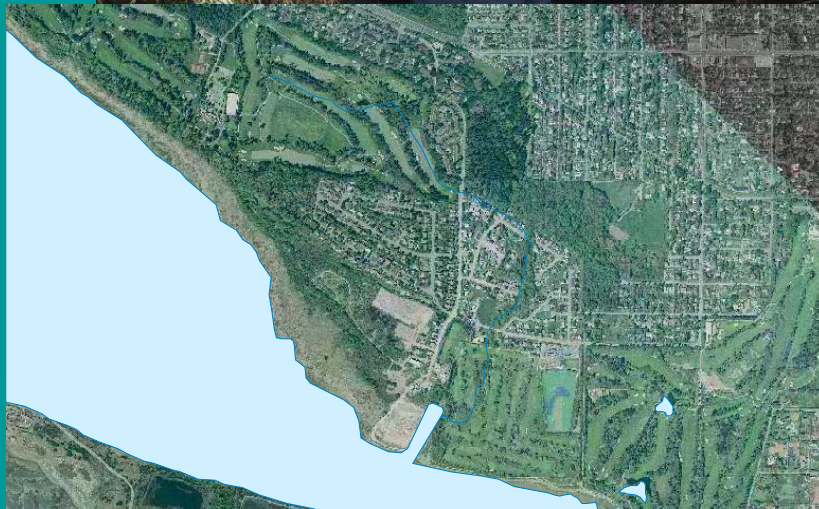
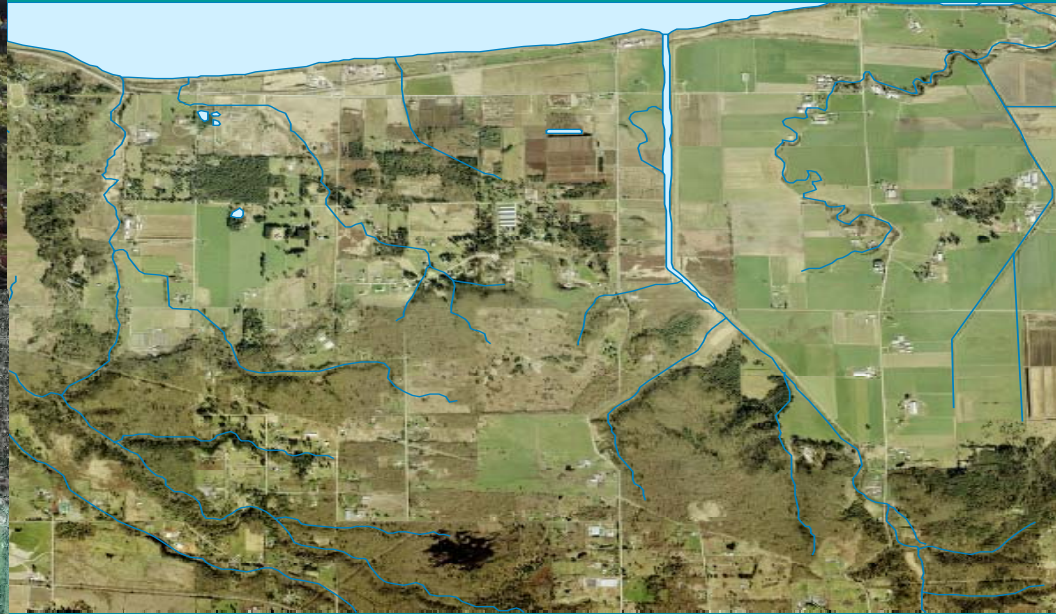


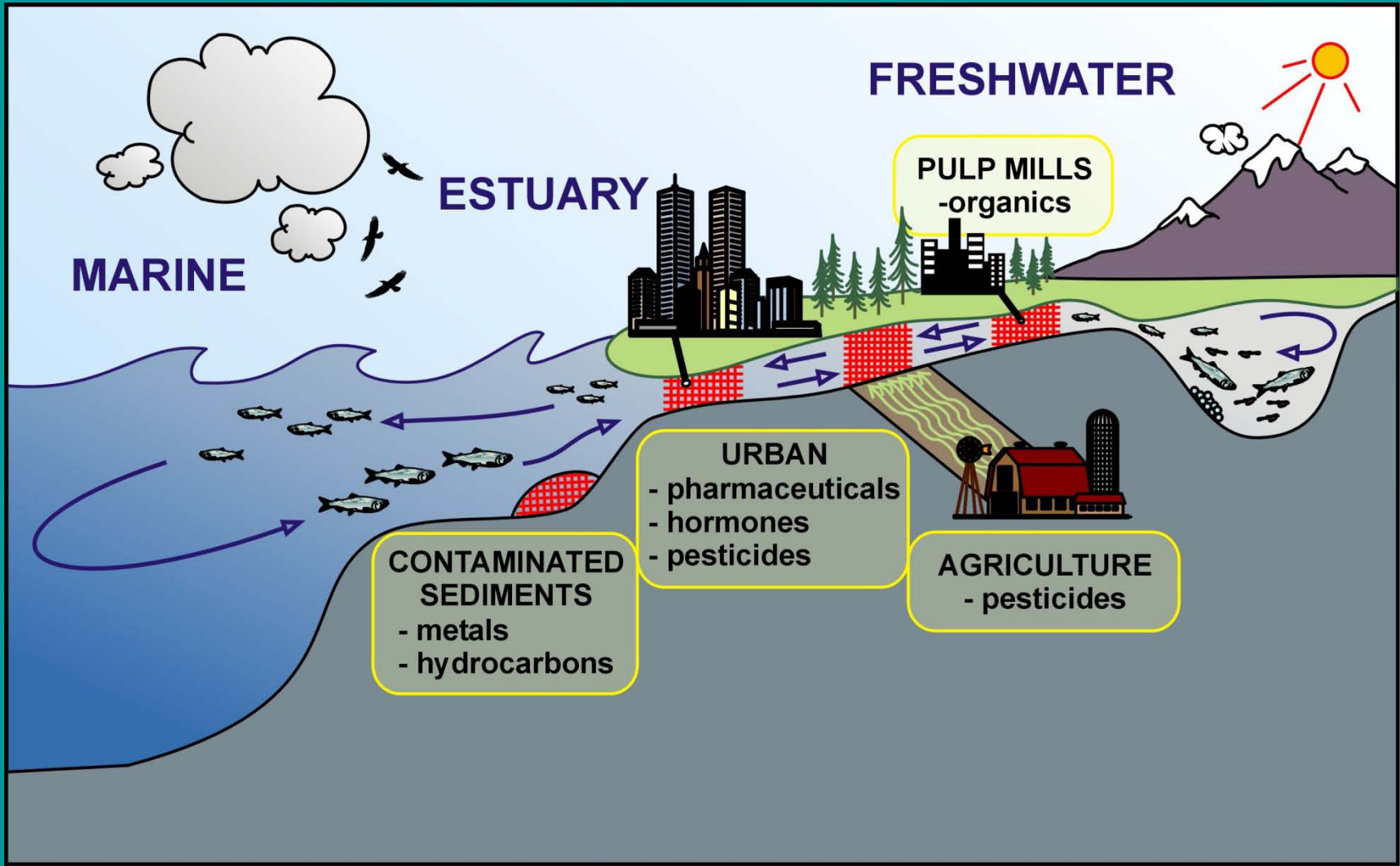
Salmon are sensitive: Life history, habitat, and contaminants

