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Great Lakes Research Review

TABLE OF CONTENTS

Great Lakes Research Review

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INTRODUCTION

Jack Manno

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. . . Research never occurs in a political or institutional vacuum. Scientific research sometimes clarifies issues raised by lay observations and public concerns. These then frequently get interpreted into laws, regulations and agreements.

Welcome to the second issue of the Great Lakes Research Review, published cooperatively by the New York Great Lakes Research Consortium, the New York Sea Grant Institute and the Great Lakes Program at the University of Buffalo. The purpose of this publication is to fill the gap between newsletter-type reports of Great Lakes research activity and publication of results in peer-reviewed professional journals. We hope it will succeed in providing, as DEC's Gerry Mikol said in the last issue, "an important bridge between those investigators who have spent their professional careers on Great Lakes ecosystem research and others that need the information distilled into a format that allows quick review and understanding of the status and nature of their efforts." We hope to provide the reader with enough detail to understand important and complex scientific questions as they relate to public policy concerns.

Volume 1, No. 1 was published in July, 1994, and focused on research related to the fate and transport of toxic substances. This issue covers research related to the effects of toxics. Contributors include investigators associated with the cooperating organizations as well as invited guests. This issue is not intended to be comprehensive or to provide the readers with an inventory of effects-related research. It is a collection of articles which paints a picture of the complexity of the issues and some of the ways we have for asking relevant questions and seeking answers. This review assumes that the public policy implications of the presence of toxic chemicals in the environment is in itself important. In that spirit, this issue begins by looking at two fascinating and interrelated policy debates which arise out of conflicting interpretations of the known and suspected effects of toxic chemicals in the Great Lakes environment: the "ecosystem approach" to policy formulation and environmental management and the recent calls for a ban on the use of chlorine as an industrial feedstock.

Research never occurs in a political or institutional vacuum. Scientific research sometimes clarifies the issues raised by lay observations and public concerns. These then frequently get interpreted into laws, regulations and international agreements. These, in turn, help determine subsequent research funding priorities by affecting what regulators and managers need to know in order to implement the laws, regulations and agreements. This cycle is neatly demonstrated by **Michael Gilbertson** in his guest commentary *Complexity, Causality and the Ecosystem Approach*.

The results of field research in the late 1960s and early 70s by Gilbertson and some of his colleagues demonstrated the insidious effects of toxic chemical pollution on fish-eating birds in the Great Lakes. These discoveries greatly influenced the form and substance of the Canada-U.S. Great Lakes Water Quality Agreement of 1978. The Agreement then created an institutional imperative that the IJC focus on toxic substances in its dealings with U.S. and Canadian government agencies. Institutional mandates encouraged toxicologists, modelers, epidemiologists and others to focus their attention on Great Lakes contaminants. This emphasis on toxics, to the exclusion, some would argue, of equally or more urgent matters, led to a backlash against the IJC's exclusive focus on water quality. Gilbertson's argument in favor of a renewed focus on the original purpose of the GLWQA is a response to this backlash.

Gilbertson's frustration with the unrealized potential of the Agreement is shared by many. Their concerns have turned into a call for a phaseout of the use of chlorine as an industrial feedstock, a call endorsed by the IJC. **Don Mackay**, a chemist and modeler at the University of Toronto, takes up the discussion of a chlorine ban. In his article, *A Perspective on the Chlorine Controversy*, he discusses the environmental chemistry and the general evidence for the ecotoxicology of chlorine. He offers an alternative perspective, one he believes more responsibly addresses concerns for the effects of organochlorines in the environment.

In *Great Lakes Human Health Effects Research: An Overview of Priorities and Issues*, **Sheila Myers** et al report on an analysis done of Great Lakes-related human health research. It describes the types of research being done and the institutional context for this research. The authors compare the current inventory of research with published documents which have identified health research priorities. The article highlights gaps between the research needs and what is actually being accomplished.

PCBs are a class of organochlorines with potential to affect human health and are among the most studied of environmental contaminants. Understanding exposure routes is a key aspect of determining how to limit the effects of exposure. In *Dynamics of PCBs in the Aquatic Environment*, **Brian Bush** and **Michael Kadlec**, researchers active in the Great Lakes Research Consortium, shed fascinating light on the dynamics of PCBs in sediment, water and biota.

In the following article, *In Vitro Neorotoxicology of Great Lakes Fish-Borne Contaminants*, **Richard Seegal** and collaborating Consortium members describe work being done at the Wadsworth Center at the New York State Health Department using a cell culture line that acts similarly to the cells of the central nervous system of mammals. This work lays the foundation for understanding how PCBs can cause changes in cognitive function. This work is crucial for eventually discovering the link between exposure to particular contaminants and potential harm to the brain functioning of exposed animals and humans.

One of the main strategies for protecting people against exposure to fish-borne contaminants has been the issuance of fish consumption advisories warning that people, particularly children and women of child-bearing age, should limit or eliminate their intake of certain sizes of certain species of fish and some wildlife. **Barbara Knuth** asks and answers the question, *Fish Consumption Advisories: Who Heeds the Advice*? She summarizes the results of several studies she has led at the Human Dimensions Research Unit at Cornell's Department of Natural Resources. Knuth concludes that effective advisories must be designed and targeted to specific audiences. She also reminds us that mere understanding of the advisories does not guarantee compliance.

The final article, *Exposure Characterization, Reproductive and Developmental Health in the New York State Angler Cohort Study*, reports on progress in assembling a cohort of Lake Ontario anglers and the studies being undertaken to determine if this group shows negative health effects from consumption of Lake Ontario fish. Pauline Mendola and her colleagues at the School of Social and Preventive Medicine at the University at Buffalo describe the purpose and design of the study as well as the health concerns on which this study is based.

No single publication can present a comprehensive picture of the effects of exposure to toxic chemicals in the Great Lakes. I hope this issue will inform our readers of the kinds of questions being asked and policy-related issues they raise. If you have any comments, please send them to:

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The next issue of Great Lakes Research Review will be edited by Helen Domske, Associate Director of the Great Lakes Program at SUNY Buffalo. The theme of the next two issues will be Great Lakes Fisheries. If you are interested in submitting an article or would like more information regarding author's guidelines, contact:

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Guest Commentary

Complexity, Causality, and the Ecosystem Approach

Michael Gilbertson

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When I started working on toxic chemicals in the Great Lakes, about twenty-five years ago, there was a certain order to the agenda and an optimism about what my fellow scientists and I expected that we were going to achieve during our careers. We had shown some of the effects on the reproduction and development of fish-eating birds and mammals caused by a relatively small group of organochlorine substances. The results of our research were acknowledged in the formulation of the 1978 Great Lakes Water Quality Agreement and of national legislation in both the United States and Canada and we expected that the results of the research would lead rationally to the effective control of these specific substances both in commerce and in releases to the environment.

Recently, I have been trying to make sense of what went wrong and why there are still birds with deformed bills and fish that cannot reproduce and that are unsafe to feed to pregnant mink, let alone to humans. We seem to have lost the agenda in a massive quagmire of "complexity." This second issue of Great Lakes Research Review, concerned with the Human and Ecological Effects of Toxics, is perhaps an appropriate place to air some of these concerns.

One of the sources of frustration has been an inappropriate level of skepticism within the scientific and regulatory community. Skepticism expressed by scientists or executives, working for industrial interests implicated by the evidence of pollution, is to be expected. But the level of skepticism expressed by influential government scientists, academics and administrators, many of whom were not directly involved in this research and thus stood to gain little, has been perplexing.

> *". . . We seem to have lost the agenda in a massive quagmire of 'complexity'. . ."*

In 1989, the Council of Great Lakes Research Managers hosted a workshop to answer the question "how do scientists relate observed effects to causes?" The workshop heard a philosophical paper by Glen Fox on how to answer the question, and a series of papers applying the method to case studies from the Great Lakes. In 1991, the Michigan Audubon Society hosted the Second Cause-Effect Linkages Workshop, reporting on new evidence in further case studies. There was a surprising lack of response within the scientific community to what surely was a triumph of toxicological integration.

Originally I thought that this silence was because of an unfamiliarity among the scientific community with the method and/or case studies. More recently, a colleague pointed out that the authors were proposing single causal explanations of the effects when everyone else was trained to think and practice with a multicausal approach. Even if we had obtained valid and reliable answers, few could recognize them.

The next clue came from Buzz Holling who stated that the "multicausal world of ecology makes it likely that single hypotheses, even if valid, will be rejected."

Ecology has made significant inroads into Great Lakes science particularly starting with the 1978 publication of "The Ecosystem Approach" by the International Joint Commission. The original concept was that there were limitations to the existing approach to water pollution, based on development and enforcement of water quality objectives. Persistent toxic substances are released to the Great Lakes environment through aqueous discharges, atmospheric emissions and in leachates from chemical dumps sites. Once in the environment they move from the water into sediments and into the air, and from the air back into water or onto land. Control of one route of release can result in pollution through another route. The Ecosystem approach was a tool for understanding the sources, distribution and fate of persistent toxic substances so that rational and comprehensive plans could be drawn up for their control.

It was not long before The Ecosystem Approach was being applied to management of the Great Lakes basin. A little later, the tool was transformed into the goal of "Ecosystem Integrity." The Ecosystem Approach had ceased to be a means, it had now become an end in itself. The logical extension of this transformation was to gather every Great Lakes issue under the agenda of the Great Lakes Water Quality Agreement, including the introduction of exotic species, fisheries management, protection and restoration of wetlands and habitat, biodiversity, sustainable development and even the general status of industrial socio-economics in the Great Lakes basin. Gradually, a level of complexity had been inserted into the agenda that could endlessly challenge even the most ambitious of systems analysts.

