Threats to the Health of the Bay of Fundy: Potential Problems Posed by Pollutants

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Executive Summary

The workshop "Threats to the Health of the Bay of Fundy: Potential Problems Posed by Pollutants," held in April 2010, resulted from a previous informal meeting with representatives of the lobster fishing industry in the Bay of Fundy and two of their fisherman's associations. The fishing industry is seriously concerned about various pollutants, especially pesticides, that are entering waters of the Bay and the effects that pollutants may be having on various non-target fish and invertebrate species. It was felt that an overview of the major pollution sources might serve as a useful information base for the industry and for constructive action on pollution control. The Workshop brought together members of the industry and invited speakers who specialize in various aspects of marine ecotoxicology, especially addressing problems with pesticides. Talks covered seven topics—monitoring the health of the bay; pollutants entering the Bay from river run-off; impacts of mixtures of pollutants; an overview of mercury in the Bay; the potential effects of organic pollutants; the use and potential effects of pyrethroid pesticides on marine organisms; and the toxicity of the pesticide azamethiphos. A panel discussion involving all of the Workshop participants was held focussing on the fate and effects of pesticides used by the local aquaculture industry to combat parasitic copepods known as sea lice, and the risks that such compounds pose to non-target species such as benthic crustaceans (e.g., lobsters). The discussion illustrated the major concerns, still unresolved, about pollutants discharged from the aquaculture sites, the sea lice infestation problem and its treatment, and the overall impacts of open-water salmon aquaculture along the New Brunswick coastline. It was agreed that further such discussions and presentations of knowledge of pollutants in the Bay of Fundy were needed, and that action was required by all parties to limit the risks to non-target species of chemicals used by the local aquaculture industry.

Acknowledgements

We are very grateful to the various sponsors (Department of Fisheries and Oceans, Natural Sciences and Engineering Research Council of Canada, Government of New Brunswick, and Environment Canada) for assisting financially with the Workshop. Special thanks are due to the speakers and to all of the participants for their contributions. The papers and extended abstracts were read carefully and edited by both Editors, but the contributions were not formally peer-reviewed, hence their content is the sole responsibility of the authors. The proceedings were copy-edited and indexed by Ms. Susan Rolston, Seawinds Consulting Services, Hackett's Cove, NS, and produced by Bounty Press, Halifax, NS.

About the Bay of Fundy Ecosystem Partnership (BoFEP)

The Bay of Fundy Ecosystem Partnership (BoFEP) was formed in 1997, having started two years earlier as the Fundy Marine Ecosystem Science Project. Its mandate is to identify and understand the environmental issues confronting the Bay and to find ways of working together to resolve them. It is a flexible and evolving organization, facilitating communication and co-operation among individuals and groups with an interest in Fundy and its resources. BoFEP is a "Virtual Institute", whose main objective is disseminating information, monitoring the state of the ecosystem, and encouraging co-operative research, conservation and other activities. BoFEP welcomes all partners who share the vision of a healthy, diverse, productive Bay of Fundy, be they individuals, community groups, First Nation groups, resource harvesters, scientists, resource managers, coastal zone planners, businesses, government agencies, industries or academic institutions. By sharing our knowledge and coordinating our individual efforts present and future generations will benefit from Fundy's rich and varied bounty and continue to appreciate its awesome beauty and biological diversity. To learn more about BoFEP, visit: <http://www.bofep.org>

The Bay of Fundy is Canada's sole finalist in a global campaign to determine the New7Wonders of Nature. There are 28 worldwide finalists.

You can help the Bay of Fundy become one of the top seven by voting online through www.votemyfundy.com.

The winners will be announced on 11 November 2011.

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Workshop Presentations

INTRODUCTION

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The idea of holding this workshop resulted from a meeting of representatives of the lobster fishing industry and fishermen’s associations (Fundy North Fishermen’s Association, Grand Manan Fishermen’s Association, and Fundy Weir Fishermen’s Association) on February 6, 2010, to which I was invited. It was clear that the industry was seriously worried about various pollutants that were going into the waters of the Bay of Fundy and the cumulative and deleterious effect that these might have on different fish and shellfish species. As there are several sources of these pollutants it was agreed, following further discussions, that an overview of the major sources would serve as a useful information base for members of the industry.

With invaluable help from Dr. Peter Wells and the support of the Bay of Fundy Ecosystem Partnership (BoFEP), many experts were approached with a request to participate in the workshop and to share their knowledge in an open forum. The response from everyone was positive and enthusiastic as will be evident from the Program (Appendix 1) and from the talks that were given. The positive participation of all the speakers was a *sine qua non* for the success of this workshop; their willingness to share their knowledge and contribute their time is greatly appreciated as is the willingness of Peter Wells and Brian Rogers to help keep the Workshop on track.

The talks given are printed, as a BoFEP publication, and these Proceedings will be distributed, free, to all registrants (Appendix 2) and will be available, on request, to any others interested.

The continuing encouragement of the fishing industry, *sensu lato*, is gratefully acknowledged as is the support and encouragement of Fisheries and Oceans Canada (DFO), Environment Canada (EC), the New Brunswick Department of Fisheries and Aquaculture, and the Natural Sciences and Engineering Research Council of Canada (NSERC).

MONITORING THE HEALTH OF THE BAY OF FUNDY, GULF OF MAINE

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Abstract

The Bay of Fundy, its near-shore environments, its estuaries and watersheds currently face many pollution challenges, some new (e.g., plasticizers and some pesticides), some decades or even centuries old (e.g. pulp mill wastes, sewage). Amongst the pollutants are chemicals and nutrients from aquaculture, industrial chemicals and effluents, oil-derived hydrocarbons, metals and sediments from mining, and chemicals and pathogens from sewage. Non-point pollution and combined and cumulative effects of pollution are particular concerns. Although federal and provincial legislation, along with guidelines and regulations, have been in place for decades to control point-source industrial pollution (through the *Fisheries Act*), and the introduction of "toxic chemicals" (through the *Canadian Environmental Protection Act*), the effectiveness of those regulations and guidelines demands considerable environmental monitoring by government agencies, researchers and community groups. Only with regular monitoring, reporting and follow-up action will there be assurance that the Bay's ecosystems are being adequately protected.

This paper briefly addresses monitoring the health of the Bay of Fundy—why we monitor, the challenges of multiple issues and the measurement of ecosystem health, a description of some of the monitoring programs (circa 2006) in the Bay, and new monitoring requirements to ensure protection of key species, ecosystems, and human health. This perspective is based in part on research on the concepts and key indicators of ocean health; the work of the Gulf of Maine Council on the Marine Environment's Gulfwatch program (www.gulfofmaine.org); the inventory of coastal monitoring programs in Canada, including the Bay of Fundy, from the 2006 Ecological Monitoring and Assessment Program (EMAN) workshop; and BoFEP's contributions since 1995 (www.bofep.org).

Some needs for the Bay include: maintaining the longer-term monitoring of various waters, species and habitats; developing a more complete set of marine environmental quality guidelines to interpret monitoring data on water, sediments and biota; writing periodic State of the Bay of Fundy/Gulf of Maine reports, prepared with the involvement of a number of stakeholders; and re-engaging with the relevant policy and senior managers in government and industry responsible for preventing and controlling pollution, conducting key monitoring programs, and assessing and maintaining the health of the Bay's species and ecosystems.

Introduction

The Bay of Fundy, with its various near-shore environments, estuaries and watersheds, currently face many pollution challenges, some new (e.g., plasticizers, some pesticides, various endocrine disrupting chemicals in municipal effluents) and some decades old (e.g., pulp mill wastes, sewage, PCBs, DDT residues). Amongst the full range of pollutants are chemicals and nutrients from aquaculture, industrial chemicals and effluents, oil-derived hydrocarbons, metals and sediments from mining, and pathogens and chemicals from municipal effluents and raw sewage discharges (Wells et al. 1997; Percy 1996, 2004, 2006, 2008; amongst others). Non-point pollution is of particular concern, as many river basins such as that of the Saint John River, discharge a mixture of sediments, nutrients, pesticides and many other toxic chemicals into the Bay on a continuous basis, and mercury largely from power plants continually enters from the atmosphere (see Dalziel et al., this volume). As shown by the Gulf of Maine Council's Gulfwatch program (Chase et al. 2001; Jones et al. 2001), intertidal organisms such as blue mussels in the Bay are being exposed temporally and spatially to a wide range of chemicals dissolved or dispersed in water, in and on sediment particles, and in the food chain. This is leading to concerns about which chemicals are solely contaminants (levels too low to cause measurable toxic effects), which are pollutants (levels that are high enough for long enough time to cause measurable toxic effects), and which combine and last long enough to cause cumulative toxic effects directly on biota or their habitat quality. The Bay of Fundy is large (290 km long, 100 km wide at outer bay, approx. 16,000 km^2) and salt-water exchange is in the billions of litres, twice daily. However, as shown by monitoring programs, organism tissues, and the marine sediments reflect chemical exposures in numerous settings, often with unknown biological consequences.

National and provincial legislation has been in place in Canada since the early 1970s to control point-source industrial pollution, such as that from food processing plants, fish plants, and oil refineries, e.g., the *Fisheries Act*, oil refinery regulations and guidelines. However, the effectiveness of such regulations and guidelines controlling toxic effluents and single chemicals under the different acts (e.g., federally, the *Fisheries Act*, *Canadian Environmental Protection Act*, and *Pesticide Products Control Act*) demands considerable compliance monitoring (at the industrial source) and ambient environmental monitoring by government agencies, researchers, community groups, and the industries themselves (see Blaise et al. 1988; Day et al. 1988; Blaise 2003). Both types of monitoring are critical to ensure that accepted emission standards are being met and that the Bay's ecosystems and organisms are being adequately safeguarded.

This paper briefly introduces the topic for the benefit of this Fundy Pollution Workshop (Burt and Wells 2010)—why we monitor; the challenges of addressing multiple pollution issues; the measurement of ecosystem condition or health through use of common indicators; some of the current (circa 2006) monitoring programs in the Bay of Fundy and their results; and monitoring needs to ensure protection of key species, habitats, ecosystems, and human health. This view of monitoring is based in part on a recent consideration of the concepts and key indicators of ocean health related to the Bay (Percy and Wells 2002; Wells 2003, 2005; Wells et al. 2005); work of the Gulf of Maine Council on the Marine Environment's (GOMC) Gulfwatch program (www.gulfofmaine.org); Chase et al. 2001; Jones et al.. 2001; Jones and Wells 2002; Pesch and Wells 2004), and the Ecosystem Indicator Partnership (ESIP) program (C.Tilburg, ESIP, pers. comm.); BoFEP's sponsored research and syntheses since 1995 (www.bofep.org); and the inventory of coastal monitoring programs in Canada, including the Bay of Fundy, from the 2006 Ecological Monitoring and Assessment Program (EMAN) workshop (Hazel et al. 2006). This work should also be considered within the broader overview of monitoring ocean health in Canada (see Strain and MacDonald 2002).

To understand the urgent needs associated with pollution from aquaculture (the theme of this workshop), the reader is encouraged to read the other papers of this Proceedings and access the key reference sources on monitoring, some of which are listed below. The talk based on this paper is appended to the Proceedings.

Monitoring the Bay of Fundy – A Synopsis

Why Do We Monitor?

Through various programs, the Bay's ecosystems or their components are monitored to address specific questions—What is the present health or condition of the Bay? Are conditions improving, deteriorating, or staying the same? Are there unsuspected environmental problems in the Bay? To answer these questions successfully, we need to monitor with indicators or measurements of various kinds that collectively can provide data on the Bay's health (Wells 2003, 2005; Wells et al. 2005) and analyse the data using the methods and models of ecological risk assessment. Because our suite of current techniques that can be deployed across the Bay is limited (e.g., the ESIP-GOMC program identifies only three indicators for contaminants—coliform bacteria, chemical residues in mussels, and TRIAD data; see GOMC website), new and more sensitive monitoring methods are needed, using the knowledge and skills of chemistry, biochemistry, ecotoxicology, ecology, and statistics. We also need to ensure that there is enough information to adequately answer the above questions and that this information is used to make the right decisions to protect the Bay (see the Fundy Information Collaboratory at www.bofep.org, and the Environmental Information: Use and Influence study at www.eiui.ca). Finally, adequate resources (e.g., institutional, financial, scientific, regulatory) to keep the monitoring programs operating in both the short and long term are fundamental to their success, a constant challenge and concern for those involved in monitoring.

What Are the Challenges of Monitoring?

Monitoring faces at least three primary challenges in the Bay of Fundy. The first challenge is to sort out the number and complexity of the stresses confronting the Bay, i.e., the issues, be they be ones of resource extraction or environmental change, including contamination and pollution. The second challenge is the need to understand the dimensions of ecosystem health and to have appropriate and sensitive indicators of the Bay's health included in monitoring programs, paying particular attention to having enough statistical power with each indicator to detect significant change in the ecosystem, and to establish correlative and/or cause-effect relationships. The third challenge is to find funding for programs over the long term, to provide credible spatial and temporal data.

Almost forty (38) issues were identified for the Bay at the 1996 Bay of Fundy Workshop (Percy et al. 1997), At the 2007 Aquatic Toxicity Workshop in Halifax (www.atw.org), a wide range of water quality issues currently studied and in the media were reported (Wells 2008), including:

- pesticides (Minas Basin—freshwater quality was No 1 issue due to concerns about presence of pesticide residues in groundwater and well water); herbicide use—Vision, using glyphosate as active ingredient, over woodlots in Cumberland Co., NS; and past use, such as Agent Orange use in DND property at Camp Gagetown, NB, and persistent forest pesticides used since the 1940s;
- specific contaminants, e.g., oil pollution and wildlife, relative to both offshore oil spills and coastal oiling;
- chemical effects at aquaculture sites—heavy metals, e.g., mercury (Hg), and pesticides;
- contaminants in sediments from dredging operations in harbours;
- mercury, nitrogen and sewage, considered by the GOMC as the priority chemical stresses in the Gulf of Maine;
- effects of industrial and municipal operations, e.g., impacts of fish plant effluents on coastal water quality;
- risks from LNG tankers in outer Bay of Fundy; and
- mining—potential impacts of sediment mineral extraction operations proposed for estuaries, e.g., Shubenacadie River, NS.

In a recent paper on emerging issues in the Gulf of Maine (Wells 2010), the list of current issues was long. They include (alphabetically): aquaculture impacts; coastal development and land use; hydrocarbon transport; coastal development in the GOM region; industrial chemicals and effluents; mining, including aggregate extraction from the bottom; nutrients, eutrophication, and algal toxins; sewage (organic loading, chemicals, pathogens); toxic chemicals, including pesticides; and the impacts of energy removal by tidal power projects. It is well known and documented that the Bay is exposed to a myriad of physical and chemical stressors on a daily basis (many refs, see the Fundy Information Collaboratory at www.bofep.org). Despite the large water and sediment volumes, and the twice daily flushing with large tides (up to 18 metres), the potential exists for effects caused by, or related to, these issues and other issues to occur, or for the contamination to become pollution. There is widespread industrial/toxic chemical contamination but relatively little evidence to date of pollution per se, e.g., adverse toxic effects in the Bay (Wells et al. 1997). However, there are some cases of pollution; they include the benthic effects of dredging spoils at the ocean disposal site (outer Saint John Harbor) (K.-L. Tay, Environment Canada, pers. comm.), historic impacts of pulp mill pollution on the L'Etang Estuary (D. J. Wildish, many papers), the widespread occurrence of imposex (a reproductive disorder) in marine gastropods (N. J. Prouse, unpubl. data), and the bioaccumulation of many compounds in mussels, marine mammals, and likely other animals in the food webs, such as trace compounds in mussels (Chase et al. 2001), mercury in the pelagic food web (Dalziel et al., this Proceedings) and pesticides in lobsters (Burridge, this Proceedings).