Peter S. Ross (DFO), Lesley Shelley (SFU),
Chris Kennedy (SFU), Keith Tierney (UofA),
David Patterson (DFO), Wayne Fairchild
(DFO), and Robie Macdonald (DFO)

Fraser sockeye habitat has changed over the last 100 years



1) *Running the gauntlet.* Sockeye must transit a number of contaminated zones during their life: non-point runoff, point source and spills



A single (visible) accident

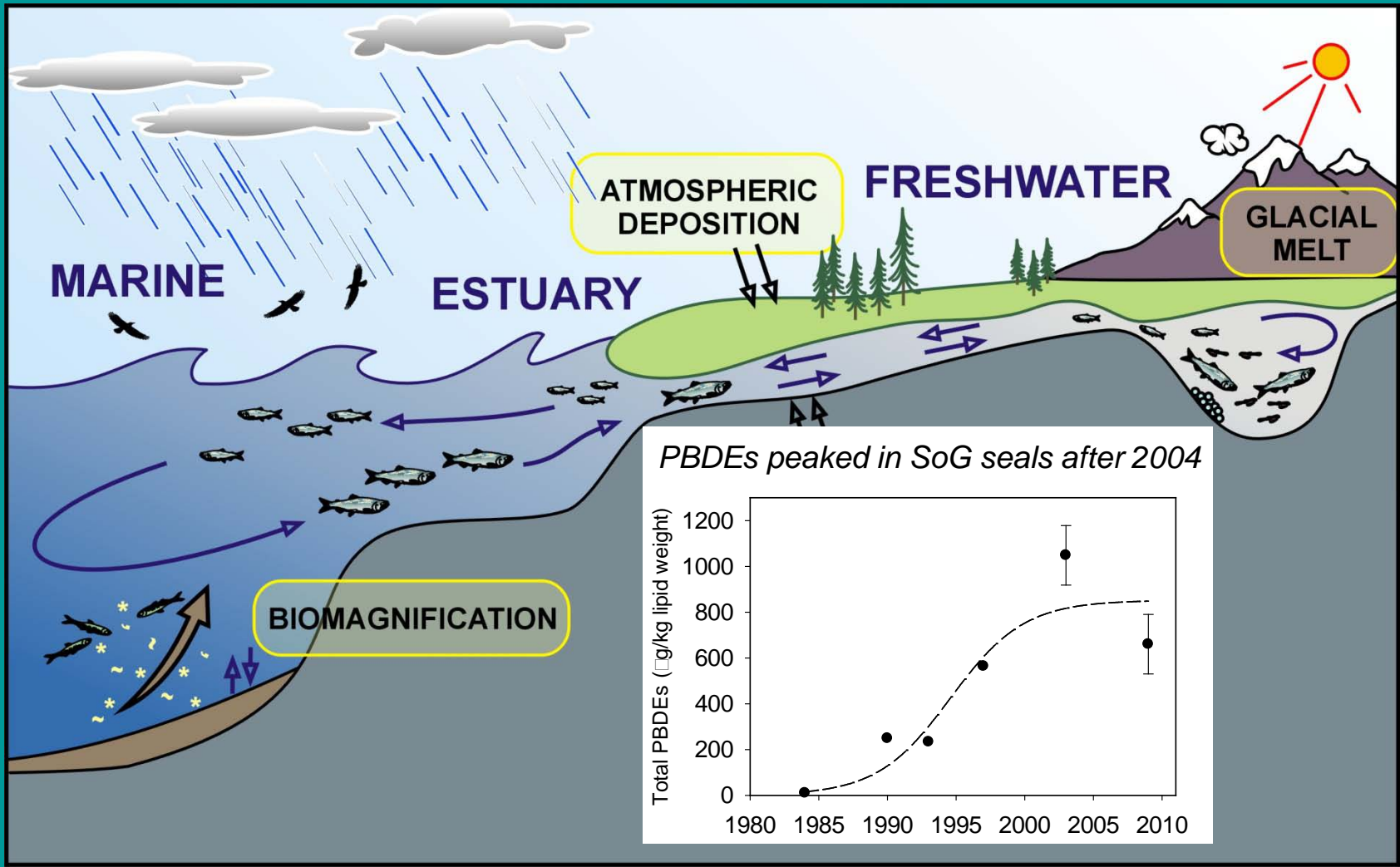


- At 0720 am on August 5, 2005, a single rail car carrying NaOH released most of its 53,000 L into the Cheakamus River.
- 500,000 fish died within hours, suffering from gill haemorrhaging, suffocation and burns.
- Eight government agencies were on scene within hours.
- Strict regulations and emergency response protocols have reduced the impacts of such visible incidents over the past few decades.
- However, the migratory lifestyle of sockeye means that they must run a gauntlet of risks associated with accidents, multiple point sources and non point sources of pollution.