> " . . . The Ecosystem approach was a tool for understanding the sources, distribution and fate of persistent toxic substances so that rational and comprehensive plans could be drawn up for their control. . ."

This complexity and the scientific skepticism among government managers about the effects of pollution by persistent toxic substances particularly on human health and fisheries resources, relegated pollution to a submarginal concern. Suddenly, those of us who had been working for decades on the effects of pollution of the Great Lakes with persistent toxic substances were being told that we had "hijacked" the Great Lakes Water Quality Agreement. The Agreement had become, in the minds of most, a Great Lakes Ecosystem Agreement, and government documents now routinely began to omit the words "of the waters" from quotations of the purpose of the Agreement "to maintain and restore the physical, chemical and biological integrity of the waters of the Great Lakes Basin Ecosystem."

If, in these twenty-five years, we had achieved the original goals set out in the Agreement and no longer had reproductive and developmental effects in humans, fish and wildlife caused by persistent toxic substances, it might be advantageous to start working on a broader agenda and maybe even to transform the Great Lakes Water Quality Agreement into a Great Lakes Ecosystem Agreement, if there is enough government money.

But until such time as these effects are no longer occurring, I would advocate a return to the original purpose of the Great Lakes Water Quality Agreement and of the original meaning of the Ecosystem Approach. In this way we might be able to bring back a certain amount of order to the agenda which may lead more effectively to the total prohibition of releases of persistent toxic substances and complete cessation of the occurrences of toxicological effects on vertebrate reproduction and development.

A Perspective on the Chlorine Controversy

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Abstract

Various groups, including the International Joint Commission, have advocated a policy "to sunset the use of chlorine and chlorine containing compounds as industrial feedstocks..."

Other groups, including the chemical industry oppose this policy. The roots of the resulting controversy are first examined. Aspects of the environmental chemistry and toxicology of chlorine compounds, especially the organochlorines, are then discussed.

It is shown that in addition to being a powerful and valuable oxidant, chlorine tends to confer stability and hydrophobicity on organic molecules, properties which are valuable commercially but can be troublesome environmentally. Recent judgements on this issue by various scientific groups are reviewed. A personal perspective is presented to the effect that mistakes have been made in the past, that chlorine and chlorine containing chemicals require special consideration, but that the reasoning behind the concept of a "chlorine ban" is fundamentally flawed.

What is needed, however, is not mere rejection of this concept and a return to "business as usual", but formulation of an alternative strategy which will achieve the same environmental goals. Elements of such a strategy are suggested.

Roots of the Controversy

The element chlorine has been subjected to intense scrutiny in recent years as a possible contributor to environmental contamination, especially in the form of organochlorine (OC) compounds. The International Joint Commission which oversees Canada-U.S. agreements on the Great Lakes has recommended in its Seventh Biennial Report (IJC 1994) that the Governments of the United States and Canada:

> "consult with industry and other interests to develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks, and examine the means of reducing and eliminating other uses, recognizing that socio-economic considerations must be taken into account in developing the strategies and timetables."

Activist and public interest groups, notably Greenpeace, have vigorously lobbied for phase-out of chlorine as an industrial feedstock. There is a lively debate on this issue with the chemical and pulp and paper industries on one hand advocating continuance of chlorine use, and activist groups on the other advocating an immediate ban. The public, academic community and government agencies occupy the middle ground between these extreme views.

The "ban chlorine" movement has several roots. Since about half the chemicals on priority lists are OCs, elimination of chlorine would apparently solve half the contamination problems. For reasons discussed later certain OCs are persistent, bioaccumulative and toxic, PCBs (polychlorinated biphenyls) being an example. There is a tendency to attribute these properties to all OCs. Since most organochlorines are synthesized industrially, i.e. they are "man made," there is a perception that they are more harmful and less degradable than "natural" chemicals.

There is widespread frustration in environmental circles that the Great Lakes are not being decontaminated as fast as occurred in the 1970s. Indeed levels of OCs seem to have levelled off in the last ten years, especially in the Lower Great Lakes. Efforts by Federal, State and Provincial Governments using traditional instruments such as effluent limits are seen to be ineffective, especially when much of the contaminant loading is from the atmosphere, sediments or leaking dumps.

There is a widely held view that industrial processes involving chlorine inevitably cause discharge of by-product OCs such as HCB (hexachlorobenzene) or OCS (octachlorostyrene).

Finally, there is suspicion that some OCs cause very subtle but damaging effects on reproduction, and cause hormonal disturbances at very low levels. If no level can be judged to be safe, then total elimination or zero discharge is necessary. This implies zero use of chlorine. The arguments for a chlorine ban are simple and compelling, and are seen as an effective instrument to break the present gridlock.

The Environmental Chemistry of Chlorine.

At the outset it is useful to identify a problem of terminology which surrounds the use of the word "chlorine". It is variously used to mean (i) the element, (ii) the molecule Cl_2, (iii) inorganic compounds containing chlorine such as chlorine dioxide and (iv) organic compounds containing chlorine, i.e. the "organochlorines" or OCs. It is often not clear what is implied by "chlorine-free" or "totally chlorine-free" or "chlorine feedstocks". At least we should be precise in our terminology. A glance at the periodic table shows that chlorine occupies a position just one electron short of the inert argon. Indeed, its thermodynamically favoured state is as chloride ion Cl^- with a full complement of electrons. Much of its chemistry is driven by this desire to accept an additional electron, or in more general chemical terms, its oxidizing tendency.

This strong oxidation capability, manifested as a Standard Oxidation Potential of 1.36 volts is exploited industrially, domestically and municipally as an ability to oxidize organic matter ranging from lignin to coffee stains and pathogenic microorganisms. Probably the single most significant contribution of chemistry to human well-being has been the elimination of cholera and typhoid by disinfection of potable water using chlorine. This oxidizing ability also renders chlorine gas highly toxic and has resulted in its use in chemical warfare and gives rise to hazards associated with accidental chlorine releases.

But most environmental concerns relate to organochlorine (OC) compounds in which chlorine plays three roles: it imparts chemical stability; it is a relatively large, heavy atom which reduces solubility in water and vapor pressure; and its electronegativity enhances the tendency of organic acids such as phenols, to dissociate (i.e. it reduces pKa).

Stability and Persistence

It is noteworthy that while methane (CH_4) reacts with oxygen to form CO_2 and H_2O releasing some 800 kJ/mol, the corresponding reaction with chlorine to form CCl_4 and HCl yields a respectable 400 kJ/mol. Essentially hydrocarbons burn with chlorine to form lower energy products, namely chlorinated organics. OCs are thus stable, low energy compounds with low enthalpies of formation and low heats of combustion. CCl_4 was thus once commonly used as a fire extinguishing agent. This thermochemical tendency results in the potential to form substances such as chlorinated dioxins in incinerators, and to form chlorinated phenols when chlorine is used to oxidize lignin.

This stability is exploited commercially in the low molecular weight OCs solvents such as TCE and PCE which are widely used for dry cleaning and degreasing. These solvents have convenient vapor pressures, or boiling points, and they can be handled safely without fear of explosion. This feature is also exploited in the use of polyvinyl chloride (PVC) as a stable outdoor construction material and in various heat transfer fluids, refrigerants and pesticides.

The problem is that this stability can be disadvantageous in the environment. Some of these OCs are persistent, surviving for periods of months and years in the environment. This renders them susceptible to long range atmospheric transport and to bioaccumulation in food chains, especially in fresh water systems where there is limited dilution. Freons survive long enough to enter the stratosphere. Chlorinated solvents which have been carelessly disposed of have become notorious groundwater contaminants.

This stability has led to a view that all OCs are very stable and no degradative pathways exist by which these compounds can be destroyed by existing communities of organisms. They have perhaps not evolved the capability of degrading OCs. The reality is that most OCs, even those which are virtually totally anthropogenic such as PCBs are susceptible to microbial degradation, albeit at times very slowly. There is, of course, a multitude of natural OC compounds. Nature is no stranger to OCs.

An important feature of this stabilizing tendency is that it is incremental, i.e. each chlorine added tends to increase stability by a certain factor. There is no leap in stability imparted by the presence of chlorine. This is shown in Figure 1 which gives biodegradability data for a series of chlorophenols (Banerjee 1987). In this case each chlorine added tends to cause persistence to increase by a fairly constant factor. From the viewpoint of the synthetic chemist chlorine is thus an invaluable tool in the chemical toolbox because it can impart stability. It is a useful elemental building block in the design of agrochemicals.