A major challenge is determining what the criteria are for health and ecosystem health for the Bay, and ensuring that appropriate physico-chemical, biological, and ecological indicators are monitored. In popular usage in the environmental context, health is a broad term referring to the state or condition of the ocean habitats and species, in this case the Bay of Fundy. The formal definition is freedom from or coping with disease, and having the capacity for maintaining organization or renewal, i.e., it is a measure of structure and functioning of the ecosystem under stress, in the short term (Wells 2003, 2005). If the Bay is healthy, species and ecological processes are present and functioning as expected, e.g., fish are present, feeding, growing, developing and reproducing, and species generally resident in the Northwest Atlantic are present. But present ecological conditions may be much different from baseline, original or pristine conditions (pre-European settlement), the comparison having to be made over many years, and referred to as changes in environmental quality, ecosystem health and ecological integrity, e.g., species diversity is diminished (e.g., some species are extinct or extirpated, such as sea lions), individuals are smaller (e.g., tuna, halibut), reproductive potential is diminished (e.g., smaller fish produce fewer eggs), and community structure is reduced, as has occurred on Georges Bank. The terminology and concepts were described by Wells (2003, 2005), among others, in an attempt to clarify the discussion of health and ecosystem health in the Bay of Fundy and Gulf of Maine.

One other useful model is that of health assessment, used by the medical fraternity and applicable to marine ecology and pollution studies. From medicine, the physician identifies symptoms; identifies and measures vital signs; makes a provisional diagnosis; conducts tests to verify diagnosis; makes a prognosis; and prescribes a treatment. In marine pollution studies, we make measurements in the field; identify unusual or unexpected conditions; monitor and investigate, including both laboratory and field approaches; interpret the data; and initiate management responses and additional monitoring. This approach is applicable to the Bay of Fundy and greater Gulf of Maine (Wells 2003, 2005).

Choosing appropriate indicators and conducting long-term monitoring programs plays a pivotal role in describing the health and ecosystem health of the Bay (Strain and MacDonald 2002; Wells et al. 2005; C. Tilburg, ESIP, pers. comm.). This paper is a brief description of some of the ongoing monitoring programs, leaving out the complex discussion of deciding what to measure in the short term, what to measure over the longer term, and how to decipher the data relative to marine environmental guidelines, objectives, and standards (see Wells 2005).

What Are We Currently Monitoring in the Bay of Fundy?

At the EMAN (Ecological Monitoring and Assessment Network) Workshop of February 2006, at least 30 programs were described for the Bay of Fundy, and some of these are mentioned below (see Hazel et al. 2006). On the current GOMC website, the GOM Monitoring Programs Summary lists 88 programs, run by government agencies and non-governmental groups. For the Bay of Fundy, both efforts supplement the summary made for the EMAN-BoFEP Monitoring Workshop in November 1997 (Burt and Wells 1998). The major programs circa 2006 include:

► **Fisheries and Oceans (DFO)**
  - AZMP (Atlantic Zonal Monitoring Program)
  - GoMOOS (Gulf of Maine Ocean Observing System)
  - CHS (Canadian Hydrographic Service)
  - HAB (Harmful Algal Blooms)
  - Rockweed monitoring
  - Benthic macrofaunal changes (mariculture)

► **DFO/EC/Canadian Food Inspection Agency (CFIA)**
  - MSSP (Maritime Shellfish Sanitation Program)

► **Environment Canada (EC)**
  - Chemical contaminants (Gulfwatch-mussels; seabirds)
  - Disposal at sea site monitoring
  - Air quality
  - Parks Canada Atlantic Coastal Monitoring programs
  - Canadian Wildlife Service wildlife programs
  - Seabird ecology and monitoring

The Canadian Wildlife Service (EC) programs include:

Habitat
  - Coastal Habitat Distribution and Abundance - National Wetlands Inventory - Satellite Remote Sensing of Aquatic Vegetation (1985 –)
  - Eelgrass Distribution and Abundance (1985 –)

Birds
  - Coastal Waterfowl Surveys (1960s –)
  - Eastern Waterfowl Survey (1988 –)
  - Harlequin Duck surveys (1990s –)
  - Maritimes Shorebird Surveys (1974 –)
  - Phalarope Surveys and Plankton tows (2002 –)
  - Piping Plover banding (1990 –)
  - Salt Marsh Bird Surveys (2000–02)
  - Shorebird Banding (1981–2004)
  - Tern and Gull surveys (1966 –)

► **The community-led programs include:**
- Atlantic Coastal Action Program (ACAP, developed in partnership with EC in all Atlantic Provinces)
  - e.g., ACAP Saint John (NB), Bluenose (Bluenose Coastal Action Foundation), Clean Annapolis River Project (NS), Eastern Charlotte Waterways Inc. (NB)
- Ecology Action Center (EAC) salt marsh restoration study (NS)
- Clean Nova Scotia
- Bird Studies (Canada)

► **An example of industry led monitoring is:**
- The Magaguadavic River Wild and Escaped Farmed Atlantic Salmon Monitoring Program
  - Operated by Atlantic Salmon Federation since 1992
  - Runs from April to November each year
  - Enumerates nos. of wild and escaped farmed salmon entering the rivers of western Fundy
  - Screens fish for sea lice burden
  - Screens for viral and bacterial pathogens (DFO)
  - Also includes a census of the annual gaspereau run

The data and information produced from these programs can be found with Google and WAVE searches, e.g., Gulfwatch mussel data, 1993–2008, are on the Gulf of Maine Council's website, www.gulfofmaine.org. There are dozens of programs, covering a range of species, habitats, and biological processes. To date, unfortunately, there has been no attempt to summarize the data on all of these programs and give a definitive, multi-parametric statement of the Bay's health. Rather, there have been exemplary individual efforts such as that of Hargrave et al. (2005), to describe the environmental effects of the salmon aquaculture industry, and Dalziel et al. (this Proceedings) to describe mercury in the Bay's food chain. More efforts such as these are needed.

What Does this Monitoring Tell Us About the Health of the Bay of Fundy?

A number of messages are clear from the various monitoring programs underway. The linkages between land based activities and coastal health are "real"—we must monitor the watersheds and estuaries, as well as coastal waters. The Bay's ecosystem is functioning but its integrity has changed and declined, largely through the removal of species or species biomass, the transformation of most salt marshes to agricultural land, and the physical blocking of many water bodies with dams and other barriers (many refs). Biodiversity has been reduced; some species are at risk, e.g., Atlantic salmon, sturgeon, American shad, sea cucumbers, phalaropes. Some habitats have undergone marked changes and reduction, e.g., wetlands such as salt marshes. The ecosystem is exposed to a wide range of chemicals, with some effects, e.g., imposex, bioaccumulation in tissues. Cumulative change of the whole ecosystem is not fully understood nor described comprehensively, a prerequisite to appropriate regulatory use of the monitoring data, and the deployment of precautionary measures to prevent further degradation.

What Else Is Needed? – Recommendations

Numerous monitoring needs remain for the Bay of Fundy. The established longer-term monitoring programs of various waters, species and habitats, such as Gulfwatch and others as listed above, need to be maintained and resourced. The longer term monitoring programs need to use a standard set of indicators for priority issues, achieved through consensus as in ESIP of the GOMC (C. Tilburg, ESIP, pers. comm.). We need to progress from reporting on the status of multiple single indicators to reporting on the Bay's health using one or more comprehensive indices, as with the stock market (Figure 1). A more complete set of marine environmental (water, sediment, tissue) quality guidelines to interpret monitoring data on water, sediments and biota is needed urgently, using mechanisms such as the Canadian Council of Ministers of the Enviroment (CCME); this was strongly recommended by Arthur Hanson in his keynote talk at the 2004 BoFEP Bay of Fundy Science Workshop (Hanson 2005, in Percy et al. 2005).

A series of State of the Bay of Fundy/Gulf of Maine reports, prepared by a full range of stakeholders using current monitoring data, should get underway more quickly, as directed at the 2004 Gulf of Maine Summit and 2009 Regional Association for Research on the Gulf of Maine (RARGOM) GOM conference. These have started as of June 2010 as theme papers under GOMC sponsorship, and are on the web (www.gulfofmaine.org/state); they may eventually contribute to a full synthesis report. Finally, following from the example of the University of New Hampshire workshops in December 2002 and January 2004, monitoring specialists and environmental scientists should engage more frequently to exchange information and to have formal discussions with policy and decision makers in government and industry responsible for preventing and controlling pollution and maintaining the health of the Bay of Fundy and the greater Gulf of Maine.

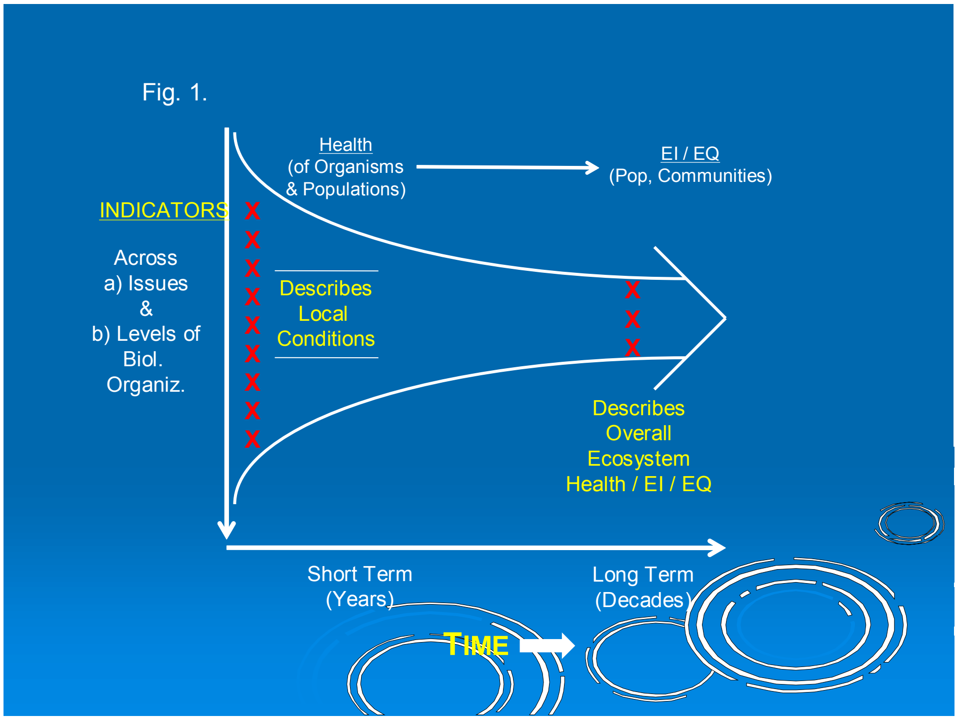

Figure 1. A hypothetical view of what is required for monitoring the health and ecological integrity of the Bay of Fundy. The numbers of environmental indicators change with the monitoring objectives, and over time and space. For describing local conditions in the short term (months to years), many specific or unique measures of the ecosystem are required, obtained by monitoring individual organisms or their populations (as done by local community groups). In the longer term (years to decades), monitoring the greater Bay of Fundy requires a few key indicators (as resolved by the ESIP program and used by government agencies), preferably expressed collectively as one or more indices of the ecosystem health or ecological integrity of the entire bay. Some of the key indicators may be the same as used for shorter time monitoring, but institutionally will be deployed over long time periods to produce the data required to analyse for trends.

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POLLUTANTS IN RIVER RUN-OFF FROM FOREST SPRAYING AND EFFECTS ON ATLANTIC SALMON

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Extended Abstract

Forest spraying with pesticides is conducted primarily to manage damage from insect pests and to slow down unwanted vegetation. Vegetation is managed with herbicides as part of regular forest management plans and tends to be predictable, and usually coincides with areas of recent harvest. Insect pests, on the other hand, tend to explode onto the scene in sometimes epidemic proportions, after years at low population numbers (Armstrong and Ives 1995; Carter et al. 2009). Insects choose their own preferred areas of forest to attack, without consulting our forest management plans. At the peak of the last spruce budworm outbreak, around 1975, the forest insecticide treatments in the Atlantic provinces looked more like a military operation than peacetime pest control. We were at war with the spruce budworm over the standing timber resource (Armstrong and Ives 1995).

During this time one of the insecticide formulations sprayed, called Matacil 1.8D, had the insecticide aminocarb as the active ingredient and also had an "inert" chemical called 4-nonylphenol in it (NRCC 1982). The application of this insecticide formulation over many forest areas of the Atlantic provinces for more than a decade has provided a real world example of how contaminants can subtly affect wild fish populations, particularly the Atlantic salmon. Over four years at the peak of spraying from 1976 to 1979, around 2 million hectares were sprayed annually in eastern Canada (Fairchild et al. 1999). Concerns over direct toxicity of 4-nonylphenol to salmon and other aquatic organisms convinced New Brunswick to stop spraying the insecticide formulation containing 4-nonylphenol in 1981 (McLeese et al. 1981). Other jurisdictions in Eastern Canada continued to spray the 4-nonylphenol formulation (Fairchild et al. 1999).

During the mid-1990s, research with trout in the United Kingdom was pointing to the possible estrogenic nature (behaving like the female hormone estrogen) and effects of 4-nonylphenol (Jobling et al. 1996). Using this observation as a starting point, the times and areas where the forest was sprayed with 4-nonylphenol were assessed for potential effects on Atlantic salmon populations. The information available revealed three levels of significant relationship between the spraying of 4-nonylphenol and reductions in the catch of Atlantic salmon at the appropriate later date. The apparent stage of effect was the smolt stage, when salmon run from fresh water to salt water (Fairchild et al. 1999). The latter part of the smolt stage coincided with the timing of forest spraying for the spruce budworm, between about mid May to mid June.

How this came to be for salmon we now think we understand better. Laboratory tests confirmed that salmon smolts were sensitive to 4-nonylphenol at very low concentrations lasting for only two 24-hr pulses five days

apart. We were able to show effects, including reduced growth in sea water, months after the exposures had taken place in fresh water (Arsenault et al. 2004). Further to this we undertook open ocean experiments where salmon smolts exposed to low concentrations of 4-nonylphenol in fresh water were released to the North Atlantic from Ireland, and their rate of return as adults assessed. Smolts exposed to 4-nonylphenol returned to the coast in lower numbers than other treatments and controls (unpublished results). Taken together, these results suggest a strong relationship between the presence of 4-nonylphenol in salmon rivers and the subsequent decline in adult salmon populations as measured by-catch data (Brown and Fairchild 2003). Adding weight to the argument is another species that seems to have been affected in a similar way during the same time period. Blueback herring (part of the gaspereau fishery) had a decline in catch that was also predicted by the timing of a prior large 4-nonylphenol exposure in the Miramichi River system (Fairchild et al. 1999).

We should be able to apply these lessons to other contaminants and the aquatic environment. The effects on salmon with the benefit of hindsight are quite evident when the right question is asked. There are, however, very few situations that allow the kind of analysis that was undertaken with salmon to make the case. Information is often not available or maintained in a consistent enough manner to be useful. Concerns over the potential contribution of pesticides to the decline or recovery of salmon populations have been expressed on both coasts of the United States of America and include suggested regulatory changes (NOAA and US Fish and Wildlife Service 2005; NOAA 2008, 2009).

Will we have a better track record when the next forest insect pest epidemic brings the spray planes out again? It is unlikely that industry will ever again be permitted to spray large quantities of a compound like 4-nonylphenol in future forest spray programs. Environmental regulation changes and public concern for the environment has led to the use of less toxic and less persistent insecticides (e.g., Bt) and to insecticides directed at narrower groups of animals (insect hormone disruptors). However the potential for subtle effects from chemical exposures to go unnoticed remains, and the diverse modes of action of pesticides currently in use may yet teach us lessons on how closely related some organisms are to our pest insect targets.

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IMPACTS OF MIXTURES OF POLLUTANTS IN RIVER RUN-OFF FROM AGRICULTURAL PRACTICES

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Extended Abstract

Aquatic organisms are routinely exposed to pesticides because these compounds are widely used and are regularly detected in stream biomonitoring. The presence of mixtures of insecticides is particularly troublesome since these compounds can directly alter the abundance and diversity of aquatic invertebrates, which are valuable as food for fish and as consumers of algae. Since reduced abundance and variety of taxa can alter important relationships between organisms, how to incorporate the increased complexity of mixtures into impact assessments needs to be addressed urgently. Assessing the effects of mixtures of organophosphorus (O-P) insecticides are particularly relevant because they are extensively used in worldwide agriculture and constitute roughly 70 percent of the insecticide load applied in North America. We have selected two O-P insecticides to examine in detail, both of which are among the top ten most commonly used: chlorpyrifos and dimethoate. Our findings suggest that different members of the aquatic community respond differently to the two insecticides either when applied singly or jointly and furthermore that the two insecticides are not equally toxic. The implications of mixtures containing pesticides of different potency will be discussed.