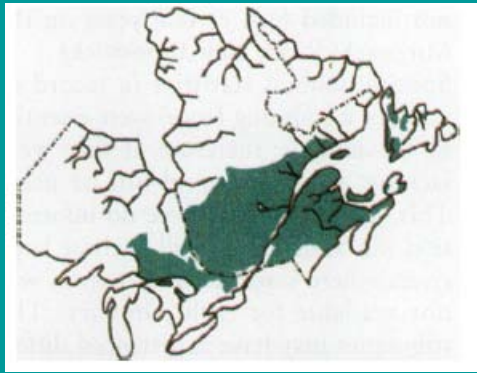
The contaminant gauntlet in sockeye habitat

- Culverts, dams, bridges, rail crossings, hydro crossings: silt, hydrocarbons, road salt, creosote, metals, and pesticides.
- Waste water treatment plants: flame retardants, pharmaceuticals and personal care products, pesticides, metals, pathogens and nutrients.
- Forestry activities: herbicides applied after logging (glyphosate and triclopyr), wood preservatives and antisapstains (e.g. creosote, CCA, PCP; DDAC), hydrocarbons and dioxins associated with burning.
- Agriculture: current use pesticides (500 products).
- Non point source pollution: runoff and atmospheric deposition introduce legacy and current use chemicals into remote environments.

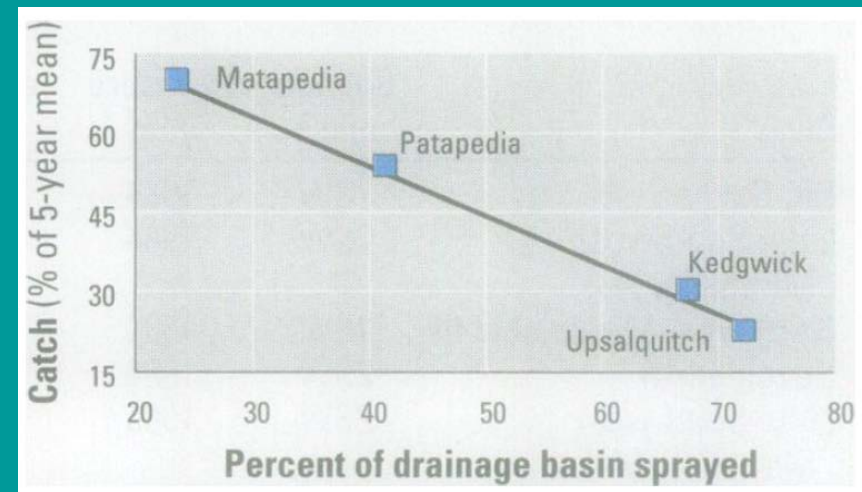
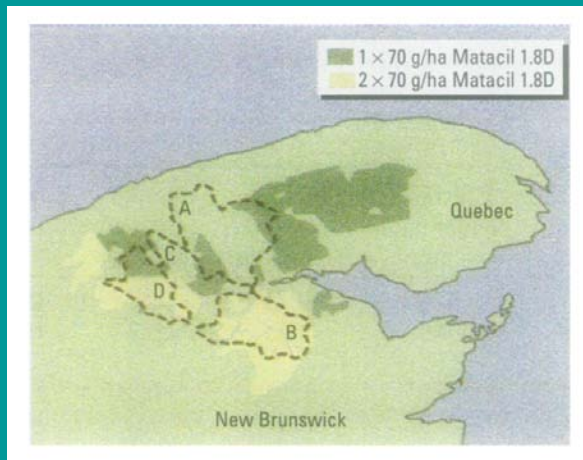
2) *Carrying the risk*: Sockeye are exposed to endocrine disrupting contaminants throughout their lifetime; many of these are banned but ubiquitous



Population impact: Reduced Atlantic salmon returns in Eastern Canada were eventually linked to 4-nonylphenol used as a dispersant in Matacil 1.8 D applications

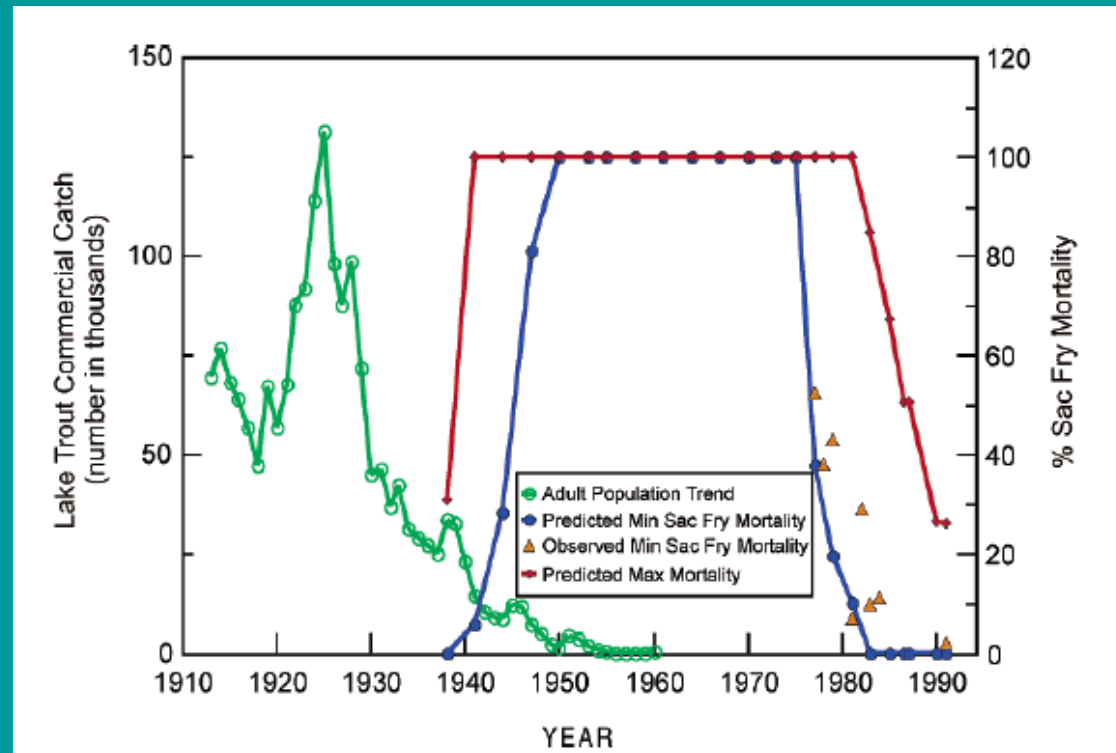
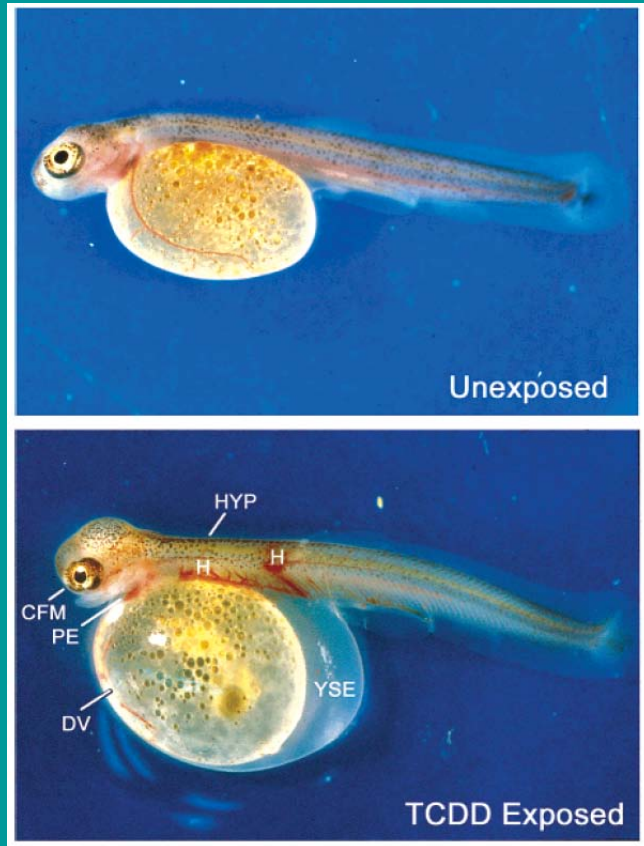