Hydrophobicity

The role of chlorine as a modifier of solubility in water and thus hydrophobicity is critical to its environmental fate and effects. This is best illustrated by an example. Benzene has a Le Bas molar volume of 96 cm^3/mol. Substitution of Cl for H results in an increase of about 21 cm^3/mol so that hexachlorobenzene has a molar volume of some 220 cm^3/mol, over three times the volume. Every chlorine added reduces solubility (strictly liquid solubility)

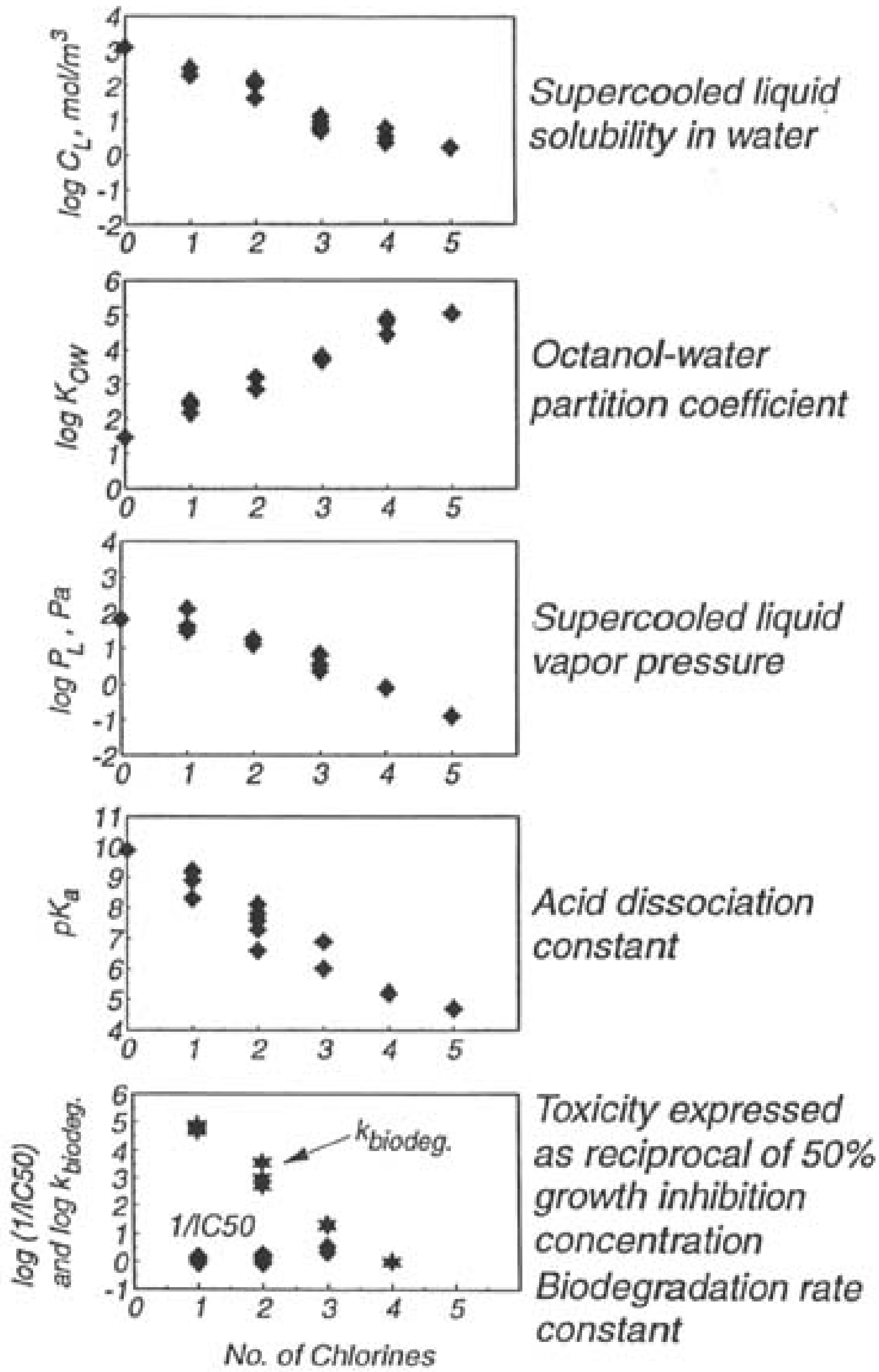

Figure 1

Plot of selected physical-chemical properties, biodegradability and toxicity of a series of chlorophenols showing the incremental effect of chlorine substitution. (Adapted from Shiu et al. 1994 and Banerjee 1985).

by a factor of about 5 and increases the octanol-water partition coefficient KOW by about a factor of 4.

There is thus a systematic change in these properties, as well as vapor pressure, boiling point and pKa with chlorine addition. This leads to fascinating and invaluable quantitative structure-property-activity relationships, by which properties can be correlated and even predicted as illustrated in Figure 1 which contains data from Shiu et al. (1994).

Again the effect is incremental. KOW is especially important because it is a very direct indicator of the lipid-water partition coefficient which controls bioconcentration in aquatic systems. Whereas benzene has a KOW of about 130, hexachlorobenzene has a KOW of 500,000 and some PCBs, "dioxins" and DDT have values exceeding 106. The implication is that concentrations in small fish can be a factor of 105 greater than that of the water in which they swim and respire. Food chain biomagnification can result in additional concentration increases of about a factor of 3 per trophic level in aquatic systems and by 10 or more in avian and mammalian systems.

The implication is that a concentration of 1 ng/L of a substance such as a PCB in water (as is typical in the Great Lakes) will cause a concentration of about 105 ng/L in small organisms and about 106 ng/L or 1 mg/kg or 1 ppm in larger fish. A resident of the Great Lakes who consumes 1000 L per year of water and only 1 kg of fish will be annually exposed to 1 mg of PCB in drinking water and 1000 mg in fish. Fish consumption dominates exposure. This is also the case for fish-consuming wildlife such as birds, mammals and even marine mammals such as whales in the St. Lawrence Estuary.

Essentially the hydrophobicity imparted by chlorine can cause extreme bioconcentration and high exposure. This phenomena was first identified qualitatively by Rachel Carson in 1962 but has subsequently been quantified in bioaccumulation models such as those of Gobas (1993) Thomann (1989) and Clark et al (1990).

A further implication is that hydrophobicity tends to increase organism body residues and thus toxicity, although the issue of how chemical structure, and the presence of chlorine in a molecule influences toxicity is beyond our scope here. This tendency is also incremental as shown in Figure 1.

If a KOW exceeding 105 is regarded as highly bioaccumulative, it is interesting to explore how many chlorines must be added to a parent organic molecule to achieve this undesirable condition. Figure 2, which is adapted from Mackay and DiGuardo (1994), is an attempt to depict this graphically. It shows that mono-aromatics need 5 or 6 chlorines, di-aromatics such as biphenyl or dioxin need only 2 or 3 fewer and alkanes and cycloalkanes behave quite differently, requiring many more chlorines to become bioaccumulative. The physical chemical causes of these tendencies are generally understood and are reasonably predictable.

There now exists an impressive capability of describing and even predicting the environmental fate of OCs from a knowledge of molecular structure. A small subset of these chemicals is of particular concern because of their environmental stability or persistence, their hydrophobicity or bioaccumulative tendency and their toxicity. Examples are the PCBs, chlorinated "dioxins" and "furans," hexachlorobenzene, mirex and toxaphene. It must be re-emphasized that the effect of chlorine is both incremental and predictable. There is an erroneous perception that the presence of chlorine in a molecule causes a quantum leap in persistence, bioaccumulation and toxicity. In reality the effects are gradual.

Responses of the Scientific Community

Concerns about the presence of OCs in the environment in general, and in the Great Lakes in particular and about a "chlorine ban" have prompted several groups to conduct reviews of OCs. Some of these reviews have been sponsored by parties who have an admitted interest in commercial exploitation of chlorine, but the groups which have authored the reports are independent, and it is hoped, impartial. Five are of note.

Solomon et al. (1993) have reviewed the chemistry and ecotoxicology of OC compounds in pulp mill effluents especially with a view to quantifying the benefits of using chlorine dioxide (ClO2) as a substitute for chlorine (Cl2) in pulp bleaching. That review, which was sponsored by the Alliance for Environmental Technology, an industry consortium, concluded:

"Based on the data available, the Panel concludes that, mills bleaching with high chlorine dioxide substitution (100%), employing secondary treatment and with receiving water dilutions typical of most mills in North America, present an insignificant risk to the environment from organochlorine compounds. However, the Panel is of the opinion that sufficient evidence exists from responses observed at non-bleached mills to suggest that other (non-halogenated) compounds which are released or formed during the production of pulp cause responses, such as induction of MFOs and changes in hormone levels. The identification of these compounds and the elucidation of their mechanisms of action should be a priority.