Chlorpyrifos and dimethoate are insecticides that are used in the protection of a vast array of cash crops including apples, potatoes, tomatoes, and various berries. These two insecticides are designed to eliminate pest insects that feed, burrow or otherwise damage crops and are generally thought to be highly effective. The mechanism by which these insecticides eradicate pests is by binding the protein, in this case an enzyme, that mops up the important neurochemical, acetylcholine. Acetylcholine is responsible for sending signals between neurons in the brain—the chemical equivalent of the wiring of a telephone system. Organophosphorus insecticides such as chlorpyrifos and dimethoate prevent the mopping-up of acetylcholine and therefore continuous signals are sent, which in insects generally results in uncontrolled muscle firing (tremors) that prevent effective movement and breathing. This mechanism is the primary means of killing pest species, in scientific jargon the “primary mode of action”.

Interestingly, different species may be more or less susceptible to treatment with pesticides. Susceptibility has been best studied in cockroaches and mosquitoes, both of which have developed resistant strains in response to the use of chemical agents like insecticides. How this occurs is of particular interest. In aquatic insects, many of whom are old lineages, where effects do or do not occur can be very informative about the patterns of susceptibility and/or sensitivity within and between different taxa. Sensitivity differences between taxa are also important because linkages between species, such as predators and their prey, can reduce the numbers of other insects and the general quality of an aquatic habitat. In this study, we have found that insect predators (like stoneflies) were more affected by insecticide treatment than other groups of insects and that the loss of predators resulted in a cascade effect on other species.

Comparing the effectiveness of insecticides in mixtures is a cutting edge approach to environmental toxicology because most of the existing test data (pre 2005) has generally used single compounds (e.g., one insecticide) and has also generally only used single, laboratory-reared species. Although this work has been meaningful and useful, research needs to move towards more relevant mixtures of synthetic chemicals and/or natural compounds and more realistic species compositions. What has become quickly apparent in our own studies is that moving to more realistic scenarios will be increasingly difficult. Even in this study, which examined a relatively simple, two-insecticide mixture, we have found that neither the doses nor the responses can be "added-up". Specifically, we have found that mixtures of even similar compounds exhibit dose-dependent effects. This means that whether the mixture is more or less toxic than we would expect from single-insecticide toxicity data will depend on the dose. Our research to date suggests that low doses of chlorpyrifos and dimethoate mixtures are less toxic than we would expect (antagonistic) and that higher doses of chlorpyrifos and dimethoate are more toxic than we would expect (synergistic). This finding alone suggests several more questions, such as: (1) at what point does antagonism become synergy? (2) is the cross-over point the same within and between species or regions? (3) will more complex mixtures share these patterns? We are only beginning to have answers to many of these questions; a great deal more research will be needed to address them fully.

We also found in our study of the effects of mixtures of chlorpyrifos and dimethoate that the two different insecticides were not equally potent. In particular, dimethoate was much less toxic, even at high doses, than chlorpyrifos. In some insect groups, treatment with dimethoate actually increased the abundance of some species (e.g., collector-gatherers, like chironomids). This suggests that dimethoate will be ineffective in the management of some pest species and furthermore that, in mixture, dimethoate may reduce the effectiveness of other insecticide compounds. Chlorpyrifos, on the other hand, did the opposite causing dramatic reductions in some groups (e.g., scrapers, like mayflies). It seems likely that mixtures of compounds that are variable in their toxicity may promote resistance in pests, which clearly has implications for managers and researchers.

This study has determined that our current understanding of the effects (and effectiveness) of a simple, two organophosphorus insecticide mixture is insufficient to make accurate predictions in a controlled setting such as an artificial stream. Our ability to make relevant predictions in real ecosystems is questionable. Since impacts from mixtures of pesticides are prevalent and widespread, the need for a better understanding of these patterns becomes urgent.

MERCURY IN THE BAY OF FUNDY, GULF OF MAINE

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Extended Abstract

A major goal of our Bay of Fundy study was to prepare an annual budget of mercury flux for the Bay of Fundy. We knew, from earlier work on the sediments (Loring 1978), that the Bay was a relatively pristine environment which would enable us to interpret mercury levels in a coastal ecosystem without interference from major industrial or urban contamination. To achieve this, we considered the atmospheric and oceanic flux to the Bay with both our observations and the work of others.

The atmospheric input is calculated both directly on an areal basis and indirectly through river runoff. The later also includes mercury leached from the soil and bedrock. The National Atmospheric Deposition Program-Mercury Deposition Network (NADP-MDN) provided mercury and methyl mercury wet deposition concentrations at the St. Andrews, NB (mercury only) and Kejimikujik, NS sites (Figure 1 red dots; Table 1). Eight weather stations were chosen from around the Bay to estimate best the rainfall over the entire bay (Figure 1 blue dots). The surface area of the Bay of Fundy was estimated electronically at 13,860 km^2 (Stan Johnston, DFO, pers. comm.). Rainfall was averaged for each season to enable a calculation of a total deposition on the surface waters of the Bay of 104 kg total mercury, of which 4.4 kg was methyl mercury (Table 1). The calculation of gaseous mercury evasion from the Bay of Fundy was based on an average application of experimental results from Halifax Harbour of 85 kg/yr (Steve Beauchamp, EC, pers. comm.) and 107 kg/yr from a Canada-wide marine study (Richardson et al. 2003).

Riverine input was measured at ten locations around the Bay in the fall of 2001 and the spring of 2002 to measure mercury levels at times of low and high runoff (Figure 2). Mercury levels in river water were low at <4 ng/L, with the exception of the Salmon and Shubenacadie rivers (Table 2).

The latter rivers had higher mercury levels during low fall runoff of 9.9 and 14.6 ng/L, respectively. The Saint John and Petitcodiac Rivers with their association with the larger urban and industrial centers of Saint John and Moncton, respectively, would be expected to have higher metal values. However, the higher mercury levels measured in the adjacent Salmon and Shubenacadie rivers are probably natural and related to the weathering of similar bedrock.

The average mercury and methyl mercury in river water (Table 2) were used to calculate the annual riverine input, given the estimated river flow into the Bay of Fundy of 0.85x10^{10} m^3/yr from Nova Scotia and 3.44x10^{10} m^3/yr from New Brunswick (McAdie 1994), which results in a combined flux of 185.3 kg THg/yr and 9.39 kg MeHg/yr.

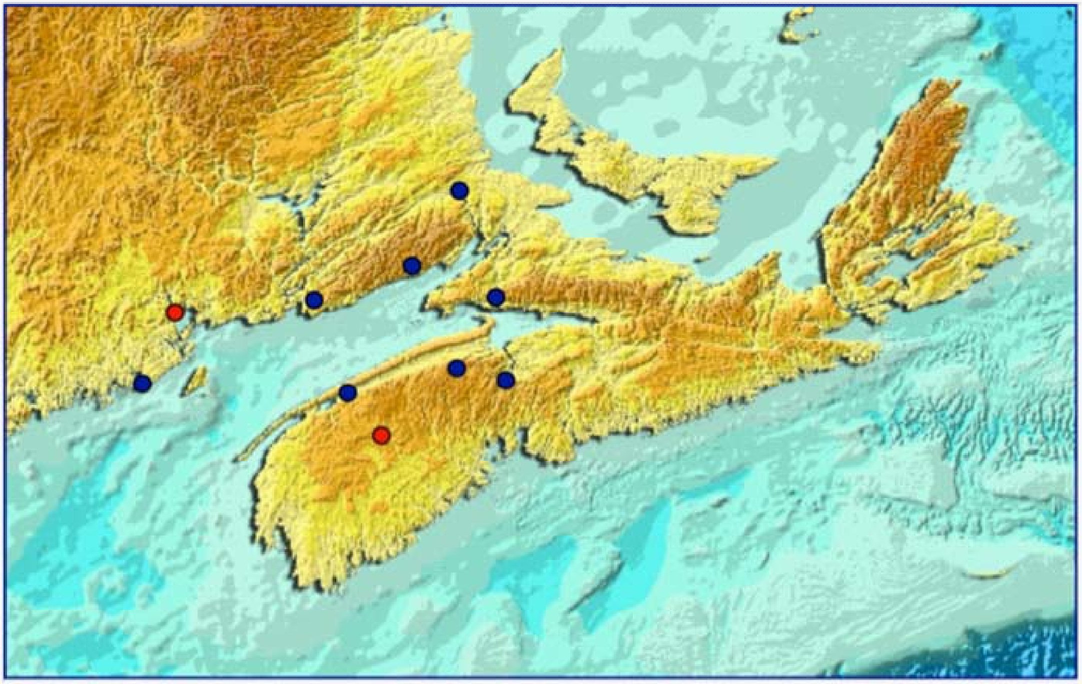
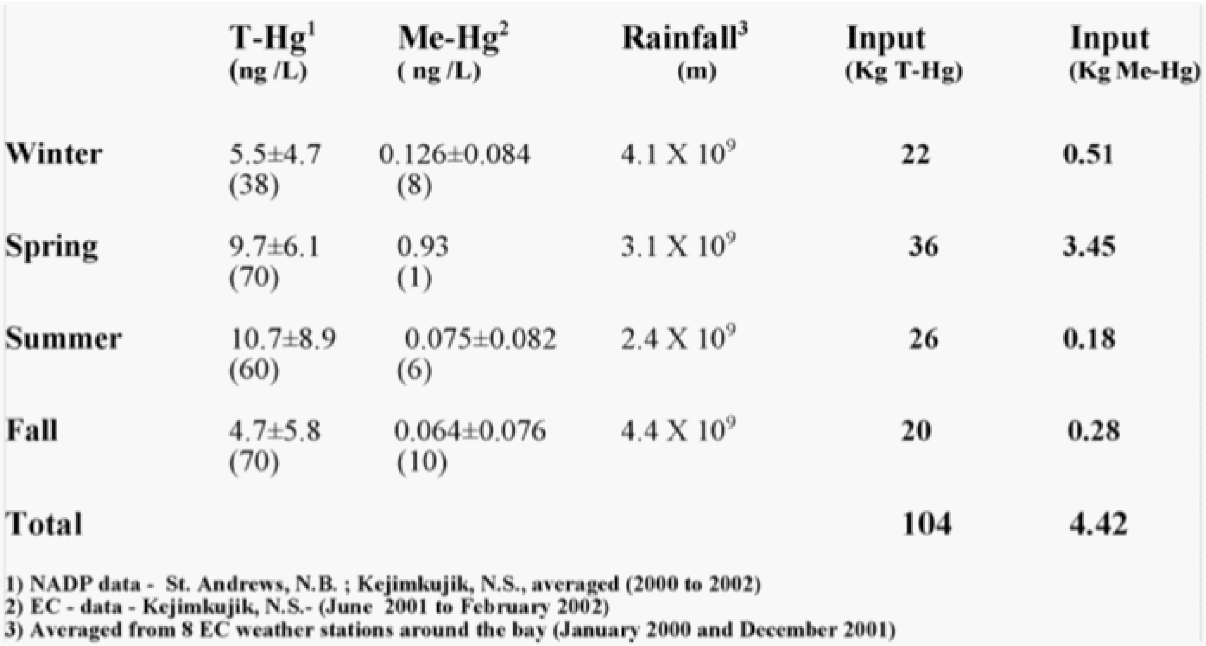


Figure 1. NADP-MDN mercury deposition sites at St. Andrews, NB, and Keji, NS, and eight Environment Canada rainfall sites used to calculate total deposition.

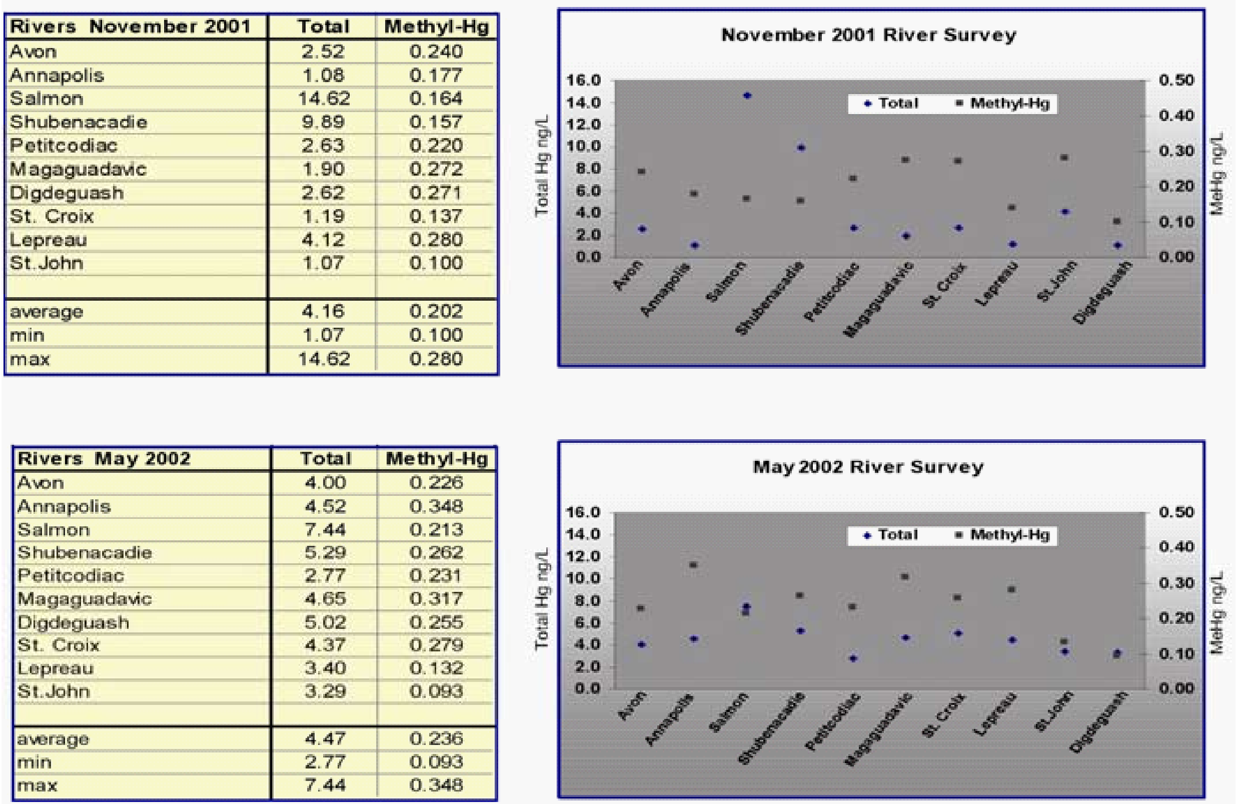
Figure 2. Total mercury and methy mercury were measured in the fall (2001) and spring (2002) from ten rivers draining into the Bay of Fundy.



	T-Hg[1] (ng /L)	Me-Hg[2] (ng /L)	Rainfall[3] (m)	Input (Kg T-Hg)	Input (Kg Me-Hg)
Winter	5.5±4.7 (38)	0.126±0.084 (8)	4.1 X 10⁹	**22**	**0.51**
Spring	9.7±6.1 (70)	0.93 (1)	3.1 X 10⁹	**36**	**3.45**
Summer	10.7±8.9 (60)	0.075±0.082 (6)	2.4 X 10⁹	**26**	**0.18**
Fall	4.7±5.8 (70)	0.064±0.076 (10)	4.4 X 10⁹	**20**	**0.28**
Total				**104**	**4.42**

1) NADP data - St. Andrews, N.B. ; Kejimkujik, N.S., averaged (2000 to 2002)
2) EC - data - Kejimkujik, N.S.- (June 2001 to February 2002)
3) Averaged from 8 EC weather stations around the bay (January 2000 and December 2001)

Table 1. Average mercury precipitation by season, Bay of Fundy.