Spruce budworm infestation in eastern Canada;
Restigouche River system in NB/QC



Salmon catch inversely correlated with
Matacil 1.8D applications in Restigouche
River

Population impact: Elevated dioxin-like contaminants explain complete reproductive failure for Ontario lake trout (*Salvelinus namaycush*) between 1945-1980



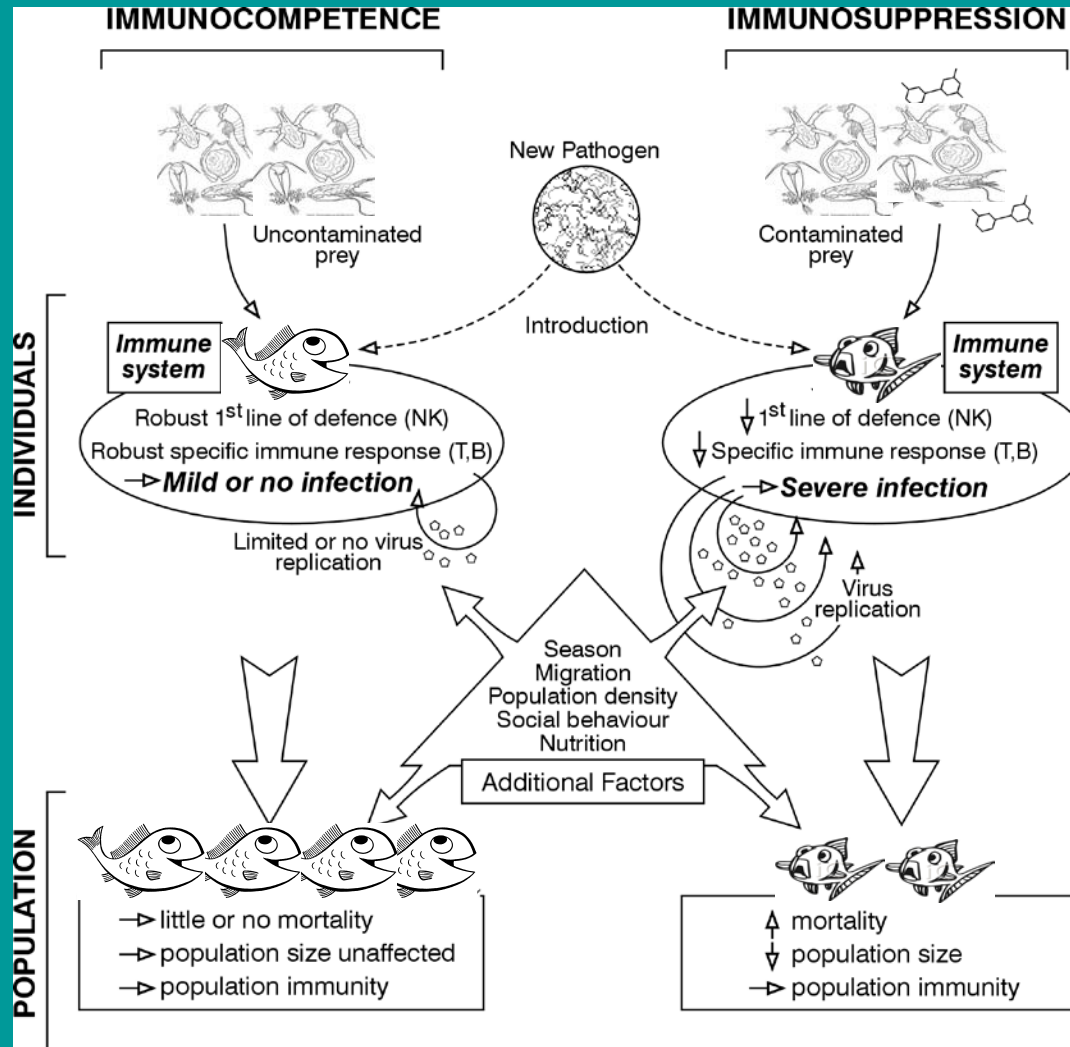
Lake trout fry exposed to dioxin have multiple signs of toxicity including edema and malformations that lead to death

Contaminants today are more likely to disrupt endocrine systems in sockeye than outright kill them