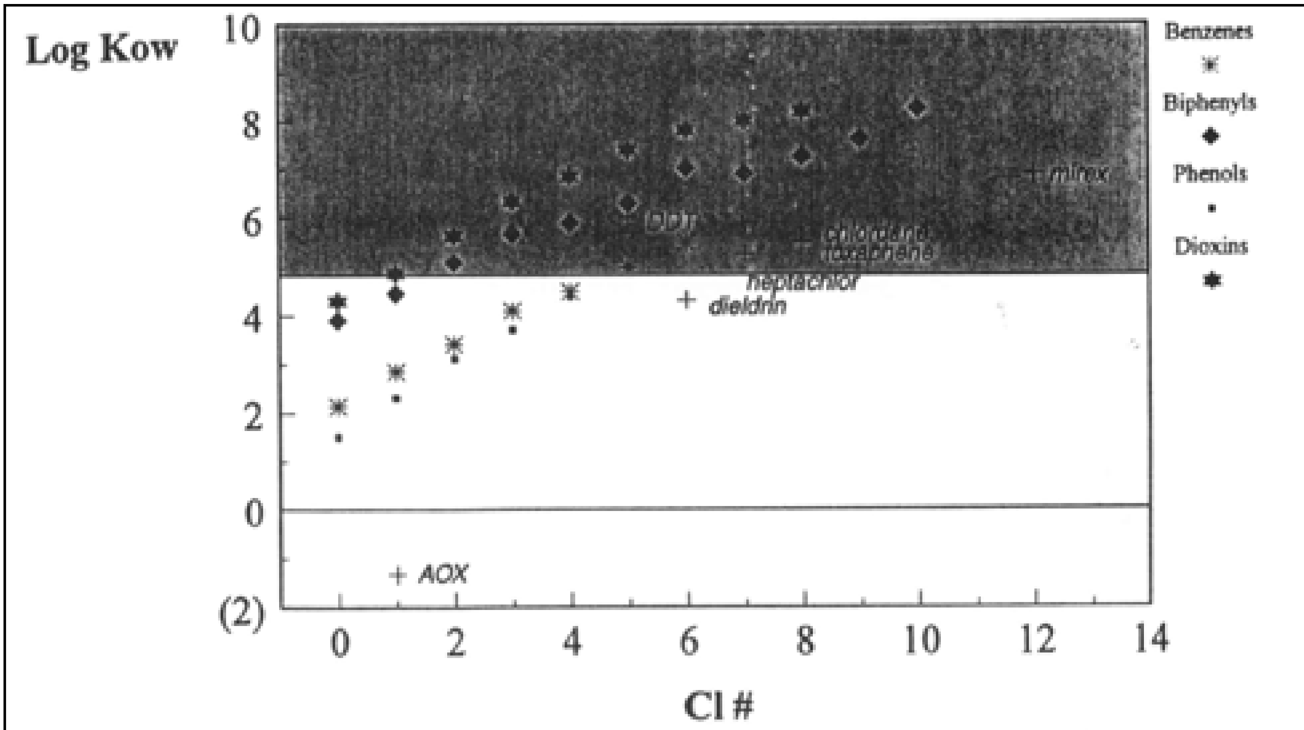

Figure 2.
Plot of KOW versus chlorine number for various homologous series of organic compounds showing that addition of sufficient chlorines causes substances to achieve a level hydrophobicity (log KOW of 5) sufficient to cause appreciable bioconcentration, as indicated by the shaded zone (adapted from Mackay and DiGuardo 1994).

Regulatory assessments and recommendations should take into account the high probability that process changes, such as conversion to chlorine dioxide, and improved effluent treatment can result in many or most mill operations generating no significant adverse impacts on ecosystems from organochlorine compounds. There is a need to monitor these ecological changes over the next few years to determine the nature, extent and rate of change of the responses."

The U.S. Chemical Manufacturers Association sponsored a report compiled by Cantox of Mississauga, Ontario, guided by an expert panel of eight and published as a supplemental issue of Regulatory Toxicology and Pharmacology (Dalzell et al. 1994). The study examined five classes of chlorine compounds (chlorine, PVC & VCM (vinyl chloride monomer), PCBs, pesticides and solvents) and three categories (chlorine use or presence in pulp bleaching, water disinfection, and in incineration). A group of chemicals was selected for scrutiny, industrial, accidental and natural sources were quantified, the physical and environmental chemistries were examined, the toxicology to aquatic, marine, avian, mammalian, organisms including human was evaluated and a final comparison made of past, present and likely future exposures and effects.

The report concluded that the presence of chlorine does not necessarily confer unique toxic or bioaccumulative properties, and that OCs can not be considered as a single group for health or environmental risk assessment.

It stated that "chlorine and chlorinated organic chemicals have, in the past been used and discharged to the environment without a full appreciation of their fate in the environment and potential to cause adverse effects. In response to ecological and toxicological concerns, appropriate controls and technological advances have been implemented to reduce environmental concentrations. Although there is a need to continue to learn more about these chemicals, the principal factors that affect their fate and toxicity are now reasonably well understood and provide assurance that most chlorinated organic chemicals can now, and in the future, be used without adverse effects."

In April, 1994, the American Chemical Society urged members of the U.S. Congress to "repudiate calls to eliminate the future use of all chlorine" adding that a proposed EPA study would waste scarce resources by shifting research dollars to focus on this vast category" (of chlorinated compounds).

In July, 1994, a panel of Michigan scientists reported on an evaluation of the scientific basis for the IJC chlorine sunsetting proposal (C and EN 1994). The panel concluded that there was no justification for sunsetting chlorine and that current regulations were reasonably adequate.

In August, 1994, the Society for Environmental Toxicology and Chemistry (SETAC) sponsored a "Pellston" series workshop on organochlorine compounds. Invitees were from North America, Europe, Japan and Australasia. A news release stated:

"Chlorine containing chemicals cannot be treated as a single class of chemicals. The scientists noted that calls to ban all uses of chlorine to protect the environment are not supported by a critical review of the scientific evidence. They felt that most chlorine chemicals can be produced and used safely. However, the scientists did agree that actions are needed to restrict or ban a small group of chlorine-containing chemicals such as PCBs, DDT, and dieldrin, which are highly toxic, persistent, and bioaccumulative. Existing supplies of these chemicals should be destroyed and, to the extent possible, their releases from highly contaminated landfills and sediments should be controlled. Some highly toxic, persistent, and bioaccumulative chemicals are also produced unintentionally (e.g. dioxins), and the scientists recommended that sources of these types of materials be identified to eliminate such emissions.

While many nations have recognized problems associated with highly toxic, persistent, and bioaccumulative chlorine-containing chemicals and consequently have banned their production and begun to destroy their existing supplies, other countries continue to produce chemicals like DDT. Some countries are unable to destroy chemicals such as PCBs because of technical and financial constraints. To solve this global issue, the scientists suggested an international agreement similar to the Montreal Protocol (which dealt with ozone-destroying chemicals). This agreement could have provisions for educational, technical, and financial assistance."

Based on a critical review of the scientific evidence, the important findings from this workshop concluded that:

"Chlorine is being used for beneficial purposes. A total ban on chlorine use to protect the environment is not supported by the evidence."

Examination of these reviews reveals a clear, common theme: <u>the scientific community does not favor a chlorine ban.</u>

A Personal Perspective

To this point I have attempted to be factual and unbiased. Ultimately, however, any commentary on this issue involves personal judgement and hence bias. In concluding, therefore, I stray into the arena of personal judgement and express opinion tainted with bias.

First let's place this issue in its historical context. Prior to 1960 there was a climate of vigorous and largely unchecked synthesis and commercial exploitation of OC compounds. Chlorine was widely used as an oxidant with little regard to by-product formation. In large measure this situation existed as a result of the absence of sensitive analytical techniques such as gas and liquid chromatography. There was a misconception that the environment was so large that it had a virtually unlimited assimilative capacity for contaminants. In any event, contamination was viewed as an acceptable penalty paid for prosperity. Bioaccumulation was not understood. Environmental toxicology was still in its infancy. Governments had no truly environmental agencies with the exception of groups managing fish, wildlife and water resources.

Silent Spring ushered in the end of this era and has catalyzed three decades of increased environmental awareness, concern and science. Public groups dedicated to improvements in environmental quality grew and learned to "fight pollution," exploiting a receptive news media. Public pressure was translated into political response and agencies such as the USEPA, Environment Canada and State and Provincial departments were created and grew in size and influence. Significant improvements in environmental quality resulted, especially in the Great Lakes Basin where phosphorus and OCs have been effectively controlled.

Ironically, this success in improving environmental quality has not been accompanied by a diminished public concern. There is still widespread intolerance of inadvertent exposure to chemicals, especially OCs. There is also a growing dissatisfaction with government bureaucracies which have proliferated to the extent that they are often paralysed by the need to consult a multitude of agencies and groups euphemistically called "stakeholders." There is an epidemic of "paralysis by analysis." There are fears that there may be unidentified toxic substances in the environment which are playing subtle roles as hormones or endocrine disrupters. Toxicologists have made great strides in identifying subtle effects of toxicity. Emphasis is on our ignorance rather than our knowledge.

Perhaps the "ban chlorine" movement is an inevitable symptom of life in this evolved climate. It is an attractively simple remedy which could solve half our problems, and break a frustrating gridlock.

There are, I suggest, five persuasive reasons that the "ban chlorine" movement is not sound policy.

First, banning chlorine will not diminish our legacy in the Great Lakes of contamination by "yesterdays" OCs such as PCBs, HCB, DDT or mirex. All we can do is patiently wait for the slow geochemical immobilization of these contaminants. With few exceptions these OCs are irretrievable. Of course there should be no new discharges. Current discharges are believed to be slight compared to previous loadings.

Second, a chlorine ban would result in severe economic penalties to the chemical and paper industries and probably to others. It is far from clear that environmental quality or human wellbeing would actually improve. Certainly for many individuals and communities there would be loss of quality of life.

Third, the ban is a slap in the face to the dedicated chemists, engineers, biologists, toxicologists and regulators who have in recent decades strived to identify and understand the environmental chemistry of chemical substances, separate the damaging OCs from the innocuous OCs, and assign controls appropriate to each substance based on its fate and effects.

Fourth, a chlorine ban may address half the priority pollutants, but it risks diverting attention from the other half which includes many potent toxics such as mercury, lead, chromium, arsenic and PAHs as well as difficult-to-analyze nitrogen and sulfur containing aromatics. In reality, most of the banned chlorine containing chemicals will not be priority pollutants. What possible benefit will be gained by banning PVC as a construction material?

Fifth, and perhaps most persuasive to the chemist and the toxicologist is the fundamental problem of the regulation of an element as part of a compound. One of the first lessons of chemistry is that a reactive metal called sodium will combine with a noxious green gas called chlorine to form an innocuous white powder called sodium chloride, or common salt, which is essential to life. The properties of compounds are not the sum of the elemental parts just as the Mona Lisa is not just the sum of a piece of canvas and some paint. The entire scientific and engineering discipline of ecotoxicology is predicated on understanding and controlling compounds, not elements. Should all mercury, silver and arsenic compounds be banned as well?

There is, however, one rather sad justification for a chlorine ban. Perhaps our regulatory system has become so unmanageable that the only way of controlling OCs is to take this very imperfect route. Such a justification represents an admission of failure to regulate, and failure to apply fundamental science in support of public policy. This justification may seem far-fetched but in 1994 the Canadian Government solved the problem of cross-border smuggling of cigarettes by reducing the tax on cigarettes, thus avoiding an unpleasant confrontation with First Nations groups!