Rivers November 2001	Total	Methyl-Hg
Avon	2.52	0.240
Annapolis	1.08	0.177
Salmon	14.62	0.164
Shubenacadie	9.89	0.157
Petitcodiac	2.63	0.220
Magaguadavic	1.90	0.272
Digdeguash	2.62	0.271
St. Croix	1.19	0.137
Lepreau	4.12	0.280
St.John	1.07	0.100
average	4.16	0.202
min	1.07	0.100
max	14.62	0.280

Rivers May 2002	Total	Methyl-Hg
Avon	4.00	0.226
Annapolis	4.52	0.348
Salmon	7.44	0.213
Shubenacadie	5.29	0.262
Petitcodiac	2.77	0.231
Magaguadavic	4.65	0.317
Digdeguash	5.02	0.255
St. Croix	4.37	0.279
Lepreau	3.40	0.132
St.John	3.29	0.093
average	4.47	0.236
min	2.77	0.093
max	7.44	0.348

Table 2. Total and methyl mercury in river water (all concentrations in ng/L).

Seawater was collected at standard depths at five sites in June 2001 and August 2002 (Figure 3). These locations were chosen to determine the flux of mercury with oceanic water movements (Ken Drinkwater, pers. comm.). Significant differences ($P<0.05$) were not detected in seawater concentrations between either depths or years (Kruskal-Wallis or independent t-tests). Total mercury and methyl mercury concentrations were 237±74pg/L and 58±22pg/L, respectively. The tidal flux and the residual flows via surface and deep currents were calculated with the Scotian Shelf and Gulf of Maine 3-D, non-linear numerical circulation model (see Figure 4; Hannah et al. 2001). However, given the homogeneity of mercury concentrations in the water column, both horizontally and seasonally, there is no net flux into or out of the Bay of mercury via ocean currents. The tidal flux into and out of the Bay was estimated to be $5.8\text{x}10^{12}$ m^3yr^{-1}, and together with the average surface concentration of methyl mercury (0.062 ug m^{-3}) and total mercury (0.204 ug m^{-3}), results in a balanced tidal flux into and out of the Bay of 358 and 1179 kg/yr, respectively. Similarly, the residual surface flow into the east side of the Bay is balanced by the ~$3.0\text{x}10^{12}$ m^3yr^{-1} outflow on the Grand Manan side of the bay resulting in a flux of 186 kg MeHg/yr and 612 kg THg/yr. A comparable deepwater flux is predicted in the Northeast Channel with a flux of $3.0\text{x}10^{12}$ m^3yr^{-1} in and out of the Bay, together with deepwater methyl mercury (0.067 ug m^{-3}), and mercury (0.237 ug m^3) concentrations, resulting in a 201 Kg MeHg/yr and 711 kg THg/yr flux.

Plankton and nekton size categories were collected on the mouth of the Bay in 2000, 2001, and 2002 (Figure 5). Planktonic organisms were fractionated into seven logarithmic size categories from phytoplankton and flagellates (25 to 65 µm) to macrozooplankton (2 to 4 mm) and pelagic organisms were size fractionated into a further three fractions from ichthyoplankton and krill (4 to 8 mm) to small fish and shrimp (16 to 32 mm) (Table 3). The planktonic, and to some extent the nektonic, categories were assumed to be transported with the tidal movement and residual currents described above. Given a plankton/nekton concentration of 2.5, 1.5 and 1.0 ng THg/m^3 for tidal, surface, and deep residual flow, from our understanding about the preferred depth of each size category, yields a flux calculation of 14.6, 4.5, and 3 kg/yr, respectively.

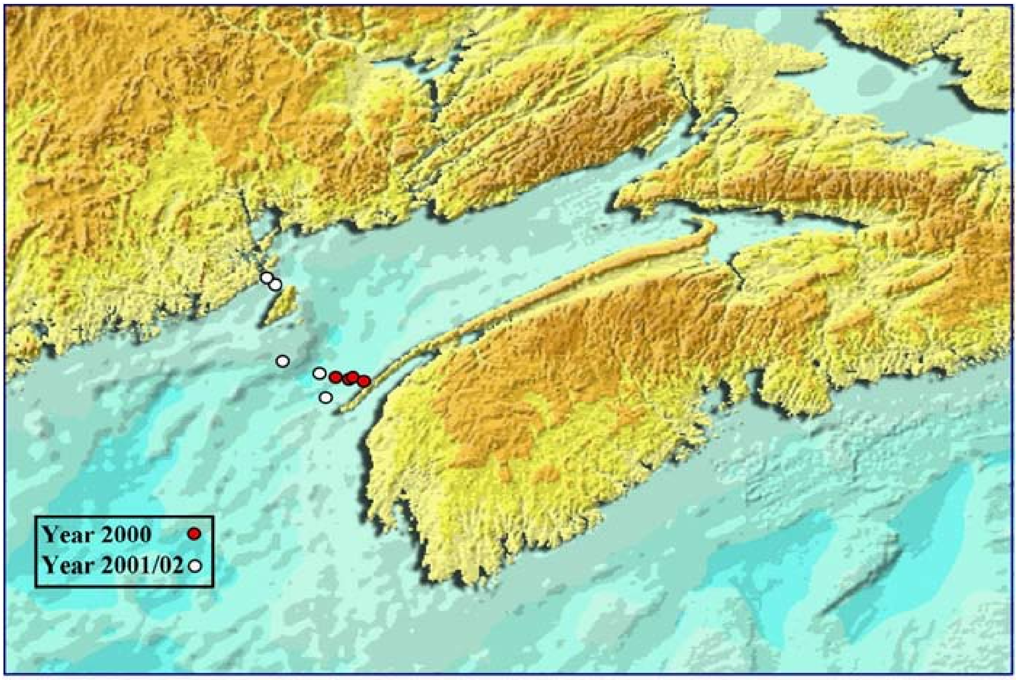


Figure 3. Seawater sampling sites from 2000, 2001, and 2002 for total and methyl mercury.

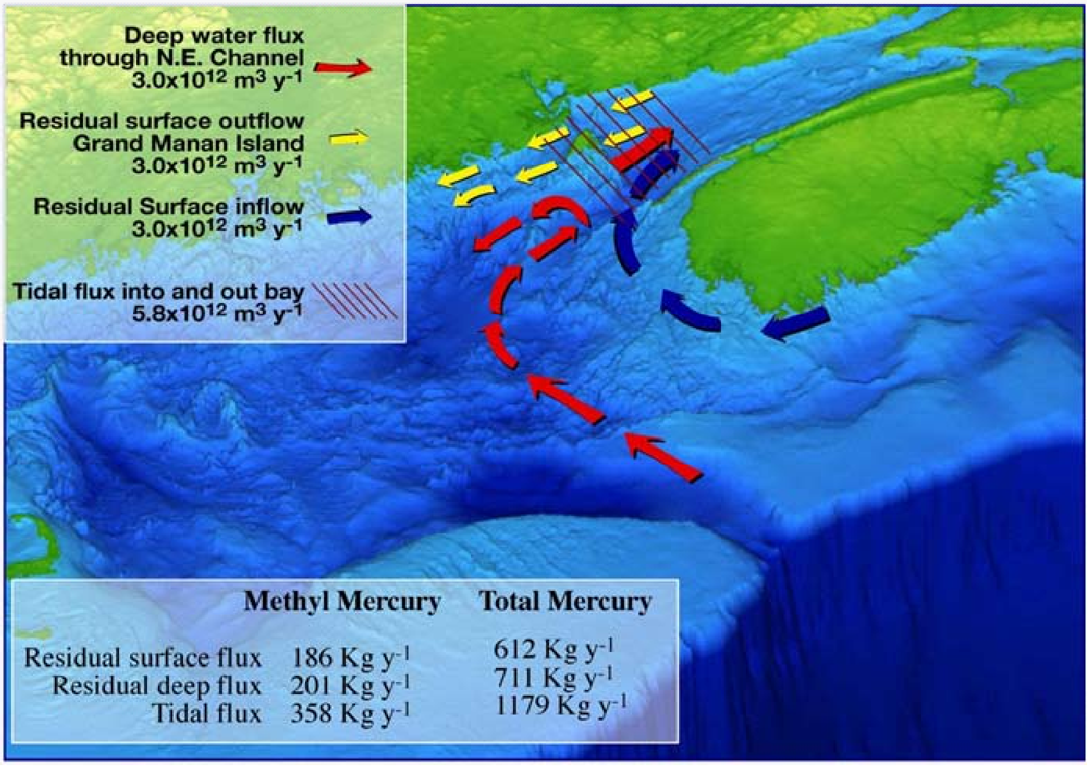


Figure 4. Ocean current regime in the Bay of Fundy.

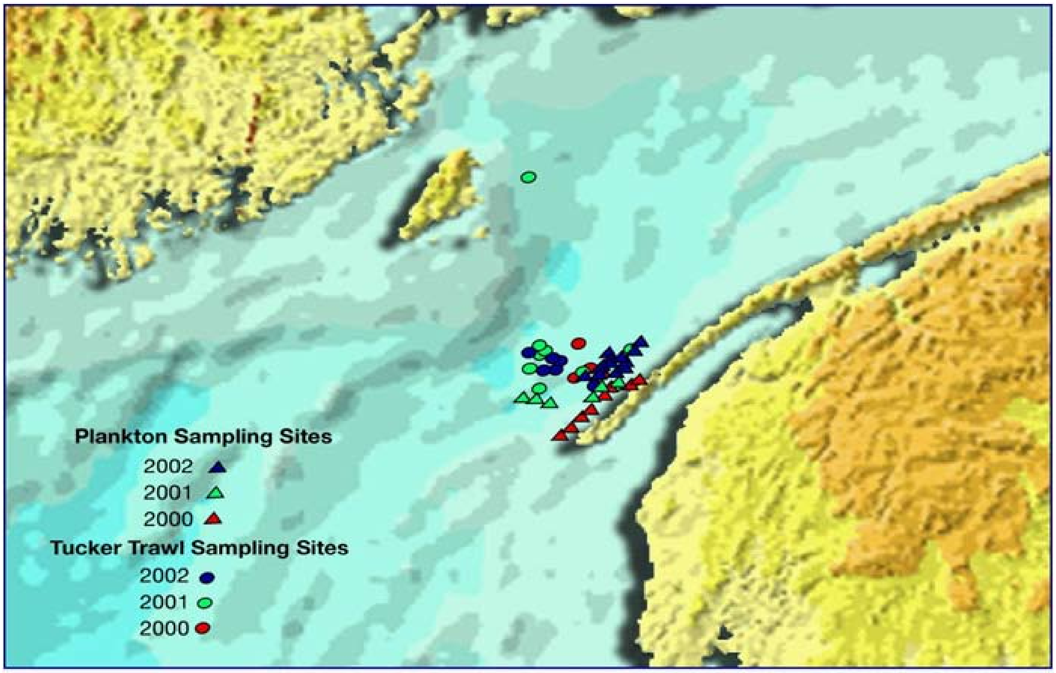


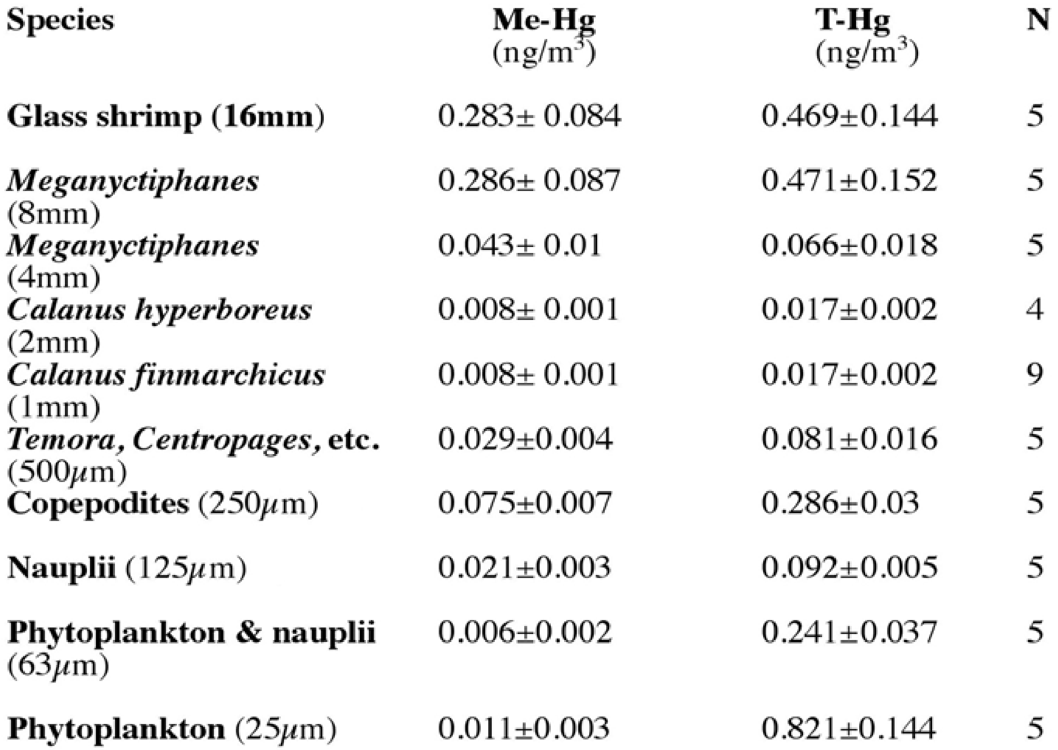
Figure 5. Planktonic sampling sites from 2000, 2001, and 2002 for total and methyl mercury.

Bottom samples were taken with a Van Veen grab at locations within the sedimentary basin north and east of Grand Manan over the three years of this study. This is basically the only deep deposition basin in the Bay. A sedimentation rate calculated from ten Pb^{210} estimates in the Grand Manan Basin, yielded 0.144±0.078 g dry/cm^2 (John Smith, BIO, unpub. ms). This deep depositional region has been estimated from earlier bottom surveys to be ~$2.5X10^9$ m^2 in area (Pelletier and McMullen 1972). The present mercury measurements of 16.8±6.2 ngTHg/g dry in Grand Manan Basin sediments enable us to calculate a total annual deposition of ~60 kg/yr.

Other authors have emphasized the importance of salt marshes as a deposition area for particulates in the Bay of Fundy (Gordon et al. 1985; Chmura et al. 2001). Sediment studies suggest that the head of the Bay is a major depository for sediment derived from seabed and cliff erosion and river runoff (Amos and Tee 1989). Hung and Chmura (2006) have estimated the addition of mercury in salt marsh sediments of the Bay of Fundy at 170 ± 93 kg/yr.