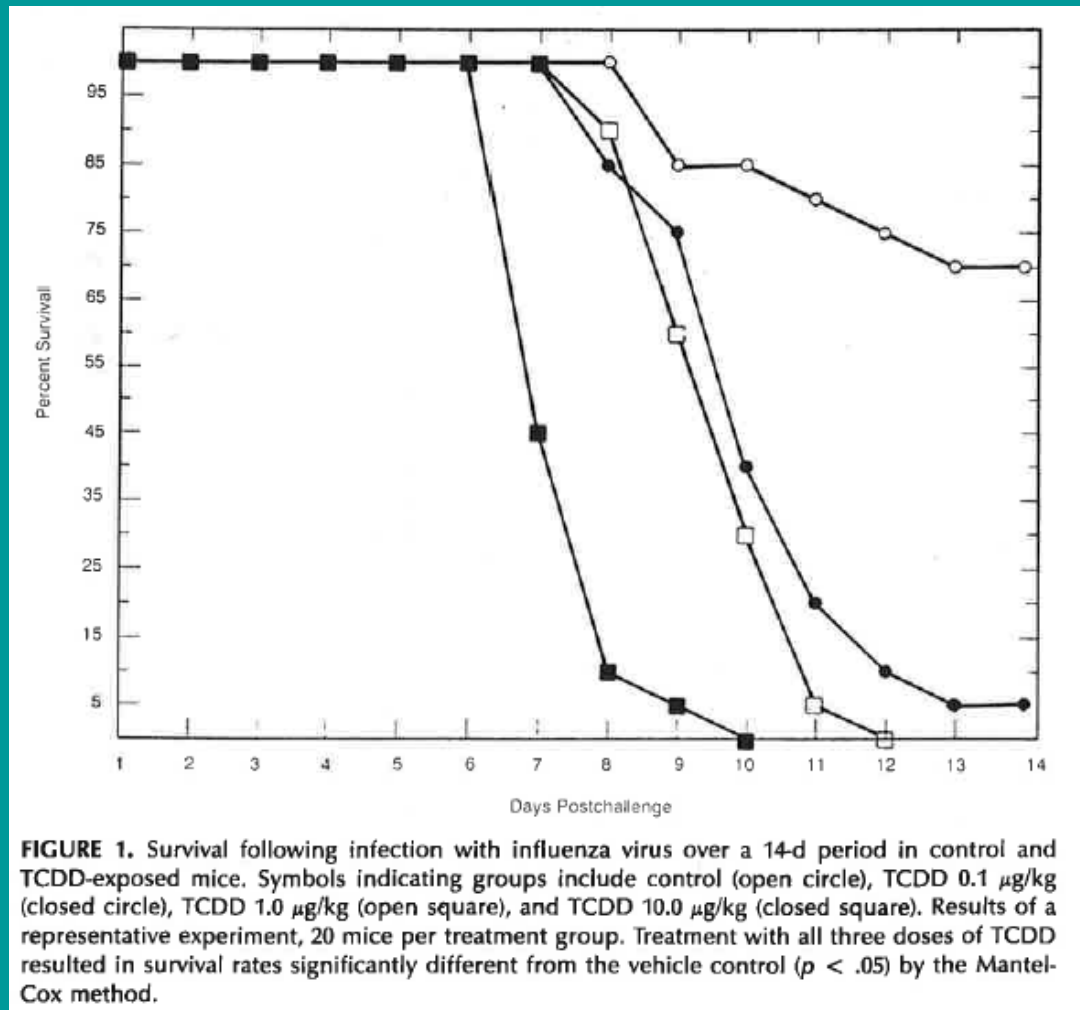
- *Olfaction and related behaviours*: predator avoidance; homing to natal stream; detection of prey, conspecifics and mates (Tierney et al).
- *Growth and development*: parr-smolt transformation, metabolism and energetics (Fairchild et al.).
- *Immune function*: disease resistance (Shelley et al.).
- Abundant evidence from the literature, and some clues from BC work.

Host resistance is multifactorial, but contaminants can increase disease susceptibility

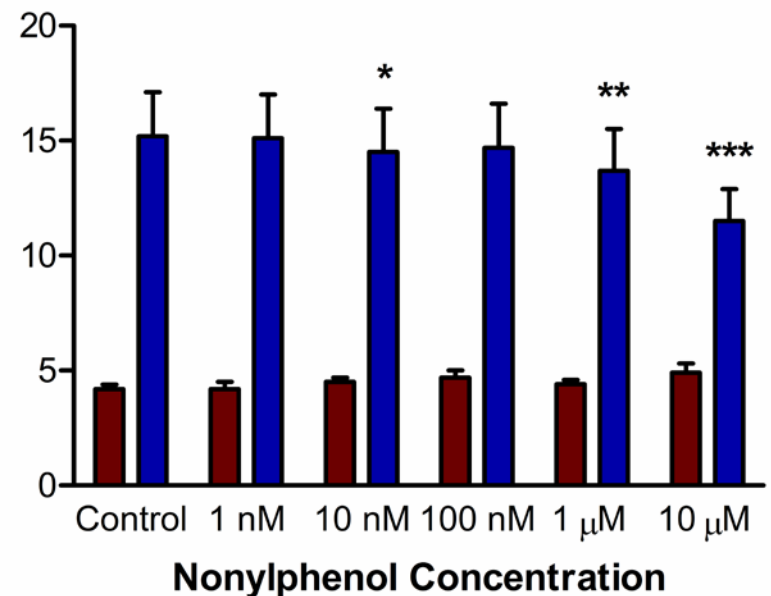
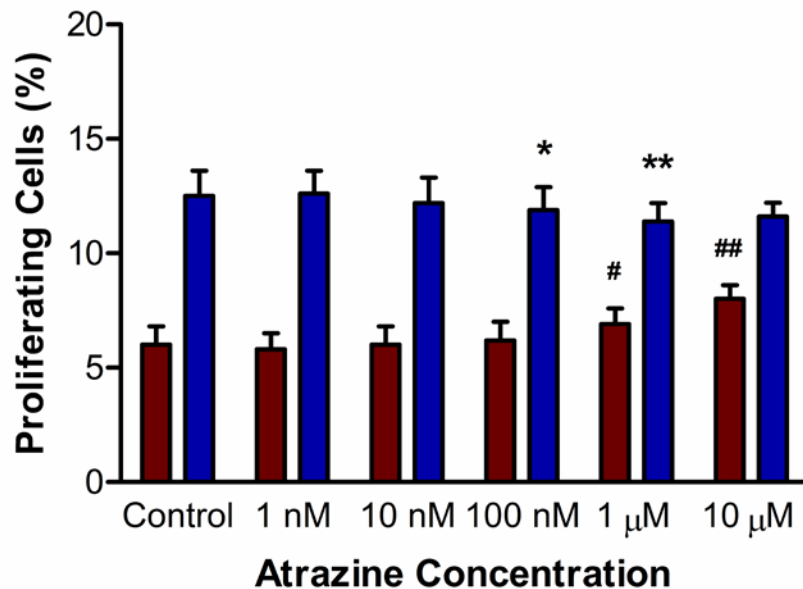


(from Ross et al. 2003)

Contaminants, the immune system and disease-associated mortality: Dioxin increases influenza-associated mortality to 100% in mice at 10 ppb