Whereas I have expressed a personal judgement that the "ban chlorine" movement is ill-advised, I am not advocating that we ignore the proponents of that movement. They have legitimate concerns. We still do not understand the environmental chemistry of many OCs, notably chloroparaffins and Absorbable Organic Halogens (AOX) produced by pulp mills. We still do not have an adequate accounting of sources or loadings to the Great Lakes. Some chlorinated substances are still used in situations in which substitution of non-chlorine compounds is preferable. We must (and can) do a better job of incineration to ensure elimination of chlorinated dioxins from the effluent gas. The subtle toxicology of many OCs is still not understood. Much remains to be done to ensure that the risks from OCs to humans or the ecosystem are indeed acceptably small.

The challenge is to identify and implement pragmatic scientific, engineering and regulatory actions which will accomplish this goal. The advocates of a chlorine ban have identified one approach; we should not dismiss that approach without proposing another strategy which is demonstrably superior. I end with an outline of the elements of a suggested strategy. It transpires that many of the elements are in place, at least in part.

A Suggested Strategy

First, since it is compounds (not elements), or at least groups of compounds with similar properties, which should be controlled, these compounds must be identified and possibly prioritized. Relevant physical chemical property information should be obtained. Several such lists already exist, as do compilations of data. Obviously many OCs will be on this list, and should be accorded special attention.

Second, the region of interest must be defined. It should be a Great Lake, or a part of a lake such as Green Bay or Hamilton Harbour, or the entire Great Lakes Basin. In modeling terms this is defining the mass balance envelope. Relevant environmental data must be obtained including hydrology and meteorology.

Third, the sources of these substances in this region must be identified and quantified including industrial, municipal, domestic sources, spills, landfill leachate and advectively inflowing air and water. This will give external loadings in units such as kg/year and will identify the more important sources. Such data are rare and represents, at present, the main impediment to progress.

Fourth, prevailing levels of the substances in air, water, sediments and biota should be documented to yield not only average concentrations, but also total amounts (kg) in the region of interest.

Fifth, a mass balance reconciliation or modeling exercise must be conducted in which loadings, environmental data and chemical properties are brought together to give estimates of environmental investigations, there are few examples of agreements such as this which include definite targets. The closest is the rather hypothetical virtual elimination scenarios developed for the IJC by its Virtual Elimination Task Force (IJC 1993).

Conclusions

I suggest that the public is not so naive as to expect rapid or complete elimination of toxics from our ecosystem. They do, however, expect to be provided with concrete assurances and evidence that "things will get better". At present, the only assurances are that "things seem to be improving", but not as fast as they did in the 1970s. Frustration flourishes in this vacuum of leadership and vision and leads to ingenious measures to break the present gridlock of inaction. The "ban chlorine" movement is, I believe, such a response. For the reasons outlined earlier I find it to be misguided, and if implemented will be largely ineffective and economically disruptive. Our best response is not simply to dismiss it or oppose it; it is to demonstrate that the goal which it seeks to accomplish can be achieved by other, more rational, economic and effective actions.

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Great Lakes Human Health Effects Research in Canada and the United States: An Overview of Priorities and Issues

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Introduction

For the past two years, the Great Lakes Research Consortium has managed the Canada-U.S. Research and Information Exchange Network (RIEN) on the health effects of exposure to toxic substances in the Great Lakes environment. RIEN has facilitated the exchange of information among scientific investigators, research managers, funders and interested public. We have maintained a library of peer-reviewed and informal scientific and policy papers and a bibliography that is updated daily and made available on the Internet through the Great Lakes Information Network. We have also maintained a regularly updated compendium of active research investigations, including information about research methods and goals. With this information, we have published a newsletter and served as an information resource to government agencies and public interest groups, as well as the researchers themselves. RIEN focuses not only on scientific data but also on the social and institutional forces driving the quest for information about health effects.

The RIEN has tracked and documented information on 75 research projects directly related to considerations of human health and the Great Lakes environment. This information is continually updated by contacting researchers directly, and by drawing on such sources as the annual reports produced by the Department of Health Canada, the IJC Council of Great Lakes Research Managers, the Great Lakes Protection Fund and the Agency for Toxic Substances and Disease Registry (ATSDR). The projects involve a range of research on humans, laboratory animals, or wildlife in the Great Lakes basin. This article describes the human health related research that is presently being undertaken and considers whether and how this research, in sum, constitutes a binational research strategy to address the most important questions regarding the effects on human health of exposure to toxic contaminants in the Great Lakes ecosystem.

U.S. and Canadian Research Programs

Research on the U.S. side of the Basin has been conducted mainly by universities and state health departments. Funding for this research has come from a variety of sources including the Environmental Protection Agency (EPA), the National Institutes of Health, the National Institute of Environmental Health Sciences, and the Great Lakes Protection Fund.

Most of the currently active research specifically on the effects of Great Lakes pollutants is coordinated through the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) . The ATSDR was given responsibility for Great Lakes health-related research after the U.S. Congress amended the Great Lakes Critical Programs Act of 1990. This act , in addition to creating the research program within ATSDR, mandated that the EPA, in consultation with ATSDR and the Great Lakes States, submit to Congress a report assessing the adverse effects of water pollutants in the Great Lakes ecosystem on the health of persons in the Great Lakes States. The report, which is due in early 1995, will summarize the recent research results from projects that ATSDR has funded since 1992. In 1992 Congress appropriated \$2 million for ATSDR to initiate the Great Lakes Human Health Effects Program, \$3 million was appropriated in 1993 and 1994 and another \$4 million is authorized for 1995.

These funds are contracted out to state agencies in the Great Lakes region, including state universities. Unlike some grant programs, ATSDR has made a conscious effort to build a coherent research program out of the discrete projects. The principle investigators have been brought together to share information from their projects with each other and the public through ATSDR sponsored symposia. To guide its grant program, ATSDR established the following priority areas:

• determining the profiles and levels of Great Lakes toxicants in human tissues and fluids;

• identifying sensitive and specific human reproductive and developmental endpoints and correlating them to exposure to Great Lakes toxicants;

• determining the shortand long-term risks of adverse health effects in progeny which result from parental exposure to Great Lakes toxicants (special emphasis on reproductive, developmental, behavioral, neurological, and endocrinological endpoints);

• investigating the feasibility of establishing registries and surveillance cohorts in the Great Lakes region;

• establishing a chemical mixtures database with emphasis on tissue and blood levels in order to identify new cohorts, conduct surveillance and health effects studies, and establish registries or surveillance cohorts (U.S. Federal Register Notice, May 15, 1992).

Since 1992, ATSDR has funded ten projects that study the potential for adverse effects from the consumption of contaminated fish in the Great Lakes Basin. A new Federal Register Notice is expected in 1995 announcing a call for proposals for additional research projects.

In Canada, human health research has traditionally been coordinated under the Federal Department of Health. Research projects were first initiated under the Great Lakes Health Effects Program (GLHEP), a five-year federal initiative created in response to health issues addressed in the 1987 protocol of the Canada-United States Great Lakes Water Quality Agreement. The GLHEP is now under the direction of a new program called Great Lakes 2000; a six year $20 million, multi-departmental program.

The Department of Health's goals for the Great Lakes are to:

• work closely with federal, provincial, and municipal governments to develop and implement Remedial Action Plans for the Areas of Concern in the Great Lakes Basin;

• determine the nature, magnitude, and extent of effects on human health associated with exposure to contaminants (chemical, microbiological, radiological) from all sources of pollution in the Great Lakes Basin;

• develop and implement strategies to reduce or eliminate risks to human health related to pollution in the Great Lakes Basin; and

• increase communication and consultation among agencies and the public and provide timely, useful information to foster understanding and appropriate action on health and environmental issues (Great Lakes Health Effects Program, April 1992 and personal communication, Moe Hussain).

Most of the research undertaken by the Canadian Department of Heath has been carried out by principle investigators from within the department, although some grants have been let to Canadian universities and non-governmental organizations. There has been some effort to coordinate the Canadian and U.S. programs. The Great Lakes Health Effects Program and ATSDR have cosponsored symposia in Ottawa and Detroit for their associated researchers. There was also an abortive attempt by the Great Lakes Research Consortium to create a binational Consortium of federal agencies involved in Great Lakes health related research.

Research Priorities

In 1987 representatives of the U.S. and Canadian governments signed protocols amending the Great Lakes Water Quality Agreement. Among the promises the parties made were to, 1) establish monitoring and research programs to identify the impact of persistent toxic substances on the health of humans; 2) develop reproductive, physiological and biochemical measures in wildlife, fish and humans as health effects indicators and establish a data base for storage, retrieval, and interpretation of the data and; 3) conduct research to determine the significance of effects of persistent toxic substances on human health and aquatic life. Furthermore, Annex 17 2(1) states that both parties shall "develop approaches to population-based studies to determine the long-term, low-level effects of toxic substances on human health."

In order to assess whether or not there was a common understanding of research needs in the Great Lakes basin , we reviewed the 1987 protocols to the Great Lakes Water Quality Agreement as well as the research priorities as described in published documents of the International Joint Commission's Science Advisory Board (Science Advisory Board, 1991) and the published conclusions reached by several conferences and meetings that have been held among health experts in the Basin. From this review we identified three categories of research needs which have are most pressing:

a) the need to characterize exposure pathways and levels;

b) the need to monitor and survey particular populations at high risk of exposure to Great Lakes contaminants; and

c) the need to clarify the relationship between exposure and various effects.

