets are cleaned with a goal of reducing anti-foulant input to the aquatic environment.

That, as it appears that all jurisdictions require some monitoring of sediment geochemistry, these sediments samples should be utilized for further metal analyses.

Disinfectants

- A suite of chemical compounds including:
  - Iodine compounds
  - Chlorine compounds (bleach)
  - Virkon®

Concerns with Disinfectants

- Fish farmers:
  - Potential effects on fish
- Environment:
  - Largely unstudied
  - Solvents and surfactants (alkylphenols?)

Scotland

The total of disinfectants used on Atlantic salmon grow out sites in Scotland in 2003-2006.

Year	Total quantity of disinfectants used (Kg)
2003	1848
2004	7543
2005	4015
2006	3901

Source SEPA

Disinfectants used in Chile 2003 (all aquaculture)

<u>Disinfectant Group</u>

- Potassium persulfate + organic acids: Virkon ®
- Iodophors: Iodine + detergents
- Chlorine: Chloramine-THypochlorite (HClO2) Chlorine dioxide (ClO2)
- Quaternary ammonium compounds: Benzalkonium chloride Superquats ® Aldehydes: Glutaraldehyde, Formalin 40%
- Alkalies: Calcium oxide: CaO or quicklime,
  Calcium hydroxide; Ca(OH)2 or slake lime,
  Sodium carbonate: Na2CO3 or soda ash
- Phenols: Creolina Synthetic phenols, halophenols
- Alcohol: Ethanol 95% and 70%

Source Bravo 2005

- **Research Gap**

  There are very little available data regarding the presence of disinfectants and particularly of formulation products in the marine environment. Studies need to be conducted to document the patterns of use, the temporal and spatial scales over which compounds can be found.

- **Recommendation**

  That regulatory agencies in all jurisdictions require yearly reporting of the quantities of disinfectants used by salmon farms and that these data be made available to the public.

Malachite Green

- Carcinogen and can affect genetic material
- Banned in all jurisdictions
- Reports of Malachite Green discovered in farmed salmon, suggesting it is still being used.
- This is an enforcement issue, not only for regulatory agencies but also for fish farmers.
- Eels in Germany have been shown to have very low concentrations of malachite green and its metabolite.

Anaesthetics

- Generally very few products
- Only Norway and Scotland report usage
- In Canada only MS-222 and Metomidate are registered.
- In Chile Benzocaine, Isoeugenol and tricaine methyl sulphonate (MS-222®) are licensed for use.
- Considered low risk in terms of fish and environment

Norway

Compound	2002	2003	2004	2005	2006
Benzocaine	500	500	500	500	400
MS-222®	675	699	737	960	1216
Isoeugenol	0	0	0	0	6.5

Source Jon Arne Grottum and www.fishfarmingxpert.no

Scotland

Compound	2003	2004	2005	2006
MS-222	9.4	22.8	22.7	33.4
Benzocaine	25.6	25.4	11.9	5.5
2-propanone(L)	98.5	374.3	179.8	120
2-propanol(L)	30	25	2.5	0
Phenoxy ethanol(L)	28	5.9	7.2	0

Source SEPA

- **Research Gap**

  There are very little available data regarding the use patterns of anaesthetics in salmon aquaculture. Collection and analysis of these data may help determine if more studies are required to determine if any products pose a risk to aquatic biota.

- **Recommendation**

  That regulatory agencies in all jurisdictions require yearly reporting of the quantities of anaesthetics used by salmon farms and that these data be made available to the public.

Key recommendation:

That regulatory agencies in all jurisdictions require yearly reporting of the quantities of antibiotics, antifoulants, parasiticides, disinfectants and anaesthetics used by salmon farms. If reporting is already required, that these data be made available to the public. The model used by the Scottish Environmental Protection Agency is a good example.

Recommendations

Data may exist that address some of the research gaps identified with respect to antiparasitic compounds. Where field studies have been conducted as part of the registration process, the data should be more readily available to the public.

That the use of anti-foulants should be made part of regulations in all jurisdictions. These regulations should include which products are used, how and where nets are treated and how nets are cleaned with a goal of reducing anti-foulant input to the aquatic environment.

That, as it appears that all jurisdictions require some monitoring of sediment geochemistry, these sediments samples should be utilized for further chemical analyses.

That regulatory agencies in all jurisdictions require yearly reporting of the quantities of disinfectants and anaesthetics used by salmon farms and that these data be made available to the public.

Crucial Research need:

Cumulative effects of chemicals and of interactions between chemicals and between chemicals and the marine environment are largely unknown. Studies must be designed and carried out to address this need both in the near site and far-field environment.

Research Needs

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Research needs

There are very little available data regarding the presence of disinfectants and particularly of formulation products in the marine environment. Similarly little data are available for use, and fate of anaesthetics. Studies need to be conducted to document the patterns of use, the temporal and spatial scales over which these compounds may be found.