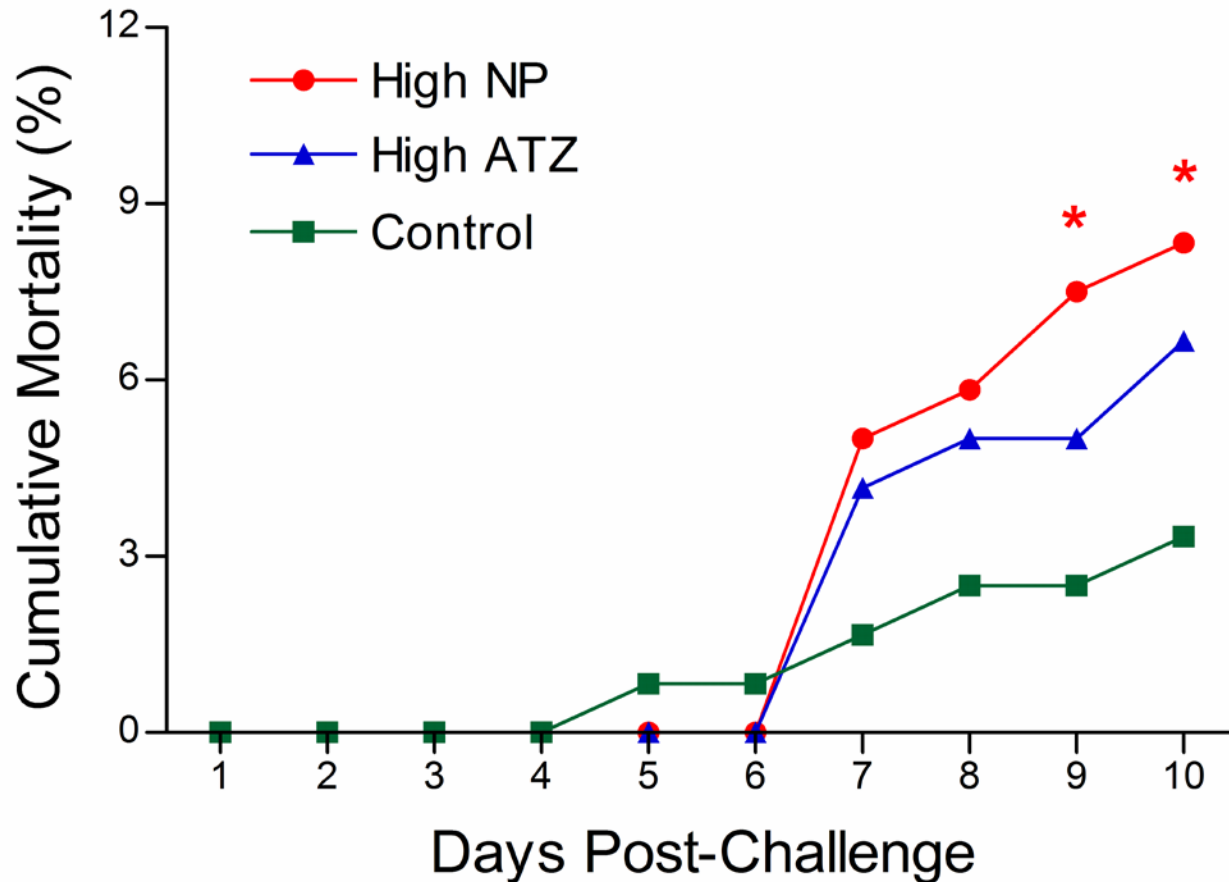
Rainbow trout leukocyte proliferation is modulated by exposure to the pesticide atrazine and the formulant nonylphenol



Proliferation of PBL from rainbow trout is decreased in LPS-stimulated cells (blue bars) and unstimulated cells (red bars) following 4-day *in vitro* incubation with atrazine (left) or nonylphenol (right). Data is shown as percent proliferating cells \pm SEM. Treatments significantly different from the corresponding control cells are shown as # ($p < 0.05$), ## ($p < 0.01$) or ### ($p < 0.001$) for LPS-stimulated cells.

(Shelley et al in prep)

Are sockeye less prepared for every day pathogens?
Mortality following infection with *Listonella anguillarum* is
increased in nonylphenol-exposed rainbow trout



(preliminary data; 40 fish per treatment group; Shelley et al in prep;
genomics signatures underway in collaboration with Kristi Miller)

Pesticides in BC

- 500 pesticides used in Canada;
- 90% of all insecticides and 56% of all herbicides in BC are applied to Fraser Valley;
- Estimated 2.5 million kg of formulants applied every year in BC;
- BC: New BC Integrated Pest Management Act: less need for permits, no reporting of pesticides used but records for crown lands on BC-wide basis stored by permit holder, private farmers do not report or keep data, no database of products used, no information on formulants, records destroyed after 3 years;
- Canada: Pest Management Regulatory Agency (PMRA-HC) does not release the formulant ingredients for commercial pesticides;

Salmon are sensitive

- Contaminants (Cu, Al, pH, OP pesticides, dioxins);
- Life history, wherein they migrate thousands of kilometers, undergo dramatic physiological alterations, and must successfully navigate critical ecological windows;
- As a result, many stocks must run a gauntlet of human threats, exposing them to acute and developmental toxicants.

Review of Report No. 2: 'Potential effects of contaminants on Fraser River sockeye salmon'

- 10 pulp mills
- 15 wood preservation facilities
- 17 cement plants
- 28 operating mines
- 24 bulk storage facilities
- 2699 federal contaminated sites
- 25 waste water treatment plants
- 37 salmonid enhancement facilities
- Numerous landfills

Review of Report No. 2: Pros and cons

- Extensive compendium of data on water, sediment quality;
- Missed several studies on:
 - forestry/agriculture
 - urban runoff
 - LRTAP
 - glacial melt
 - Food web amplification
 - Emerging concerns
 - Marine sources (#12)
- Risk-based approach based on existing data;
- Data not collected for salmon habitat context; spartan contaminant list; spatial coverage poor; temporal coverage poor; elementary lab analyses; complex mixtures not considered.
- Comparison with existing guidelines.
- Guidelines do not exist for salmon; only exist for a few contaminants; do not cover complex mixtures; rely on 96 hr exposures and do not address lifelong exposures in real world. Guidelines fail to protect salmon.

Report no. 2 Recommendations

- Review of industrial screening programs;
- Improved MEQ monitoring over time and space of salmon habitat;
- Effects-based evaluation on salmon at different life history stages;
- Inter-agency coordination for data sharing;
- Focussed research programs;
- Research on interactive effects of contaminants;
- Research on interactions between contaminants, health and disease.