Some of the projects we have identified have a component of each of these three priorities in their design. For example, a study on a cohort of anglers may look at fish consumption rates, characterize exposure levels, examine reproductive outcomes, and delineate cause/effect relationships. While another study may be designed as an analyses of cancer rates or other potential environmentally-related health endpoints in a given population but which does not attempt to identify particular exposure pathways. The following review of published literature, and projects from the RIEN inventory shows the relationship between the research needs and priorities and the actual research projects.

A. Exposure Characterization

In the Great Lakes Water Quality Agreement (Annex 12) the Canadian and US governments pledged that "An early warning system consisting of, ... the following elements shall be established to anticipate future toxic substances problems: (e) maintenance of biological tissue bank and sediment to permit retroactive analysis to establish trends over time; and (f) monitoring to characterize the presence and significance of chemical residues in the environment." Furthermore, the Agreement that "The parties shall establish action levels to protect human health based on multimedia exposure ...."

Of the exposure assessment projects in the RIEN inventory, the great majority focus on fish consumption as the route of exposure. These 41 studies include 16 research projects and/or health assessments conducted at Superfund sites in the Areas of Concern. Figure 1 shows the distribution of research projects that assess exposures to populations in the Great Lakes based on the exposure routes studied.

The U.S. program is far more directed toward looking at fish consumption as the primary route of exposure and identifying people who consume Great Lakes fish to establish cohorts for epidemiological studies. The Canadian Department of Health research efforts have been much broader, considering the health effects of air pollutants, contact with pollutants and absorption through the skin and other potential routes of exposure to harmful contaminants.

Indeed, the U.S. research community has spent a considerable amount of money and time to characterize levels of contaminants in human populations that consume Great Lakes fish. For example, the Michigan fish eaters study, started by the Michigan Department of Health in the early 1970's has been used for a number of research studies that are published in scientific journals. In addition, eight out of the ten research projects being conducted under the ATSDR Great Lakes Program consider Great Lakes fish consumption as the main route of exposure. On the contrary, the Department of Health Canada conducted a pilot study on a cohort of people in the Province of Ontario in order to determine the feasibility of conducting a large scale cohort study on fish consumption of locally caught Great Lakes Sports-fish and health effects. They concluded that a large scale study of the Ontario populous would be too costly and the results of limited use because the number of individuals at high risk through fish consumption would be too small (GLHEP, Project Profiles and Progress 1990-1993).

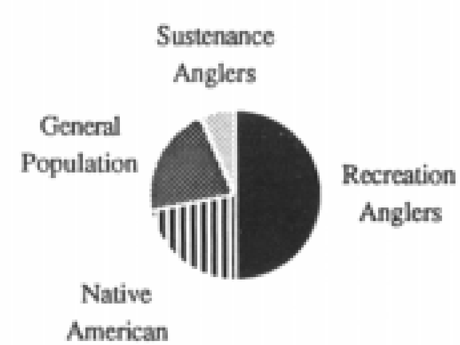

Figure 1

POPULATIONS STUDIED (N=32)

The heavy focus on exposure assessment is important because it helps to answer the question of whether or not populations in the Great Lakes are more exposed to contaminants than other populations. Preliminary research from the United States and Canada indicates that they are not, but only a few studies have examined human body burdens and made comparisons with other populations. For example, Phillips *et al.* (1990) concluded that levels of accumulation for contaminants contained in sediment, water and fish samples on the U.S. side of the Basin are no greater than in other geographic regions. In addition, Fitzgerald *et al.* (1992) compared breast milk levels of PCBs of women from the Mohawk nation near the St. Lawrence River with breast milk levels of PCBs of women reported in several regions of the U.S. They concluded that levels of PCBs of Mohawk women living along the St. Lawrence River were not any higher.

In Canada, the current levels of PCBs observed in human milk, serum, and adipose tissue are comparable to those observed in other developed countries. Canadian researchers in the Department of Health have studied the concentrations of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), as well as a few PCB congeners in human tissue samples from five Canadian municipalities within the Basin (Lebel et al. 1991; see also Williams et al. 1991). They conclude that concentrations of PCDD/PCDF are within the range of levels reported in other studies conducted throughout the world. Results are similar for PCB concentrations, although the data from comparison studies were limited and levels were higher in the Canadian samples as compared to samples from studies conducted in other North American regions (Lebel *et al.* 1991).

One study that has compared body burden levels of toxic contaminants nationwide is Phillip *et al.* (1991) based on an analyses the USEPA's National Human Adipose Tissue Survey (NHATS). Data collected from this nationwide survey were used to test the hypothesis that individuals in different U.S. regions are subject to varying degrees of toxics exposure. The objective of NHATS is to detect and quantify the prevalence of toxic compounds in the general population (Phillips *et al.* 1991).

The concentrations of 54 compounds reported by NHATS were used in this study to examine regional variations in human toxics exposure. These compounds were chosen because of their persistence in the environment and included most of the critical pollutants such as PCDDs and PCBs. The East North Central region encompasses the states of Ohio, Indiana, Illinois, Michigan, and Wisconsin, all in the Great Lakes region. The researchers found that individuals in the South Atlantic, East South Central, and East North Central states had higher body burdens of toxic substances than individuals in other regions of the country. The East North Central region ranked third out of nine regions for all categories of toxic substances for all age groups and fourth out of nine when the numbers were adjusted for any bias (Table 1).

Research programs in the Great Lakes Basin have traditionally lacked the coordination needed to integrate research data and results for a comparative look at exposures in Great Lakes populations versus elsewhere. This gap is closing, however, with recent initiatives by researchers in the Great Lakes Health Effects Program and the ATSDR Great Lakes Program to integrate and compare findings. Both ATSDR and the Department of Health Canada are investigating the means to collect and maintain tissue banks on Great Lakes populations that could be used for future research. A tissue bank would provide much needed data for longitudinal analysis of the levels of contaminants in Great Lakes populations. In addition, ATSDR recently funded the Michigan Department of Health to develop a Quality Control/Quality Assurance Program which would standardize QC/QA protocols so that the data generated by the Great Lakes Program can be comparatively analyzed.

B. Populations at Risk

Projects that study specific populations at high potential for exposure (due to fish consumption levels, residence etc.) allow researchers to follow an established cohort to track body burdens and health effects over time. In the Great Lakes Water Qual-

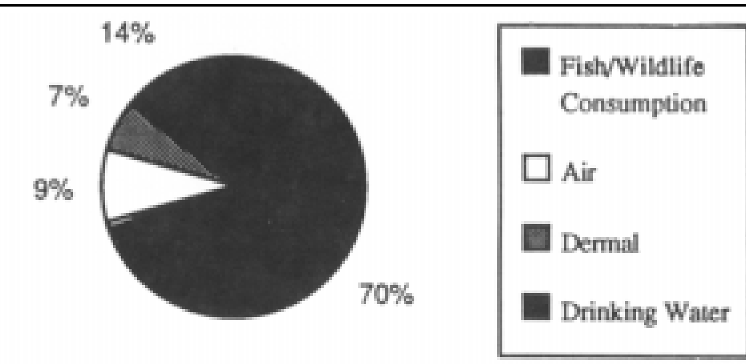

Figure 2 EXPOSURE ROUTES STUDIED (N=41)

ity Agreement (Annex 12), the governments agreed that "Monitoring and research programs ... should be established at a level sufficient to identify: (b) the impact of persistent toxic substances on the health of humans and the quality and health of living aquatic systems". Further, the 1991 Science Advisory Board to the International Joint Commission recommended that communities and individuals more highly exposed to persistent toxic substances need to be more clearly identified (Science Advisory Board, 1991).

Regions	NE	MA+	SA	EN*	ES	WN	WS	MO	PA
Pesticides	6	3.5	3.5	8	1	5	2	7	9
PCBs	8	5	2	6	1	3	4	7	9
Semi-Volatiles	7	5	3	1	4	6	2	8	9
Volatiles	5	6	1	3	7	9	2	4	8
PCDDs & PCDFs	9	2	4	1	3	7	8	5	6
@Total Ranks	35	21.5	13.5	19	16	30	18	31	41

Table 1. National Human Adipose Tissue Survey in the United States. Adapted from Phillips et al. 1991.
*EN = East North Central states which includes Indiana, Ohio, Illinois, Michigan, and Wisconsin.
+MA = Mid-Atlantic states which include New York and Pennsylvania.
@Regions which rank high for a particular category are indicated by low numerical scores.

Since 1990, there have been 32 research projects, funded by the Great Lakes Protection Fund, NIH, ATSDR, and the Great Lakes Health Effects Program, which identify and monitor populations who are thought to be more highly exposed to persistent toxic substances and which evaluate potential health effects associated with different levels of exposure. Most of the research has focused on Native Americans and anglers. There are also two studies, currently funded by ATSDR and GLHEP, that center on sustenance fish-eaters in more urban settings.

Figure 2 illustrates the different subpopulations that have been studied in the past four years and clearly shows that recreational anglers and Native Communities have been the main target groups. The focus of research on these subpopulations is not surprising given the fact that in workshops, symposia, and research throughout the Great Lakes, there have been repeated recommendations to study populations at the greatest risk of exposure to toxic chemicals in the Basin through fish consumption. Studies have shown that both Native communities and recreational anglers consume greater amounts of fish than the national average (Humphrey , 1988 and Forti *et al*. 1993).