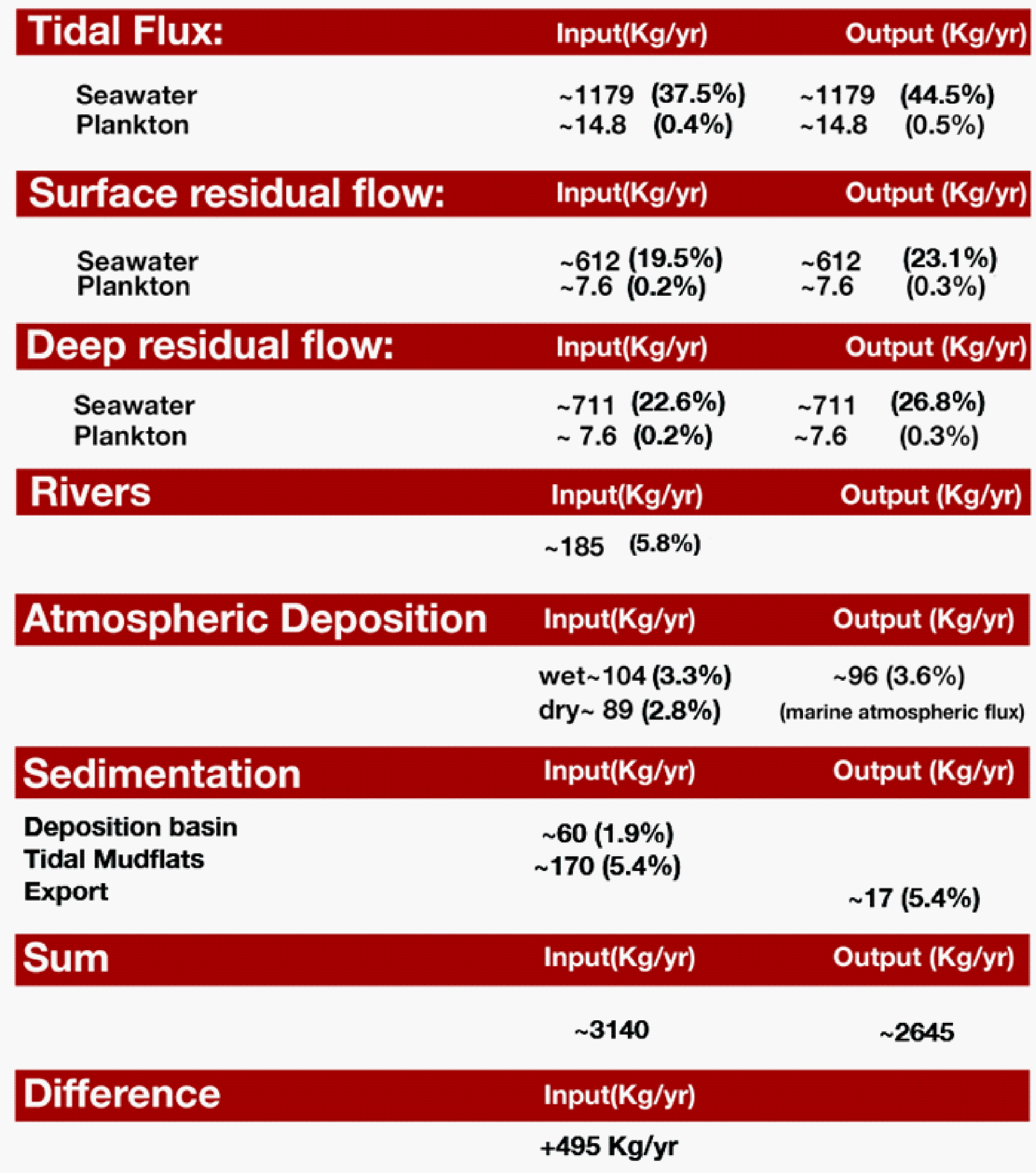
Swift et al. (1973) has estimated that 10^6 mt of sediment leaves the Bay each year. This represents a loss of 17 kg/yr with our estimate of 16.8 ng THg/g in sedimentary material.

This preliminary tabulation of the various inputs and outputs of mercury in the Bay of Fundy as a budget suggests that the Bay is acting as a sink for mercury in the long term. However, most of this input is being incorporated into the sediments, both in the Grand Manan Basin and the tidal flats. Over 80 percent of the flux of mercury is back and forth between the Bay of Fundy and Gulf of Maine. A more sophisticated modeling of mercury dynamics is underway which will incorporate the flux of mercury into and out of the sediments. Our results support earlier studies that indicate that the Bay of Fundy is a relatively uncontaminated bay for mercury.



Species	**Me-Hg** (ng/m³)	**T-Hg** (ng/m³)	**N**
Glass shrimp (16mm)	0.283± 0.084	0.469±0.144	5
Meganyctiphanes (8mm)	0.286± 0.087	0.471±0.152	5
Meganyctiphanes (4mm)	0.043± 0.01	0.066±0.018	5
Calanus hyperboreus (2mm)	0.008± 0.001	0.017±0.002	4
Calanus finmarchicus (1mm)	0.008± 0.001	0.017±0.002	9
***Temora, Centropages,* etc.** (500μm)	0.029±0.004	0.081±0.016	5
Copepodites (250μm)	0.075±0.007	0.286±0.03	5
Nauplii (125μm)	0.021±0.003	0.092±0.005	5
Phytoplankton & nauplii (63μm)	0.006±0.002	0.241±0.037	5
Phytoplankton (25μm)	0.011±0.003	0.821±0.144	5

Table 3. Planktonic mercury content at the mouth of the Bay of Fundy.



Tidal Flux:	**Input(Kg/yr)**	**Output (Kg/yr)**
Seawater	~1179 (37.5%)	~1179 (44.5%)
Plankton	~14.8 (0.4%)	~14.8 (0.5%)
Surface residual flow:	**Input(Kg/yr)**	**Output (Kg/yr)**
Seawater	~612 (19.5%)	~612 (23.1%)
Plankton	~7.6 (0.2%)	~7.6 (0.3%)
Deep residual flow:	**Input(Kg/yr)**	**Output (Kg/yr)**
Seawater	~711 (22.6%)	~711 (26.8%)
Plankton	~ 7.6 (0.2%)	~7.6 (0.3%)
Rivers	**Input(Kg/yr)**	**Output (Kg/yr)**
	~185 (5.8%)	
Atmospheric Deposition	**Input(Kg/yr)**	**Output (Kg/yr)**
	wet~104 (3.3%) dry~ 89 (2.8%)	~96 (3.6%) (marine atmospheric flux)
Sedimentation	**Input(Kg/yr)**	**Output (Kg/yr)**
Deposition basin	~60 (1.9%)	
Tidal Mudflats	~170 (5.4%)	
Export		~17 (5.4%)
Sum	**Input(Kg/yr)**	**Output (Kg/yr)**
	~3140	~2645
Difference	**Input(Kg/yr)**	
	+495 Kg/yr	

Table 4. Budget for total mercury in the Bay of Fundy.

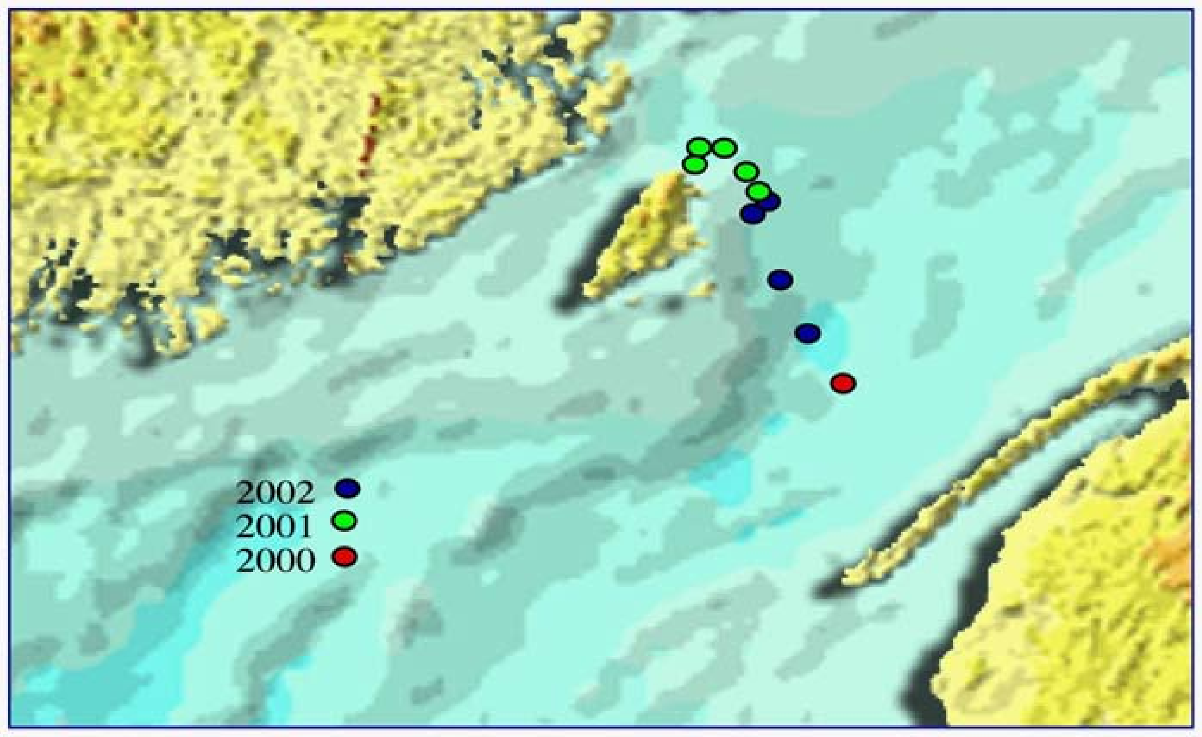


Figure 6. Sediment sampling sites for 2000, 2001, and 2002 for total and methyl mercury.

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John Dalziel is shown collecting seawater,
Peter Vass collecting plankton,
Gareth Harding size sorting plankton, and
Elsie Sunderland sampling sediment on deck.

SOME ORGANIC POLLUTANTS AND THEIR POTENTIAL EFFECTS

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Extended Abstract

This presentation deals with three groups of industrial chemicals (Table 1). They contain chlorine, bromine, or fluorine, which gives them stability at elevated temperatures and inflammability.

With the exception of dibenzo-p-dioxins/furans (PCDD/F), all were developed for specific purposes: polychlorinated biphenyls (PCB) and polybrominated biphenyls (PBB) primarily for stable heat transfer media; terphenyls (PCT), paraffins (CP), and naphthalenes (PCN) for plasticizers, flame retardants, lube oil additives etc.; and dechloranes, diphenyl ethers (PBDE), diphenyl ethanes (PBDEt), and hexabromocyclododecanes (HBCD) as flame retardants. Fluorinated compounds are present in a great variety of products ranging from Teflon to Scotchgard™ to pizza boxes. The toxicity of PCN and PCB was recognized within a few years of their introduction into commerce, but apparently soon forgotten.

Concentrations of contaminants in fish are usually presented in ng (nanograms) per gram fresh weight or per gram of lipid. A nanogram is one billionth of a gram. When needed, a thousand times smaller unit, a pg (picogram) per g is used. Another unit, TEQ (toxic equivalent) in pg per g is used increasingly for TCDD/F, PCB, and, rarely, for PCN. This unit is based on the toxic potency TCDD (2,3,7,8-tetrachlorodibenzodioxin), whose toxic equivalence factor (TEF) is set at 1.00 (Table 2). TEQ = TEF times concentration.

The TEFs of PCB and PCN are much smaller than those of PCDD/F. However, since PCB are present in much higher concentrations than PCDD/F, their TEQs approach those of PCDD/F (Table 3).

			In BoF
Chlorinated	biphenyls	PCB	Y
	dibenzo-p-dioxins/furans	PCDD/F	Y
	paraffins	CP	likely
	dechloranes		?
	terphenyls	PCT	Y
	naphthalenes	PCN	?
Brominated	biphenyls	PBB	?
	diphenyl ethers	PBDE	Y
	diphenyl ethane	PBDEt	Y
	hexabromocyclododecanes	HBCD	Y
Fluorinated	aliphatic acid		likely
	aliphatic sulfates		likely

Table 1. Chemicals discussed in this presentation.

Chemical	**TEF**
2,3,7,8-TCDD	1.0000
1,2,3,7,8-PeCDD	1.0000
2,3,4,7,8-PeCDF	0.3000
1,2,3,7,8-PeCDF	0.0300
3,3',4,4',5-pentaCB PCB126	0.1000
3,3',4,4',5,5'-hexaCB PCB169	0.0300
1,2,3,4,6,7-hxCN	0.0006
1,2,3,4,5,6,7-hpCN	0.0005

Table 2. Examples of toxic equivalence factors (TEF).

				TEQ, pg/g fw		
Species	**Mean Age**	**Mean wt, g**	**Fat %**	**PCB**	**TCDD/F**	**Total**
Herring	5.8	72.9	8.98	4.75	7.49	12.24
Salmon	1.6	5338	4.69	6.07	4.30	10.37
Eel	13.2	535	17.8	3.85	0.87	4.72

Table 3. Concentrations of PCB and TCDD/F in pgTEQ/gram fresh weight, in different species (data from Sweden).

PCB were found in herring, mackerel, and other fish from the Bay of Fundy years ago, but, with the exception of mussels, there does not appear to be any systematic monitoring of the Table 1 chemicals. Some time ago, CP were found in antifouling paints in salmon hatcheries, PCT in eggs and tissues of herring gulls, BDE in sediments (BDE 209 also in fiberglass tanks at the St. Andrews Biological Station), PBDEt in sludge of sewage treatment plants, and HBCD in polystyrene floats used in aquaculture. In my opinion, except for the Great Lakes, Canada is far behind other countries in long-term monitoring of these chemicals in the aquatic environment. Even simple measurements, not requiring complex equipment, are useful, as can be seen, for example, in data from The Netherlands (Figures 1 and 2) and from Sweden (Figures 3 and 4).

One reported concentration of the sum of seven BDEs in Atlantic herring fits the relationship observed in Baltic herring (Figure 5).

Toxicological information is not sufficient to link effects to concentration in aquatic biota. There is not even enough concentration data from the Bay of Fundy. The situation is somewhat better on the West Coast. There, extensive data are available on PCB and BDE in the Strait of Georgia sediments, and on their metabolites levels in mussels, and on PCB, PCDD/F, and organochlorine pesticides in chinook and sockeye salmon. It is rather surprising that, with the exception of the Great Lakes, Canada lags so much behind other countries. Better monitoring of known chemicals is only one factor needed for the assessment of the status of the Bay of Fundy. Biological variables must be monitored as well and, in addition, one must be always looking for unrecognized chemicals, such as unusual phosphate plasticizers, which are present in the coating of lobster traps. A well-equipped and staffed local chemical laboratory is a condition *sine qua non*.

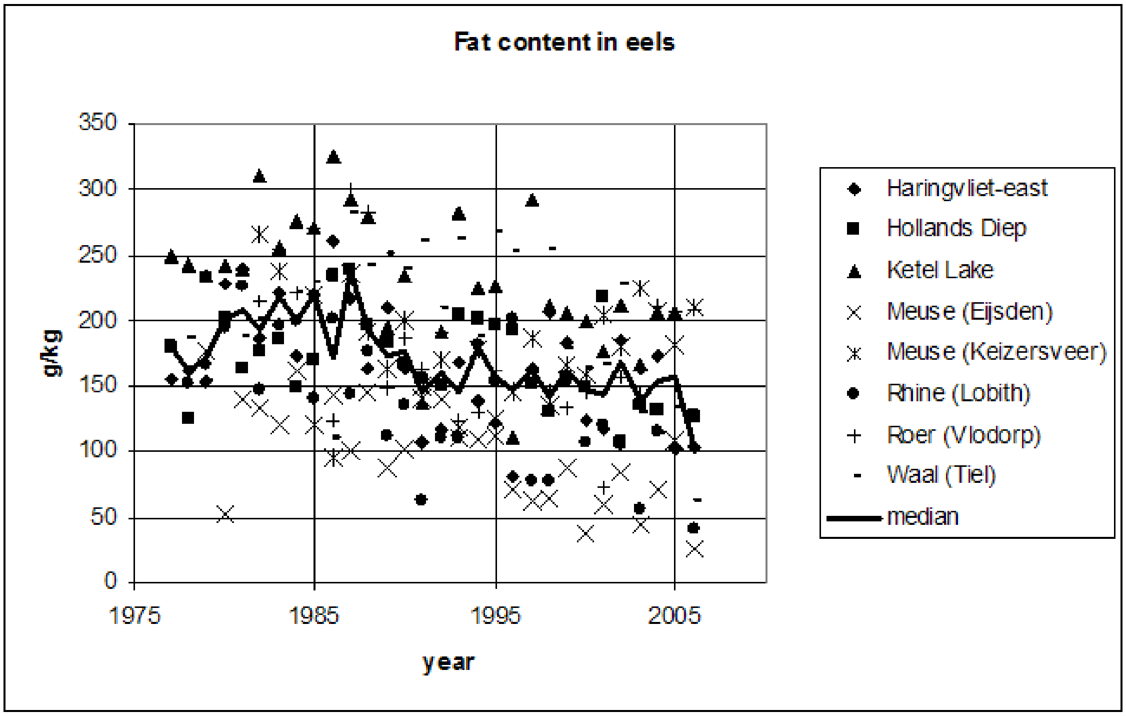

Figure 1. Fat concentration in eels from The Netherlands.