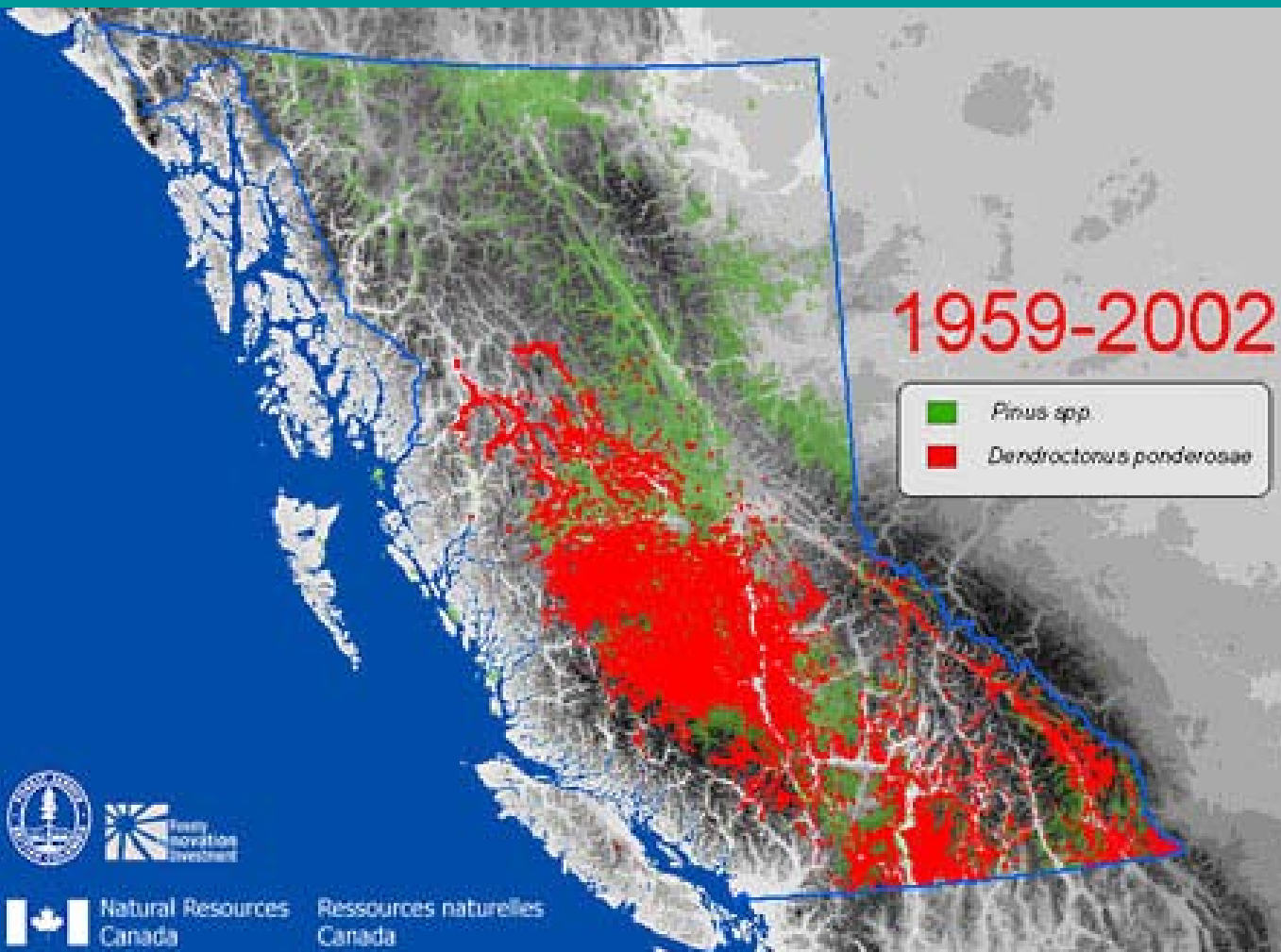
Review of Report No. 2: Gaps in scientific, institutional, operational and/or regulatory topics:

- implications of changing climate on contaminant pathways and health effects;
- factors which affect exposure to contaminants;
- factors which affect the vulnerability of fish to the effects of contaminants;
- critical evaluation of current federal (CCME) and provincial (BC MoE) guidelines to protect sensitive species (anadromous fish) and/or life history stages;
- critical evaluation of national screening criteria for both pesticides *and* their formulants (Pest Mgt Regulatory Agency, PMRA-HC);
- evaluation of screening criteria for new chemicals under *CEPA*;
- evaluation of new 2005 BC '*Integrated Pest Mgt Act*' which reduces reporting requirements for pesticide use in forestry and agricultural operations;
- s. 36 of the *Fisheries Act*, for which responsibility for monitoring, enforcement and research were transferred from DFO to EC in 2005.

The take-home messages...

- There is no *evidence* that a single contaminant has caused the recent and dramatic declines in sockeye salmon;
- There is a *strong possibility* that contaminants have contributed to the decline in Fraser sockeye over the last 20 years;
- Constrained by notable datagaps!
- Contaminant-mediated effects are likely indirect, acting to reduce defences against pathogens, alter growth and metabolism, and/or alter behaviour;
- Salmon are sensitive.

Fraser sockeye habitat is changing rapidly: mountain pine beetle infestation and management



Harvesting

Organic carbon

Sediment

Remobilization of
contaminants in soil

MSMA pesticide
applications

accelerated glacial
release of archived
contaminants

Herbicides applied
post-logging to wide
tracts

Exposure to pesticides increases activity of granulocytes, suggesting hyperimmune response at low doses

- Low doses;
- environmentally realistic range;
- Higher doses reported in the literature suppress granulocyte activity