Historical studies of anglers have shown a positive correlation between the amount of fish consumed and levels of contaminants in serum, specifically PCBs. The Michigan cohort studies (1970-1990s) specifically have spurred a number of research projects that look into fish consumption rates and potential health risks for this segment of the Great Lakes population. In studies conducted in the early 1970's and then again in the 1980's, the Michigan Department of Health surveyed a total cohort of 991 persons, 572 of whom regularly ate fish they caught from the Lake Michigan. The researchers found that the Lake Michigan fish-eater group had an average fish consumption rate that was nearly five times the national per capita fish consumption average commonly used for risk estimates (Humphrey, 1988). These studies also showed that the fish eaters had significantly higher serum concentrations of PCBs than the non-fish eaters. Research conducted on a subset of this cohort in 1989 found that PCB levels had decreased slightly in fish eaters. No statistically significant associations, however, were observed between either increased or decreased fish consumption and the PCB serum levels. Other researchers currently funded under the ATSDR's Great Lakes Program will be studying elderly members of the Michigan fishier cohort as well as identifying and developing new cohorts in the Great Lakes Basin.

Due to their traditional dependence on fish as a food source, Native communities are also considered special risk populations. For instance, the Mohawk tribe that live along the St. Lawrence River consume an average of 25g/day (1/2 pound per week) of locally caught fish. This is two to six times higher than the average amount of sport-caught fish consumed by recreational anglers (Forti *et al*. 1993).

Another study conducted on the same population suggests that certain high risk groups have changed their behavior to avoid exposure to contaminants. In 1992, Fitzgerald et al. investigated the levels of PCBs, p,p'-DDE, mirex, and HCB in the breast milk of fifty-three Mohawk women from Akwesasne who gave birth from 1988-1990. According to Fitzgerald, data from exposure assessments done between 1986-1989 on the Mohawk women showed a positive association between lifetime exposure to PCBs from the consumption of local contaminated fish and their breast milk PCB concentrations.

In contrast, Fitzgerald's study concluded that this correlation was no longer apparent among women who gave birth in 1990 because their fish consumption rates were so low. Indeed, local fish consumption has decreased over time among Mohawk women, from two meals to less than one-half of a meal per month during pregnancy. The researchers attribute this to the success of fish advisories, issued by Mohawk, state, and federal agencies, against the eating of fish from the local area by women of child- bearing age (Fitzgerald *et al.* 1992). We have however, not found any scientific studies to quantify the negative health impacts on the Mohawk people of shifting from traditional sources of readily available nutrition.

Native communities are involved in studies to examine the levels of exposure to contaminants and health risks associated with these levels. The Effects on Aboriginals of the Great Lakes Environment (EAGLE) project is currently underway in Canada, and involves Native communities throughout the Great Lakes. The EAGLE project is one of the only projects on Native communities that is taking a holistic approach to looking at the effects of environmental pollutants on a community. They are not only looking a the adverse health effects but also the effects on traditional , cultural practices and socio-economic impacts.

C. Linking Exposure and Effects

The 1991 Science Advisory Report to the International Joint Commission summarizes several workshops and meetings to discuss health effects research needs. The report concludes that "The traditional public health approach to monitoring for cancer and unusual birth outcomes is too blunt to capture the subtle reproductive effects of Great Lakes contaminants. Subtle health effects observed in wildlife provide clues for the design of experimental approaches for determining if the same or similar effects occur in human populations."

Since 1990, 40 studies have examined health effects endpoints in wildlife, laboratory animals, or humans in order to characterize causal relationships between exposure to contaminants commonly found in the Great Lakes ecosystem and various health-related effects. Most of the human health projects we reviewed include assessments of the relationship between environmental exposures and human body burdens and are considered in the previous category as well. Six of the projects simply look at patterns in the distribution of potentially environmentally-related human health effects, such as the mapping of reproductive outcomes in Ontario, or the relation of drinking water sources in New York's Great Lakes Basin to congeni-

Endpoint	Wildlife	Humans	Laboratory Animals
Reproductive Outcome	4	7	2
Reproductive Function	7	3	3
Disease	1	2	1
Immunotoxicity	1		1
Subclinical **	1	2	
Neurobehavioral		4	5
Neurotoxicity			6

Reproductive outcomes = early pregnancy loss; fetal death; birth weight; congenital anomalies.
** Subclinical effects = endocrinological or metabolic effects.

tal birth defects. These studies do not measure contaminant levels, but the results can form the basis for future research to investigate cause/effect associations and are included in this analysis. A majority of the epidemiological research linking exposure in populations to potential health effects occurs in the United States under the Great Lakes Program.

More recently some studies have been funded which look at more subtle reproductive, developmental and metabolic processes, and how certain substances can disrupt these processes. Still, as can be seen in Table 2 below, a majority of these research projects have concentrated on reproductive functioning and outcomes, such as infertility, congenital anomalies, and spontaneous fetal death. Great Lakes fish and wildlife, particularly fish eating birds and mammals have been the focus of this research for far longer than humans. Wildlife studies provide clues to the kinds of effects that could appear in humans, particularly those who live in closest contact with the contaminated ecosystem, drawing their sustenance from it. Table 2 shows the types of health endpoints being examined in wildlife, human, and laboratory studies since 1990 (some studies consider multiple endpoints).

Concern about the effects on developing embryos and newborns from exposure to contaminants in utero and from breast milk grew as a result of studies conducted during the 1980s on children born to mothers who had consumed contaminated fish. Researchers found lower birthweight, reduced gestational age, and smaller head circumference (Fein *et al*, 1984b) correlated with intrauterine exposure to PCBs. Since then there have been follow-up studies which suggested that neurobehavioral deficits may extend beyond infancy (Jacobson, *et al* 1990a and b). In addition, there have been other studies that look at reproductive outcomes such as birthweight and spontaneous fetal death, that have shown no correlation between fish consumption and adverse effects (Dar *et al*, 1992; Buck *et al*, 1993, and Mendola *et al* 1994).

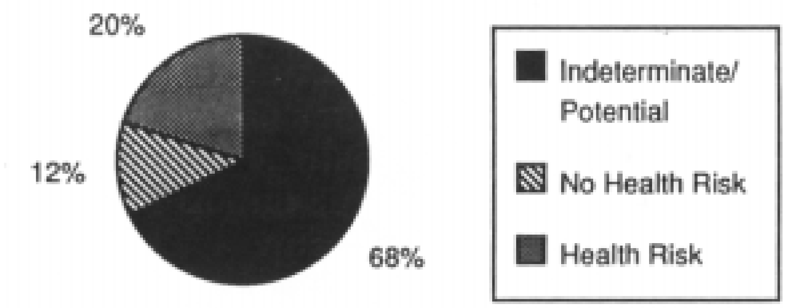

Figure 3. Public Health Risks at Superfund Sites in Areas of Concern(out of 50 sites)

Much less is known about potential behavioral effects. Besides the Jacobson's studies cited above, there have been studies on rats fed Lake Ontario salmon contaminated with PCBs, mercury and lead which showed an increased reactivity to aversive events (Daly, 1991). ATSDR is currently funding research to examine potential adverse neurobehavioral effects on a cohort of children born to mothers who consumed Lake Ontario fish.

Recent information suggests potentially disastrous consequences of widespread exposure to environmental estrogens that may disrupt the activities of certain naturally occurring hormones in an organism. The research to-date has mostly shown this relation in wildlife which have experienced reproductive and developmental abnormalities (Guillette *et al* 1994; and Fox, 1992). The potential effects of environmental estrogens on humans is an area that requires further research. One study of women showed correlation between the presence of PCBs and DDT in tissues and increased incidence of breast cancer, however, these findings have not been replicated (Wolff *et al* 1993).

Analysis of Human Health Research in the Areas of Concern (AOC)

Although the International Joint Commission has encouraged Remedial Action Plan (RAP) committees to include human health considerations in their plans, it has not issued specific guidelines for dealing with human health concerns in the AOCs. However, in the 1993 Science Advisory Board Report, the Board does identify some human health indicators for communities to consider and

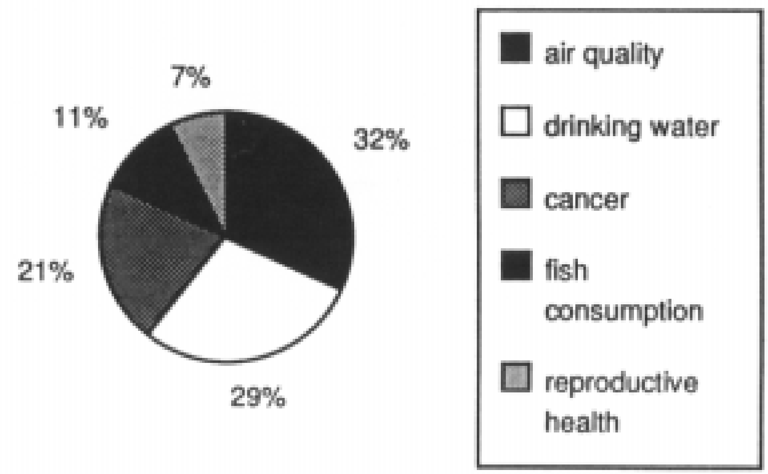

Figure 4. Community Health Concerns Identified (n=23)

recommends that "...the IJC in conjunction with several Remedial Action Plan Teams, develop guidelines for selection of human health indicators in Remedial Action Plans..." In addition, the Board recommends that the IJC "...promote the assessment of human health in the RAPs by encouraging RAP groups to involve human health experts in the RAP public advisory committees." In 1993, we conducted a telephone survey of all of the Coordinators in the 43 Areas of Concern as well as some members of the RAP Public Advisory Councils to find out how they incorporated human health concerns in their RAPs. Analysis of the responses shows that many are unsure of how to address human health issues in their AOC. Further complicating the matter is the fact that many of the RAP coordinators are from natural resource agencies, not agencies concerned with public health. Consequently, many AOCs are faced with lack of expertise in the area of human health. This trend is changing however, as more and more AOCs have successfully involved local health departments and local medical health professionals in the RAP process.