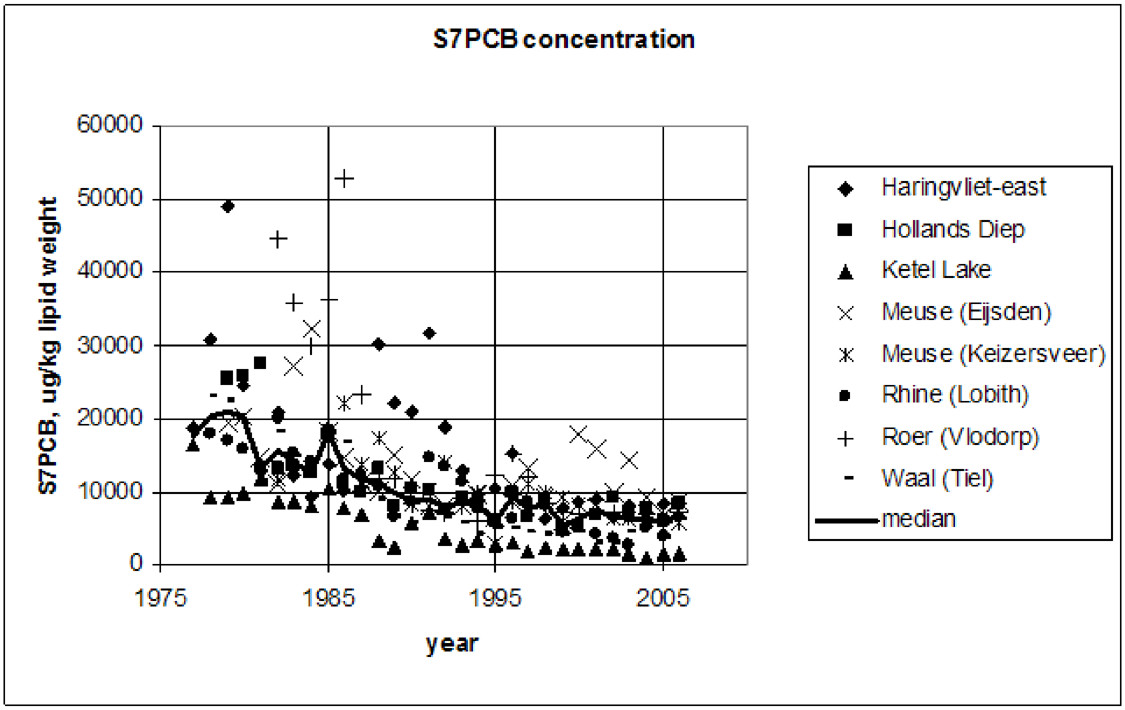

Figure 2. Sum of seven PCB concentration in eels from The Netherlands.

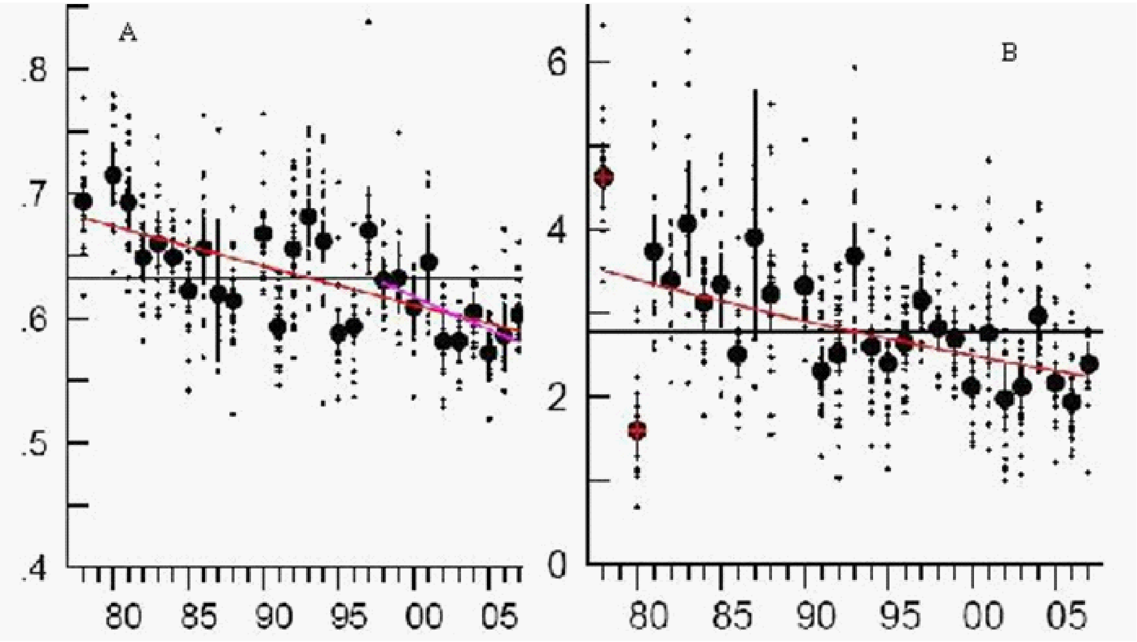

Figure 3. Baltic herring condition (100*weight,g/length^3, cm; A) and lipid % (B) plotted against years.

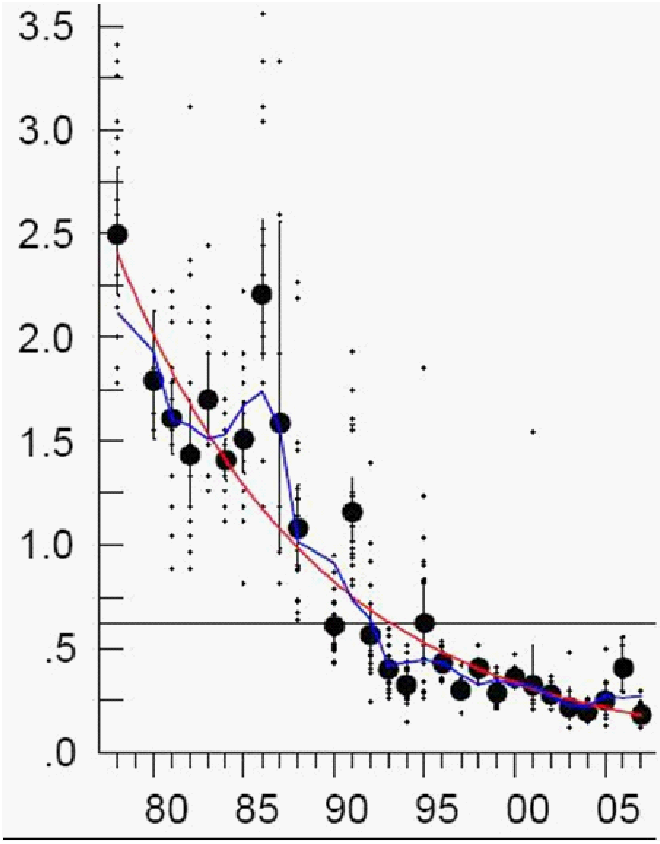

Figure 4. Total PCB (ng/g fresh weight) in Baltic herring, plotted against years.

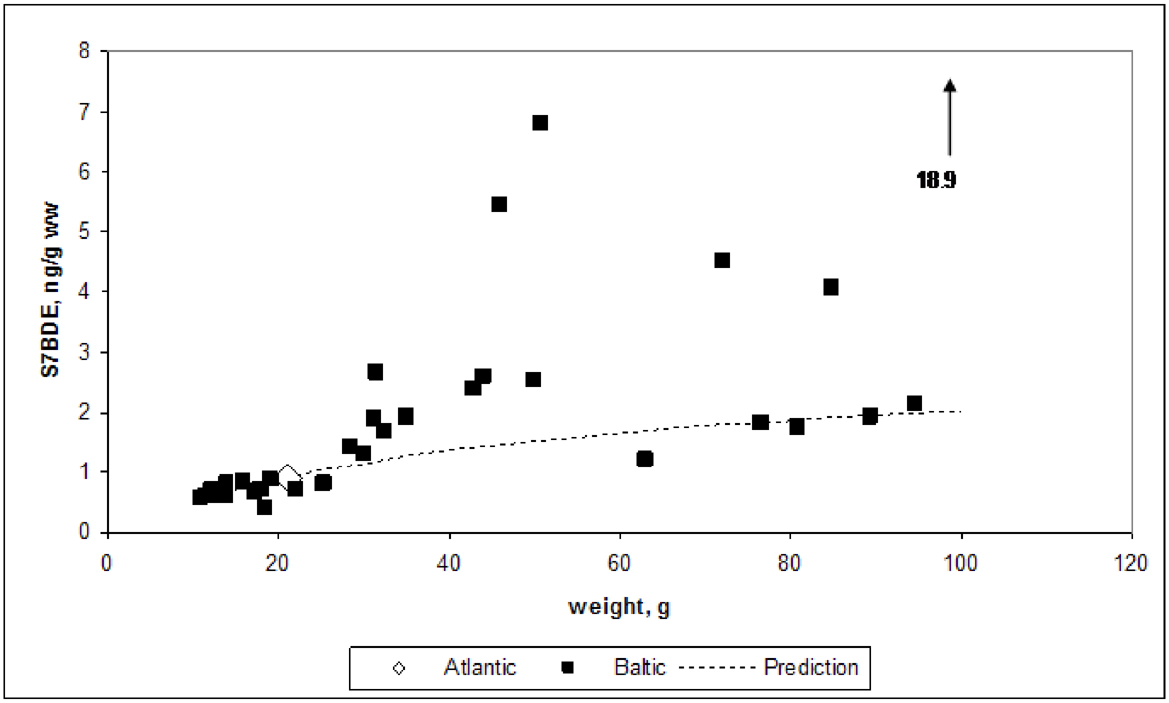

Figure 5. Concentration of the sum of seven BDEs in Baltic and Atlantic herring.

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AZAMETHIPHOS TOXICITY TO MARINE AQUATIC ORGANISMS

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Abstract

Sea lice are copepod ecto-parasites that can cause severe disease in farm-reared fish resulting in millions of dollars of loss to the aquaculture industry. Various treatment chemicals have been used to try to control sea lice outbreaks. One such chemical is azamethiphos, the active compound found in the commercial product Salmosan®. A study was conducted to look at the toxicity of azamethiphos to non-target marine organisms. The study consisted of three parts: (1) review of available literature on toxicity of azamethiphos to marine organisms; (2) laboratory toxicity tests to evaluate the effects of azamethiphos on representative organisms to determine the sensitive species; and (3) a field study in which toxicity tests were conducted on samples from the plume from a net pen dispersion.

The literature review and lab studies indicated that crustaceans, such as amphipods and the lobster, are sensitive to exposures of azamethiphos. An amphipod was chosen to serve as an indicator of toxicity to monitor samples from the dispersion study. The dispersion pattern around fish farms is very complex and will vary for each site and can be affected by current, depth, and bathimetry The dye plumes were detected up to 5 hours and 300 meters after release. Samples collected in the net pen during treatment were toxic to the amphipod but very few samples collected in the plume had a toxic effect to the amphipod. There appears to be a low risk for a harmful (toxic) environmental effect from net pen treatment with azamethiphos under the conditions used in this study.

Introduction

Sea lice are copepod ecto-parasites that can cause severe disease in farm-reared fish resulting in millions of dollars of loss to the aquaculture industry. Various treatment chemicals have been used to try to control sea lice outbreaks. In Canada the approval for the use of these products is given by Health Canada, Pest Management Regulatory Agency (Health Canada 2003). One such chemical is azamethiphos, the active compound found in the commercial product Salmosan®. Salmosan® is used as a bath treatment for the fish at 0.6 mg/L Salmosan® for one hour (2010 recommended treatment level); this is equivalent to 0.3 mg/L of the active ingredient. After the treatment is completed, the bath solution is released into the environment and allowed to disperse. Concerns have been raised about the effects of these chemicals on other organisms in the marine environment.

Studies have been conducted by Environment Canada and the Department of Fisheries and Oceans to look at the toxicity of azamethiphos to non-target marine organisms. The study consisted of three parts: (1) review of available literature on toxicity of azamethiphos to marine organisms; (2) laboratory toxicity tests to evaluate the effects of azamethiphos on representative organisms to determine the sensitive species; and (3) a field study in which toxicity tests were conducted on samples from the plume from a net pen dispersion.

Materials and Methods

Laboratory Studies

Laboratory toxicity tests have been conducted with a range of marine organisms at both the Environment Canada Atlantic Laboratory for Environmental Testing and the Department of Fisheries and Oceans St. Andrews Biological Station. The test organisms included: a bacterium, amphipods, a marine worm, sea urchin in both an adult survival and a fertilization test, two invertebrate test kits (Rototox® and Artotox®), a fish (threespine stickleback), and lobster. The procedures used in these tests followed published standard test methods.

The tests exposed a concentration series of Salmosan® to the different organisms under controlled conditions. For tests which looked at mortality, an LC50 (the concentration estimated to kill half the test organisms within a specified time period) was calculated. When a test looks at a response other than mortality (i.e., immobilization, inhibition of fertilization) an EC50 (the concentration that is estimated to have an effect on 50 percent of the test organisms within a specified time period) was calculated.

Field Dispersion Studies

Dispersion studies using Salmosan® were conducted in the Lower Bay of Fundy, NB, in 1996 (Ernst et al. 2001). Three sites were chosen: Back Bay, Deadmans Harbour, and Letang Harbour. A 50 meter Polar Circle was fitted with a tarpaulin to similiuate a net pen treatment. Salmosan® was added to the water in the tarp at 0.1 mg/L of the active ingredient azamethiphos and Rhodamine dye was also added as an aid to track the dispersion plume. This was the recommended treatment dosage at that time. A sample was taken from the tarpaulin for toxicity analysis.

After one hour the tarp was released and the plume was permitted to disperse. A flow-through fluorometer was used to measure the fluorescence of the Rhodamine dye to enable monitoring the plume movement. Longitudinal and lateral transects were made as well as depth profiles. Samples were collected for toxicity analysis from the plume over several hours.

Results

The results of selected laboratory toxicity tests conducted at the two labs are shown in Table 1 (Burridge 2003; Ernst et al. 2001). Amphipods and the lobster are very sensitive to exposure to azamethiphos with toxic effects observed at about an 80 to 290 times dilution of the original treatment solution of 0.3 mg/L azamethiphos.

Field Studies

Since amphipods were sensitive, commercially available and easy to use in testing, they were selected for the monitoring in the field dispersion studies. For the treatment solutions taken from the net pens during the three dispersion studies, all were toxic to the amphipod with calculated EC50's of 1.6 to 12.1 percent. Only a small number of samples collected from the plume after dispersion were toxic to the amphipods and these samples were collected within 50 minutes of the release of the tarp. The maximum length of the plume recorded was 1.2 km and the maximum distance from release was 3 km.

Discussion

When our study began in 1996, very little published data were available on the toxicity of azamethiphos to marine organisms. Since that time, sufficient studies were found to assess the hazard to marine aquatic organisms

(Burridge et al. 1999, 2000, 2005, and 2008; Canty et al. 2007; Mayor et al. 2008; Pahl and Optiz 1999). These studies agree with the data produced by our laboratory that crustaceans are one of the more sensitive groups to this pesticide formulation, not surprising given its target organism is a copepod. However, azamethiphos has also been shown to be acutely toxic to Atlantic salmon at 1 mg/L with a one hour exposure; this is only about three times higher than the treatment dose (Roth et al. 1996).

Laboratory studies have demonstrated that crustaceans such as lobsters are sensitive to exposure to azamethiphos. Toxic effects have been found with exposures as low as 3 percent pulse of the normal treatment dose of azamethiphos of 0.3 mg/L.

The dispersion studies conducted in 1996 showed a low risk for azamethiphos to non-target organisms under the conditions used. This study was conducted at a concentration three times lower than current practice. This study also simulated an exposure from a single net pen; in reality, multiple net pens are likely to be treated around the same time. This means sensitive non-target organisms have the potential to receive multiple pulses of pesticide, therefore increasing the risk of exposure and subsequent toxicity.