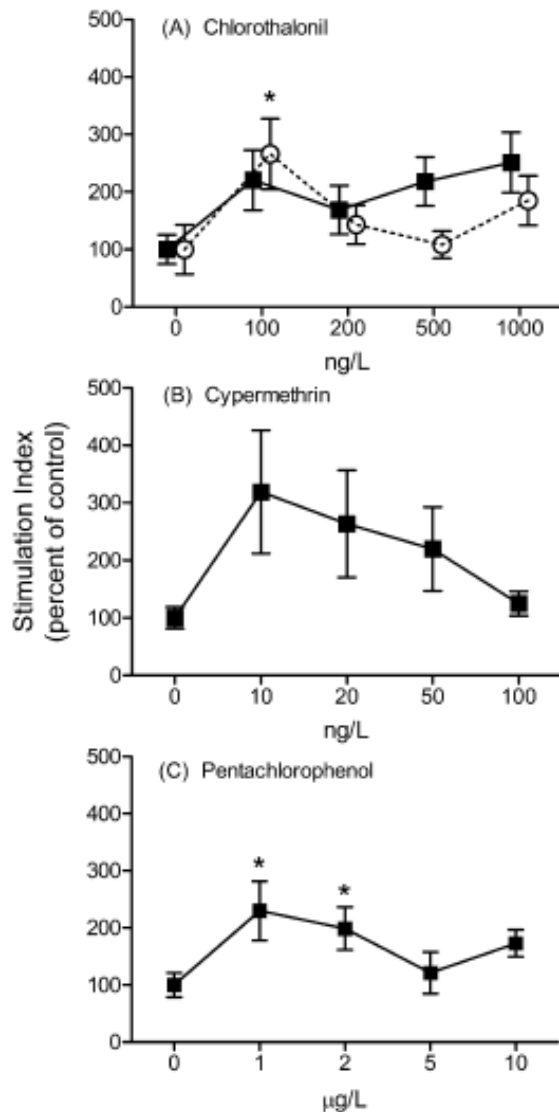
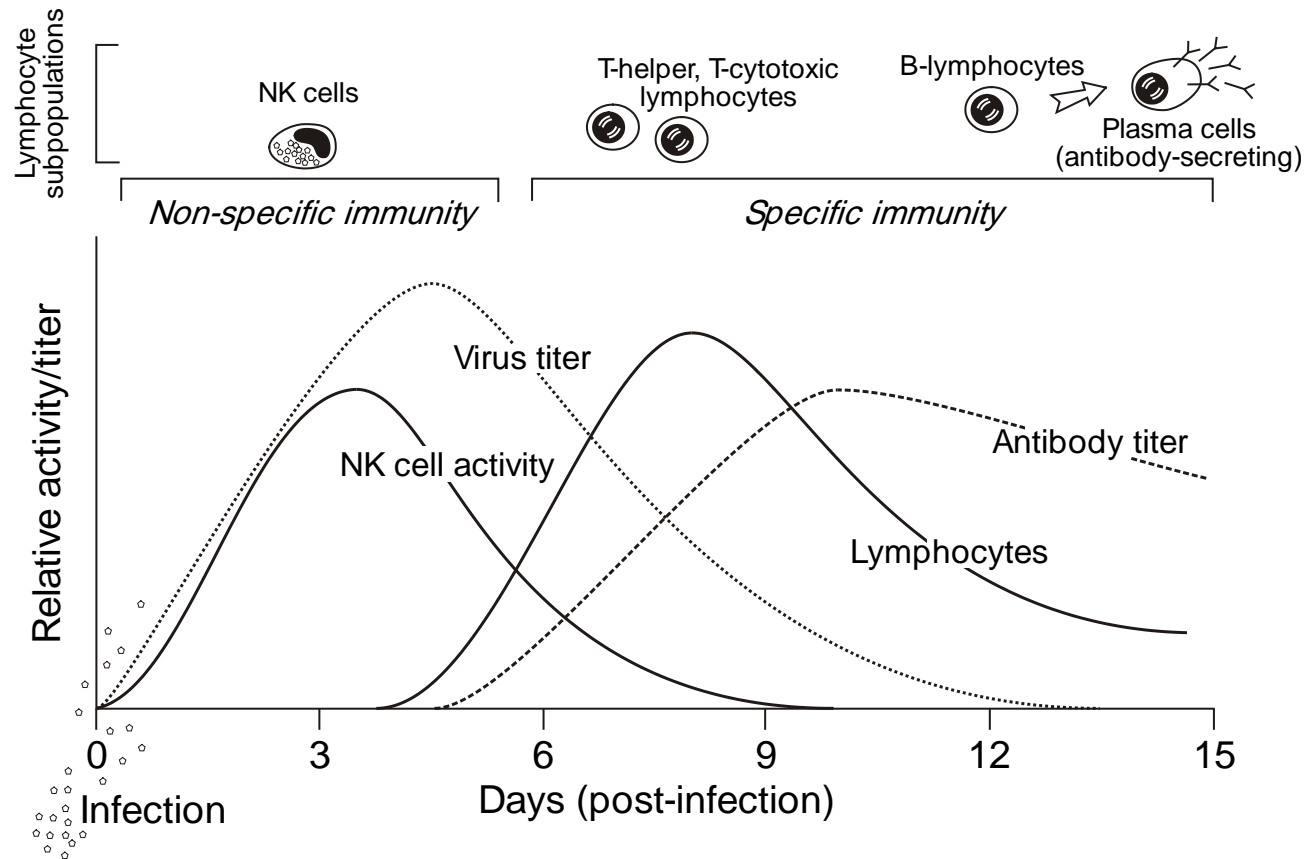


Fig. 1. Respiratory burst activity of rainbow trout head kidney leukocytes stimulated with PMA increased following 28 days of *in vivo* exposure to (C) pentachlorophenol or (A, circles) a 14-day post-chlorothalonil exposure recovery period, but was not significantly changed following exposure to (A, squares) chlorothalonil or (B) cypermethrin. Data are expressed as a stimulation index which was calculated as the mean fluorescence of PMA stimulated leukocytes divided by mean fluorescence of unstimulated leukocytes. Mean fluorescence of each sample was standardized by expressing data as percent of control for the day. Points represent mean \pm S.E.M., an * indicates that a treatment is significantly different than control (p -value < 0.05) and sample size is 12 per treatment group.

Immunotoxic chemicals can impair different parts of the immune response to infection

The immune response during virus infection



(from Ross et al. 2003)

- Atrazine: herbicide, LC50 in RBT 7.5 mg/L but PSTransformation affected at lower concentrations, withdrawn from BC in 2008;
- Chlorothalonil: herbicide, LC 50 in RBT 0.25 mg/L;
- Chlorpyrifos: insecticide, Kow 4.7, LD50 135 mg/kg;
- Cypermethrin:
- Nonylphenol (NP): 'formulant', associated with Atlantic salmon declines, water soluble, estrogenic, impairs PSTransformation; at 32% weight, we can estimate 2.5 million kg of formulants applied to BC annually.