Because the allowable treatment doses in 2010 are higher than those used on the 1996 dispersion studies, Environment Canada plans to conduct further field trials in 2010 using the current treatment regime.

Type of Toxicity Test (exposure time)	**Toxicity Result (mg/L)**	**LC50 or EC50 compared to treatment dose of 0.3 mg/L**
Bioluminescent bacteria (Microtox®) (15 minutes)	EC50 = 11.0 (1.18 - 64.5)	35 X higher
Sea urchin fertilization of egg (20 minutes)	EC50 = 2.56 (2.54 - 2.59)	8 X higher
Rototox® (rotifer) (24 hour)	LC50 > 10	More than 33 X higher
Artotox® (brine shrimp) (24 hour)	LC50 > 10	More than 33 X higher
Marine worm (96 hours + 96 hours in clean water)	LC50 = 2.31 (0.650 - 590)	8 X higher
Sea urchin adult (96 hours + 96 hours in clean water)	LC50= >1	More than 3 X higher
Fish - Stickleback (96 hours)	LC50 = 0.190 (0.140–0.250)	16 X higher
Amphipod - *Gammarus sp* (96 hours)	LC50 = <5	NA
Amphipod - *Eohaustorius estuarius* (48 hours)	LC50 = >0.020 EC50 = 0.0026 (0.002–0.0035)	115 X lower
Lobster adult (48 hours)	LC50 = 0.00139 (0.00078 – 0.00202)	210 X lower
Lobster larva stage I (48 hours)	LC50 = 0.00357 (0.00176 – 0.00537)	80 X lower
Lobster larva stage II (48 hours)	LC50 = 0.00103 (0 – 0.00428)	290 X lower
Lobster larva stage III (48 hours)	LC50 = 0.00229 (0.00106 – 0.00318)	130 X lower
Lobster larva stage IV (48 hours)	LC50 = 0.00212 (0.00078 – 0.00202)	140 X lower

Table 1. Laboratory toxicity studies of Salmosan®, containing azamethiphos (from Ernst et al. 2001; Burridge 2003).

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PYRETHROID PESTICIDES: USE AND POTENTIAL EFFECTS ON MARINE ORGANISMS

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Extended Abstract

Pyrethrins are the active constituents of an extract from flower heads of *Chrysanthemum cinerariaefolium*. This mixture of chemically related compounds has been used for their insecticidal activity since the late 19th century (Davis 1985). The pyrethrins decompose readily as they are susceptible to catabolic enzymes and sunlight. In the early 1960s, synthetic analogues that were more persistent than the natural pyrethrins were developed and referred to as pyrethroids (Barthel 1961). Synthetic pyrethroids are products developed to have the same, or better, insecticidal activity while maintaining low mammalian toxicity.

The mechanism of action of the pyrethroids involves interference with nerve membrane function, primarily by their interaction with sodium (Na) channels, which results in depolarization of the nerve ending (Miller and Adams 1982). In general, pyrethroids are most toxic to non-target insects and crustaceans. As arthropods, crustaceans such as shrimp, crabs, and lobsters are more similar to insects than to molluscs (clams, mussels, and scallops) and are very sensitive to pyrethroids (Haya et al. 2005).

There is potential for pyrethroids to reach the marine environment from runoff from agricultural operations or from drift from aerial spraying. Direct input into marine waters also occurs during application of pyrethroids to control parasite infestations (sea lice) in the finfish aquaculture industry. It was their high degradability, low toxicity to mammals, and high toxicity to crustaceans that led to the initial interest in pyrethrins as treatments for sea lice infestations. In the 1990s, a product made up of naturally occuring pyrethrins was used to combat sea lice (Burridge and Haya 1997). Two compounds, cypermethrin and deltamethrin, are registered in the United States or Canada for use in the salmon aquaculture industry. Cypermethrin, the active ingredient in the formulation Excis®, can be used in the United States; deltamethrin, the active ingredient in the formulation AlphaMax®, can be used in certain parts of southwest New Brunswick. As can be seen in Tables 1 and 2, cypermethrin and deltamethrin are extremely toxic to marine crustaceans with concentrations lethal to lobsters reported to be in the ng/L (parts per trillion) range (McLeese et al. 1980; Fairchild et al. 2010).

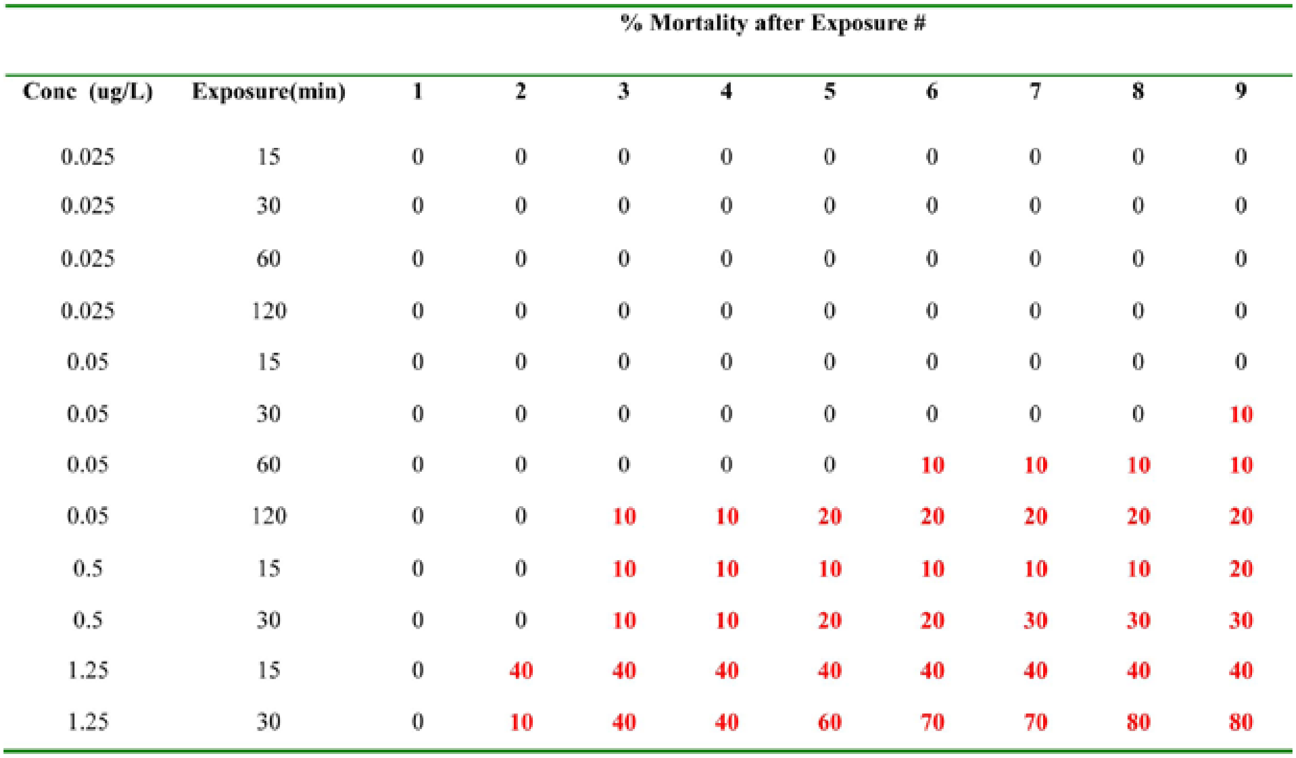
It is expected that lobsters would be exposed to effluents from bath treatments in pulses rather than at high concentrations for long periods of time. Table 3 shows the lethality of the cypermethrin formulation Excis® to lobsters after repeated short term exposures ranging from 15 minutes to 2 hours. After only two exposures to ~25 percent of the recommended treatment concentration (5 µg/L) for 15 or 30 minutes, some of the lobsters died, and in the course of the study, many more are affected (Burridge et al. 2000b).

Synthetic pyrethroids are unlikely to be accumulated to a significant degree in aquatic food chains since they are rapidly metabolized (Kahn 1983). This author warns, however, that pyrethroids such as cypermethrin and deltamethrin can persist in sediments for weeks, and if they desorb from the sediments could affect benthic invertebrates. Sediment studies with pyrethroids in marine environments are rarely reported in the primary literature.

Larval Stage	Pyrethrins*	Cypermethrin	Deltamethrin
Stage I	4.42[a],*	0.18	
Stage II	2.72	0.12	
Stage III	1.39	0.06	0.0047[b] 0.0365[c] 0.0045[d]
Stage IV	1.02	0.12	0. 0199[b]
Adults		0.040[b] 0.140[e]	0.0014[b]

[a,*] Significant $p<0.05$, Burridge and Haya 1997; [b] 96 h LC50, McLeese et al. 1980;
[c] 1 h pulse/16 day holding, Fairchild et al. 2010; [d] 16 day chronic test, Fairchild et al. 2010;
[e] 24 h LC50, Burridge et al. 2000a

Table 1. LC50 (µg/L) of pyrethroids to the larval stages, first post-larval stage, and adults of the American lobster (48 h LC50s, unless otherwise stated).



		% Mortality after Exposure #								
Conc (ug/L)	Exposure(min)	1	2	3	4	5	6	7	8	9
0.025	15	0	0	0	0	0	0	0	0	0
0.025	30	0	0	0	0	0	0	0	0	0
0.025	60	0	0	0	0	0	0	0	0	0
0.025	120	0	0	0	0	0	0	0	0	0
0.05	15	0	0	0	0	0	0	0	0	0
0.05	30	0	0	0	0	0	0	0	0	10
0.05	60	0	0	0	0	0	10	10	10	10
0.05	120	0	0	10	10	20	20	20	20	20
0.5	15	0	0	10	10	10	10	10	10	20
0.5	30	0	0	10	10	20	20	30	30	30
1.25	15	0	40	40	40	40	40	40	40	40
1.25	30	0	10	40	40	60	70	70	80	80

Table 2. Percent mortality of adult lobsters after repeated short-term exposures to Excis® (cypermethrin, 5µg/L) (from Burridge et al. 2000b).

Species	**Cypermethrin**	**Deltamethrin**
Atlantic salmon	>500[a]	3.0-10[a]
Eohaustorius estuarius	0.011 (mg/kg sediment)	0.00166[b] 0.0131[c]
Crangon sand shrimp	0.01[b]	0.045[b] 0.142[c]
Planktonic copepods	0.12 - >5[d]	
Algae	affects FW algae at mg/L[d]	140 (growth)[e]
Clams	no effects at 5 ppb[f]	

[a] no stated time, Roth, 2000; [b] 96 h LC50, Fairchild et al. 2010; [c] 1 h pulse/95 h holding, Fairchild et al. 2010; [d] data collected from several sources; [e] Haya et al. 2005; [f] Burridge unpublished results

Table 3. Toxicity of cyeprmethrin and deltamethrin to several types of organisms.

Conclusions

- Regulatory agencies take all available data into consideration prior to approving use of these compounds.
- Pyrethroids are extremely toxic to “insect-like” marine invertebrates, i.e., other arthropods.
- While *some* of the hazards to *some* non-target organisms have been identified, a lot of questions have yet to be answered, particularly with respect to cumulative effects.
- We need to know a lot more about chemical exposure in the field. This is true of all chemicals, regardless of origin.
- Data on the bioavailablity and potential effects of sediment-bound pyrethroids are lacking.
- Addressing the questions requires a multidisciplinary approach and expertise.

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Panel Discussion – Questions, Answers and Summary

Peter G. Wells[1]

This is a record of the questions from the workshop participants and replies from panel members, in the order that they occurred.

Q1 - What would be the sensitivity of other copepods to the pesticide cypermethrin? How would that compare to the sensitivity of sardines, including herring sardines? Are there threats to the herring in the Bay?

A1 - We don't have any information on the sensitivity of other copepods to this pesticide. (*Ed*: there is no reason to expect other types of copepods, being crustacean arthropods, to be much different in sensitivity to the pesticide than the sea lice (Copepoda: Caligidae).) As for herrings, there might be small effects in the pesticide plumes (after release at the cages); outside the plumes, after multiple treatments, we don't know if effects would occur to non-target fish species such as herrings.

Q2 - Berried female lobsters, often large ones, at Grand Manan Island migrate in by the aquaculture sites that have the sea lice problem. They are moving into Flags Cove. There are large cage sites near the migrating lobsters. How can we protect those migrating lobsters?

A2 - A risk analysis could be conducted to identify the greatest risk areas for those lobsters (*Ed*: The risk analysis should be conducted and will be brought to the attention of DFO.)

Q3 - Can we put aside protected areas for those lobsters or identify other ways to reduce risks?

A3 - We are running a big experiment in this case – how to reduce risks to those lobsters. One option would be to do the pesticide treatments at specific times of year, not coinciding with the lobster movements in the vicinity of the cages.

Q4 - The salmon aquaculture sites are largely in enclosed bays. The bottoms under and near the cages are soft and anaerobic. What are the risks associated with the chemicals accumulating in the sediments, especially if the weather periodically turns the sediments over?

A4 - Four answers were given to this question: (a) The pyrethroid pesticides are fairly rapidly biodegraded, hence you would not expect accumulation in sediments; (b) We are not certain about the rate of chemical accumulation or degradation in the sediments in the vicinity of the cages; (c) These rates can be measured; and (d) We do know from freshwater evidence that there is bioaccumulation of the pesticides up to a year later from such contaminated sediments. Some studies on this question of ecological risks are going to take place in the Bay. (*Ed*: Some work has been done on sediments under cages by G. Pohle, HMSC, and accumulation rates have been measured.)

Q5 - What is the "buoyancy" of the pyrethroids in seawater?

A5 - The compounds have various solubilities in seawater, specific to each pesticide and its formulation, and hence will remain in the water, either dissolved or associated with particles, for different periods of time. (*Ed*: No specific data were provided here, but could be.)

Q6 - Could the fishermen make observations to assist with the biomonitoring around the cage areas?

A6 - Possibly yes, but I have no specific ideas on this. (*Ed*: Before putting major programs into place, it would be good to obtain various viewpoints from the Fishermen's Associations.)

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[1] The author takes responsibility for the accuracy of the records of questions and answers, and apologizes in advance for errors and omissions.

Q7 - Cypermethrin is used legally in Maine (*Ed*: It is a different formulation from that used illegally in New Brunswick). When it is used in New Brunswick illegally, it is often used in very high concentrations. Could it be used legally in NB?
A7 - There has to be a request for its use. The situation in Maine has “a different fisheries status”.

Q8 - This (i.e., the pesticide issue) is a fisheries management issue. We collectively are supposed to be using EBM (ecosystem based management) and the precautionary approach, in such situations.
A8 - No answer. (*Ed*: The audience seemed in general agreement with this comment, but no further advice was offered.)

Q9 - Our cypermethrin is 40 times more potent than the compound used in the United States. Why?
A9 - We are using a different formulation in Canada. The aquaculture formulation of cypermethrin is not registered in Canada, so no cypermethrin is supposed to be used in this country. If it were registered for use, it would have the same composition as the US product. The product that is allegedly being applied illegally is an agricultural formulation that is 40 times more concentrated than the product registered in the United States and elsewhere for sea lice treatments.

Q10 - Are there toxic effects to non-target species associated with the pesticide contaminated copepods (sea lice) after treatment?
A10 - There are no data on this question. (*Ed*: We need a bright student to tackle this question!)

Comment: Surely we can collectively develop a different approach to controlling sea lice in salmon pens, rather than using a toxic chemical for control. Are we not past the point of releasing toxic chemicals into the ocean? There must be other possible methods, such as having sea lice predators in the pens (grazing the copepods off the salmon skin), or having sea lice resistant strains of salmon (where the flesh is unattractive to the sea lice). Great cheers of support for this suggestion!

Q11 - What are the differences between the various cypermethrin formulations? Can the components of the formulations be detected in the sediments? Are there active versus in-active ingredients?
A11 - The formulations are proprietary information. Their components could be detected in the sediments with appropriate chemical techniques. There are active (i.e., the pesticide) and in-active (i.e., the carrier solvent) components to every formulation. (*Ed*: This is a similar situation as was found many years ago with aminocarb, a carbamate pesticide, and its carrier solvent, nonylphenols.)

Q12 - How can we test for the presence of the pesticide in the waters surrounding the cages?
A12 - Testing for the presence of the pesticide can be done several different ways: water sampling directly (likely finding very low concentrations); using passive samplers, such as SPMDs or semi-permeable membrane devices, that can be made for specific sizes and types of chemicals (there is an advance technology for SPMDs); suspended exposure cages holding organisms such as amphipods; and settling plates to determine what is in the water column and whether normal settling of larvae is taking place.

Comment: Reflecting back to the points made about alternative techniques for lice control, there are contact and oral therapeutants that could possibly be used to make the salmon less attractive to the sea lice. Is there any information or analysis on the pros and cons of the different techniques – food pellets versus baths?

Q13 - Are there sea lice vaccines for salmon?
A13 - Not yet. Vaccines are under development but none is yet available.

Comment: We need to hear more on the sea lice situation from the provincial and federal governments. The occurrence of lice at the pens is non-uniform and unpredictable – lice one day, no lice the next. There need to be audits of their occurrence, and a determination of the legality of pesticide use.

Comment: The Government of New Brunswick has been involved in considering the legal status of sea lice treatments. The regulatory organizations have been meeting, and are planning some further action this year. The province is monitoring sea lice operations this year.

Q14 - The sea lice situation is a long-term issue. There have been both legal and illegal pesticide use. Can we have open water aquaculture in the Bay of Fundy with a long-term solution to the lice problem? Can we have more consideration of onshore, closed loop, or contained aquaculture operations? How should the industry continue? What are the main regulatory and policy issues?
A14 - No answer was given to this string of comments and questions.

Q15 - Are there alternative treatment techniques for the lice problem? Is there work on genetically modified salmon that will repel sea lice?
A15 - Yes, techniques include traps, and biological filters are being tested. And we believe that there is a treatment (BT4?) for the salmon's skin.

Q16 - Regarding the plume experiments of the pesticide water, is there a cage size effect on what is being found, as the site conditions vary from site to site?
A16 - The plume tests that were done were restricted, as they had to be conducted a certain distance from each cage site. There is some new work, a dye dispersion study, at a "full fish site", i.e., many cages.

Comment: Effects can occur with non-target species. There needs to be more testing in open water (high energy) sites and low energy, enclosed sites.

Q17 - Would there be effects of the pesticide-contaminated sea lice on the bottom communities or food chains?
Q17 - This is unlikely but untested. (*Ed*: Also see Q10.)

Q18 - What sorts of cumulative effects would be expected from the pesticide applications at multiple aquaculture sites?
A18 - Effects occurring would relate to the quantities of pesticide used. With more used, higher concentrations are likely in the water column at a distance from the site of application, and there is a greater likelihood of pesticide contacting the sediments. (*Ed*: This has not been formally studied or modeled, but should be.)

Q19 - Why are there so few aquaculture people at this workshop?
A19 - More were invited. We do not know why they did not attend!

WORKSHOP CONCLUSIONS

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Following the contributed talks, a Panel Session was held at which questions were asked by many participants (please see above). The session was well controlled by the masterful Moderator, Brian Rogers, and both questions and answers were meticulously recorded by Peter Wells who, in addition to answering some questions and making several erudite comments, also acted as Recording Secretary for the Session. The help and invaluable contribution of them both is most gratefully acknowledged.

As was obvious from many of the questions asked during the Panel Session, as well as from the answers given, much remains to be done to maintain a healthy environment in the Bay of Fundy. The deleterious effect of cypermethrin on arthropods (both terrestrial and aquatic) is clearly recognized and, because of the long half-life that this chemical has in the environment, it will affect many non-target species. In addition to the larger animals like lobsters and shrimps (which are commercially important in their own right), it also has the capacity to kill smaller organisms that are part of the food chain of commercially-important fish species such as herring. Following the flurry of activity immediately following the workshop, in discussion with representatives of the various Fishermen's Associations, it was agreed that a monitoring program should be developed to determine what effect, if any, chemical contaminants were having on lobsters and other crustaceans present in relatively shallow waters. Environment Canada has established a monitoring program to look at the persistence of pesticides in the flesh of caged Atlantic salmon and DFO personnel are developing other monitoring programs. The specific recommendation of the fishing industry as indicated above, however, did not get off the ground for various reasons in the summer of 2010. It was agreed that the initial monitoring program, as envisaged using volunteers and 'in-kind' contribution, be expanded into a fully-funded, and much more extensive, program for 2011.

The original plan to have a second, more focused, workshop late in 2010 has not materialized in the absence of the extra information needed. There are provisional plans to hold a second workshop in the Fall of 2011 when more relevant results can be available; this will likely take place as part of the 9th BoFEP Bay of Fundy Science Workshop in Saint John, NB, in October 2011. We hope that all of the Workshop participants will participate in the next one.

Appendices

Appendix 1: Workshop Program

10:00 am: **Welcome and Opening Remarks**
M. D. B. Burt, BoFEP Stress Working Group and UNB, Fredericton

10:10 am: **Monitoring the Health of the Bay of Fundy**
P. G. Wells, Dalhousie University, Halifax

> The Bay of Fundy, its near-shore environments, its estuaries and watersheds currently face many pollution challenges, some new, some decades old. Amongst the range of pollutants are chemicals and nutrients from aquaculture, industrial chemicals and effluents, oil-derived hydrocarbons, metals and sediments from mining, pathogens and chemicals from sewage, and concerns about combined and cumulative effects of pollution. Non-point pollution is a particular concern. Although national and provincial legislation has been in place for decades to control point-source industrial pollution, and the introduction of "toxic chemicals", the effectiveness of regulations and guidelines under different Acts demands considerable environmental monitoring by government agencies, researchers and community groups to ensure that the Bay's ecosystems are being adequately protected. This talk addresses monitoring the health of the Bay of Fundy – why we monitor, the challenges of multiple issues and how ecosystem health is measured, some of the current (circa 2006) monitoring programs in the Bay and their results, and monitoring needs to ensure protection of key species, ecosystems, and human health. This perspective is based in part on research on the concepts and key indicators of ocean health; work of the Gulf of Maine Council on the Marine Environment's Gulfwatch program (www.gulfofmaine.org); the inventory of coastal monitoring programs in Canada, including the Bay of Fundy, from the 2006 Ecological Monitoring and Assessment Program (EMAN) workshop; and BoFEP's work since 1995 (www.bofep.org). Some needs for the Bay include: maintaining the longer-term monitoring of various waters, species and habitats; a more complete set of marine environmental quality guidelines to interpret monitoring data on water, sediments and biota; periodic State of the Bay of Fundy/Gulf of Maine reports, prepared by a full range of stakeholders; and engagement with the relevant policy and decision makers in government and industry responsible for preventing and controlling pollution and maintaining the health of the Bay.

10:40 am: **Pollutants in River Run-off from Forest Spraying and Effects on Atlantic Salmon**
W. Fairchild, DFO, Moncton

> Forest spraying with pesticides is conducted primarily to manage damage from insect pests and to slow down unwanted vegetation. Vegetation is managed with herbicides as part of regular forest management plans and tends to be predictable, and usually coincides with areas of recent harvest. Insect pests on the other hand, tend to explode onto the scene in sometimes epidemic proportions, after years at low population numbers. Insects choose their own preferred areas to attack, without consulting our forest management plans. At the peak of the last spruce budworm outbreak, around 1975, the forest insecticide treatments in the Atlantic provinces looked more like a military operation than peace time pest control. We were at war with the spruce budworm over the standing timber resource. During this time one of the insecticide formulations sprayed had a chemical called 4-nonylphenol in it. The application of this insecticide formulation over many areas of the Atlantic provinces for more than a decade has provided a real world example of how contaminants can subtly affect wild fish populations, particularly the Atlantic salmon. How this came to be for salmon we now think we understand

better, and there are lessons that we should be able to apply to other contaminants and the aquatic environment. Will we have a better track record when the next forest insect pest epidemic brings the spray planes out again?

11:10 am: Nutrition and fresh-air break

11:30 am: **Impacts of Mixtures of Pollutants in River Run-off from Agricultural Practices**
A. C. Alexander, UNB, Fredericton

Aquatic organisms are routinely exposed to pesticides because these compounds are widely used and are regularly detected in stream biomonitoring. The presence of mixtures of insecticides is particularly troublesome since these compounds can directly alter the abundance and diversity of aquatic invertebrates, which are valuable as food for fish and as consumers of algae. Since reduced abundance and variety of taxa can alter important relationships between organisms, how to incorporate the increased complexity of mixtures into impact assessments urgently needs to be addressed. Assessing the effects of mixtures of organophosphorus (O-P) insecticides are particularly relevant because they are extensively used in agriculture worldwide and constitute roughly 70% of the insecticide load applied in North America. We have selected two, O-P insecticides to examine in detail, both of whom are among the top 10 most commonly used: chlorpyrifos and dimethoate. Our findings suggest that different members of the aquatic community respond differently to the two insecticides either when applied singly or jointly and furthermore that the two insecticides are not equally toxic. The implications of mixtures containing pesticides of different potency will be discussed.

12:00 noon: **The Mercury Flux in the Bay of Fundy, Gulf of Maine, and its Bioaccumulation in the Pelagic, Demersal, and Benthic Food Webs**
G. Harding, DFO, BIO, Dartmouth

The Bay of Fundy is a large tidally energetic embayment in the Gulf of Maine of 1.38 X 1010km2. Mercury enters the East Coast marine environment from many sources, most notably from long-range atmospheric transport, land runoff or river discharge, oceanic currents and migrating organisms.
As a priority toxic substance mercury, and especially its methylated form, are of concern due to its persistence, high toxicity, known bioaccumulation and biomagnification and suspected effects on the genetic, developmental and reproduction of aquatic organisms. Despite infamous pollution events of previous decades, such as occurred in Minimata Bay, Japan, where people were poisoned by consuming mercury in shellfish, little is known comprehensively about the fate of mercury in coastal marine ecosystems. There is evidence in the Maritimes that our loon, which spends its life as a juvenile in coastal marine waters and subsequently overwinters there as adults, has body mercury burdens well above inland populations.

In the present study total mercury and methyl mercury were measured in the Bay of Fundy in the following environmental and ecosystem compartments: a) river water; b) seawater c) sediments; d) planktonic organisms fractionated into seven logarithmic size categories from phytoplankton and flagellates (25 to 65 um) to macrozooplankton (2 to 4 mm); e) pelagic organisms size fractionated from ichthyoplankton and crustaceans (4 to 8 mm) to small fish and shrimp (16 to 32 mm); f) macrophytes; g) benthic macrofauna such as mussels, lobsters and flatfish; h) demersal fish such as cod and haddock; i) pelagic fishes such as herring, mackerel and tuna; and j) marine mammals.

Flux calculations suggest a total input of 2709 THg/Kg is entering the Bay of Fundy, of which ~108 THg/yr can not be accounted for by efflux to the atmosphere, sediments or the Gulf of Maine. This discrepancy probably could be resolved if deposition of sediments at the head of the bay were included. The anthropogenic input is predominantly atmospheric within this region and represents less than 3.7% of the total flux. Biomagnification was not noticeably different between the different trophic pathways and was ~104 from phytoplankton to tuna or a bioconcentration of 107 from unfiltered seawater to tuna.

12:30 pm: Lunch break

1:15 pm: **Some Organic Pollutants and their Potential Effects**
V. Zitko, DFO, St. Andrews – retired

The hazards and risks of environmentally important organic chemicals of chlorine, bromine and fluorine are discussed. Some potentially important organophosphorus compounds will be mentioned briefly. There is a large amount of information on the hazards of most of these compounds in the aquatic environment. On the other hand, little is known about their risks. This is because the risks are determined primarily by the presence of these compounds in the environment of the Bay of Fundy. In this respect Canada lags behind other countries by not having a continuous monitoring of their concentration in fish, shellfish and sediments (water is less important because most of the compounds are barely soluble). The presentation deals with polychlorinated biphenyls (PCB), terphenyls (PCT), dibenzo-p-dioxins/furans (PCDD/F), paraffins (CP), naphthalenes (PCN), and other chlorinated fire retardants (Dechloranes), polybrominated biphenyls (PBB), diphenyl ethers (PBDE), diphenyl ethanes (PBDEt), hexabromocyclododecanes (HBCD), and tetrabromobisphenol A (TBBPA), polyfluorinated compounds (such as PFOA, PFOS), and alkyl phenyl phosphates. Some concentrations of PCB, and PCDD/F in the Bay are known, but data on long-term trends are not available. The presence of PCT in herring gulls was detected in 1972, but there are no other data. CP were detected in antifouling paints and it is possible that their presence is more general. There are no data on PCN and Dechloranes. Some data on PBDE, PBDEt, and HBCD are available, and polyfluorinated compounds were found in the biota of the Gulf of Maine. Examples of monitoring data from The Netherlands, Sweden, and Estonia will be presented, as well as data on sediments and ospreys from the Gulf of Maine. It is impossible to estimate the magnitude of the threats to the Bay from the available data.

1:45 pm: **Azamethiphos Toxicity to Marine Aquatic Organisms**
P. Jackman, Environment Canada, Moncton

Sea lice are parasites that can cause severe disease in farm reared fish resulting in millions of dollars of loss to the aquaculture industry. Various treatment chemicals have been used to control sea lice outbreaks. One such chemical is azamethiphos, the active compound found in the commercial products Salmosan®. A study was conducted to look at the toxicity of azamethiphos to non-target marine organisms. The study consisted of three parts: (1) review of available literature on toxicity of azamethiphos to marine organisms (2) laboratory toxicity tests to evaluate the effects of azamethiphos on representative organisms to determine the sensitive species and (3) a field study in which toxicity tests were conducted on samples from the plume from a net pen dispersion.

The literature review and lab studies indicated that crustaceans, such as amphipods and lobster, are sensitive to exposures of azamethiphos. An amphipod was chosen to serve as an indicator of toxicity to monitor samples from the dispersion study. The dispersion pattern around fish farms is very complex and will vary for each site and can be affected by, current, depth, and bathimetry The dye plumes were detected up to 5 hours and 300 meters after release. Samples collected in the net pen during treatment were toxic to the amphipod but very few samples collected in the plume had a toxic effect to the amphipod. There appears to be a low risk for a hazardous environmental

2:15 pm: Nutrition and fresh-air break

2:30 pm: **Pyrethroid Pesticides: Use and Potential Effects on Marine Organisms**
L. E. Burridge, DFO, St. Andrews

Synthetic pyrethroids are chemical compounds used to kill insects and other pests. They are part of a class of compounds similar in structure and activity to pyrethrins which are naturally occurring compounds extracted from the chrysanthemum plant. Pyrethroids act by affecting the nervous system and synthetic compounds are designed to be effective for a longer period of time than the naturally occurring compounds. Synthetic pyrethroids are widely used in agriculture due to their high toxicity to insects and low toxicity to mammals. There is potential for pyrethroids to reach the marine environment from runoff from agricultural operations or from drift from aerial spraying. Direct input into marine waters also occurs during direct application of pyrethroids to control parasite infestations in the finfish aquaculture industry. Two compounds, cypermethrin and deltamethrin, are registered in the US or Canada for use in salmon aquaculture industry. Cypermethrin, the active ingredient in the formulation EXCIS®, can be used in the US and deltamethrin, the active ingredient in the formulation AlphaMax®, can be used in certain parts of southwest New Brunswick. Cypermethrin and deltamethrin are extremely toxic to crustaceans with concentrations lethal to lobsters reported to be in the ng/L (part per trillion) range. In this presentation the author will present data on persistence and toxicity of cypermethrin and deltamethrin. The potential for sensitive marine species in the Bay of Fundy to be exposed to cypermethrin or deltamethrin will also be discussed.

3:00 pm: **Speakers' Panel – Questions and Answers**

4:00 pm: Homeward bound

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