To address this issue, the Department of Health in Canada has established guidelines which are contained in the handbook: "Investigating Human Exposure to Contaminants in the Environment". The Department held regional workshops in Canada to present the handbook to RAP program leaders and health professionals in the AOCs. Although no such guidelines exist in the U.S., there is an effort by some AOC communities to come up with a framework for incorporating human health considerations into RAPs.[1]

The determining factor in whether or not an AOC addresses human health in their RAP largely depends on the type of health risks involved and the concerns of the participants in the RAP process. Some RAPs have clearly defined human health concerns, for example the Lower Green Bay RAP which states in its 1987 report: "Human health concerns are a driving force for cleaning up the river/bay ecosystem. They are probably the most visible and publicized aspect of pollution problems in the area. The beaches near Green Bay have been closed since 1938." (Lower Green Bay RAP, 1987). In contrast, other RAPs may not have clearly defined health issues. In fact, distinguishing between generalized health problems across the whole Great Lakes-St. Lawrence basin and those specific to an AOC locale is a difficult task. In some cases, it may be a general concern about human health and the environment that is catalyzing the push to include human health considerations in RAPs. In other cases it may be localized conditions associated with Superfund sites causing RAP participants to consider human health issues in RAPs.

Superfund Site Assessments as a Source of Information

Many of the U.S. AOCs include Superfund sites. Many RAP Coordinators in the U.S. said they would use the Superfund health assessments conducted by ATSDR and state health agencies to reveal what, if any, human health concerns exist in their AOC. Consequently, we conducted an analysis of 50 of the human health assessments conducted in the AOCs in the U.S. We looked for what, if any, health effects or human health risks were identified, and what the exposure routes were. ATSDR classifies the health risk by three major categories: Indeterminate/potential health risk, no health risk, or health risk. We concluded that of the 50 sites, 68% constitute an indeterminate/potential health risk, 12% pose no health risk, and 20% have a known health risk associated with exposure at the site (Figure 3). Many of the reports asserted that there was insufficient information to assess exposure or calculate health risks.

Of the 50 public health assessments conducted by ATSDR and the state health departments in the Areas of Concern, only 13 concluded that more detailed health studies were warranted. The most common reasons given for no further health studies were: 1) there is no indication of exposure; and 2) if exposure has occurred, the population potentially exposed is too small to conduct a statistically valid study.

Community health concerns identified by health officials conducting the assessments were also analyzed. Prior to 1989, a majority of the assessments did not identify community health concerns. Of the 50 health assessments analyzed, 23 indicated that there were concerns raised by members of the public over issues related to exposure to contaminants. Concerns over air quality accounted for 32%, drinking water quality for 29%, and 21% for cancer. Figure 4 shows the distribution and types of community concerns identified in the assessments.

Future Directions of Research

The governments have made substantial progress in establishing monitoring and exposure characterization programs. Indeed, at the recent State of the Lakes Ecosystem Conference, several presenters noted that the research programs in Canada and the U.S. provide fitting models for environmental health research world-wide (State of the Lakes Ecosystem Conference, 1994).

The published studies we review do not prove with certainty that populations in the Great Lakes are exposed to higher levels of toxics than other populations in the world. Rather, the few studies that have been done to compare measurable body burdens have drawn varying, and sometimes conflicting conclusions.

The epidemiological model of public health science and the risk assessment paradigm of regulatory decision-making for toxics are the principal driving forces guiding today's research priorities. Based on the assumption that epidemiology and risk assessment will suffice to answer the public's questions about environmental contamination of the Great Lakes, most current research is constructed to fit this paradigm. The problem we have yet to confront is - what happens if this assumption is wrong?

. . .Of the 50 public health assessments conducted by ATSDR and the state health departments in the Areas of Concern, only 13 concluded that more detailed health studies were warranted. . .

Currently, the following hypotheses are being tested:

- That people in the Great Lakes region are subject to toxic contaminant exposure at levels peculiar to the Great Lakes;
- That the most significant exposure route is through fish consumption;
- That the cohorts for epidemiological study should be formed from heavily exposed groups such as sports anglers, native populations that rely on wild foods for significant portions of their diet, and poor people who supplement their diets with their catch;
- That there will be correlations between exposure, body burden and measurable (if not clinically significant) negative health consequences;
- That the risk of experiencing a health impact can be measured, then compared to risks of other "life-style" activities and, if necessary, reduced through appropriate personal actions, public health policies and environmental regulations.

On the basis of these hypotheses, certain types of research receive the highest priority. They are:

- Characterizing exposure and body burdens.
- Improving understanding of the toxicity of priority pollutants and the biochemistry of exposure.
- Identifying populations at increased risk of exposure.
- Testing more highly exposed populations for certain endpoints possibly associated with their exposure (while correcting for many other exposure pathways, i.e., confounding variables)
- Comparing highly exposed populations to less exposed groups.
- Identifying, in the laboratory and in the field, endpoints to consider for further research.

What happens if the hypotheses driving current research priorities are discovered to be unfounded or only partly confirmed? This could be interpreted to mean that the health problems associated with toxic chemicals in the Great Lakes are not as important as some would choose to believe. But it could also mean that we have been asking the wrong questions and testing the wrong hypotheses.

The bigger problem is that the premise on which we base our research is not necessarily wrong, but greatly oversimplified. Any number of factors could complicate the issues. For example:

• It may be that we discover there is little biologically meaningful difference between Great Lakes exposure levels and that in the general population, or between fish eaters and non-fish eaters. Will that mean that no one is affected,...or that everyone is? Existing exposure levels may cause subtle, long term degradation of the quality of biological life support systems through hormonal and neurological system disruption or other mechanisms. Current methods are inadequate to the task of detecting such disruptions.

• It is possible that the "at risk" populations are not the fish eaters or any other group associated with exposure levels but instead, are groups associated with particular sensitivities, or individuals who have previously been exposed to something else or at a particular developmental stage.

• It is also possible that the interactions between chemical effects are as important as the toxic effects of any single chemical. Our need to link effects with specific chemicals, drives the research into chemical-by-chemical investigations.

• The effects to be studied may not manifest themselves in the exposed individual but in their offspring, hence effects observed in the population would reflect exposures a generation ago.

Current research priorities have yet to address many of these issues. Many answers are still waiting to be found.

Footnote

[1] The Great Lakes Research Consortium is hosting a workshop in February 1995 to address this issue.Workshop proceedings will be available by the summer of 1995.

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Dynamics of PCBs In the Aquatic Environment

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The disposition of PCB congeners in the aquatic environment has been investigated systematically since the inception of practical congener specific PCB analysis on capillary columns in the early 1980's (Bush et al., 1982; Ballschmitter and Zell 1982; Stalling et al., 1985). These investigations have made earlier work which used packed column gas chromatography more or less redundant, although valuable general principles were developed using that technology (Sanders, 1989). Detection limits commonly demanded by government agencies in the United States for environmental water analysis are frequently in the microgram per liter range, the lowest defined is 65ng/L on a per Aroclor basis (EPA method 608, 1984) and congener specific analysis is not required. Unless congener specific analysis is used and detection limits are in the ng/L range, vital information is lost. Risk management of, for example, hazardous waste sites or aquaculture projects near contaminant sources, is difficult if not impossible.

The major water bodies of the NE United States can be ordered in degree of increasing pollution by PCB as follows: Lakes: Superior, Huron, Champlain, Michigan, Erie and Ontario; Rivers: St. Lawrence, Connecticut, Hudson. There are also highly polluted tributaries and localized partial impoundments such as the Fox River and Green Bay, Michigan, parts of the St. Lawrence River near the aluminum industry associated with the Moses-Saunders Power Dam near Massena New York, and New Bedford Harbor, Massachusetts. To measure low PCB water concentrations (< 0.01ng/L per congener) very large volumes of water must be collected to achieve a reliable electron capture detector response (Oliver and Nimi 1988). As a result, the major part of aquatic tropodynamic studies of PCB have been undertaken in the more polluted areas.

At very low levels, there is the possibility that PCBs will be bound to naturally occurring colloidal components of the water column so that their availability (or chemical potential) is difficult to assess (Hasset,1985). We shall review congener specific work in sediment, water and several trophic levels of biota.

Sediment PCB Patterns

When analyzing cores from a transect of the upper Hudson River taken in 1984 from mile point 192.7 it was clear that fine sediment at the margin of the river had a radically different pattern from gravelly cores near the center of the river (Bush et al., 1987). The fine cores taken from several locations in the upper river (Fig. 1) resembled each other strongly, but the coarse core horizons resembled the original PCB mixture which was disposed of into the Hudson River from electrical capacitor manufacture. It consisted of a mixture of Aroclors 1242, 1016 and 1254, where Aroclor 1254 comprises roughly 20% of the residue (Sanders 1989). The PCB congener pattern shown in Figure 1 was attributed by Brown et al. (1987) to anaerobic microbial dechlorination of the PCB molecules and indeed, measurement of the reducing potential of the 192.7 river mile transect core segments (Bush et al., 1987) showed that fine sand core segments had reducing potentials as low as -0.350v (relative to the Ag/AgCl electrode) confirming the presence of anaerobic microbial activity.

The major water bodies of the NE United States can be ordered in degree of increasing pollution by PCBs as follows: Lakes Superior, Huron, Champlain, Michigan, Erie and Ontario; Rivers: St. Lawrence, Connecticut, Hudson.

This same phenomenon has been observed near the pollution sources at Massena NY, The Fox River and in New Bedford Harbor. The cause of the observed pattern change is generally agreed to be microbial dechlorination, and has been duplicated in several laboratories (Ye et al., 1992; Rhee et al., 1992). However, a very

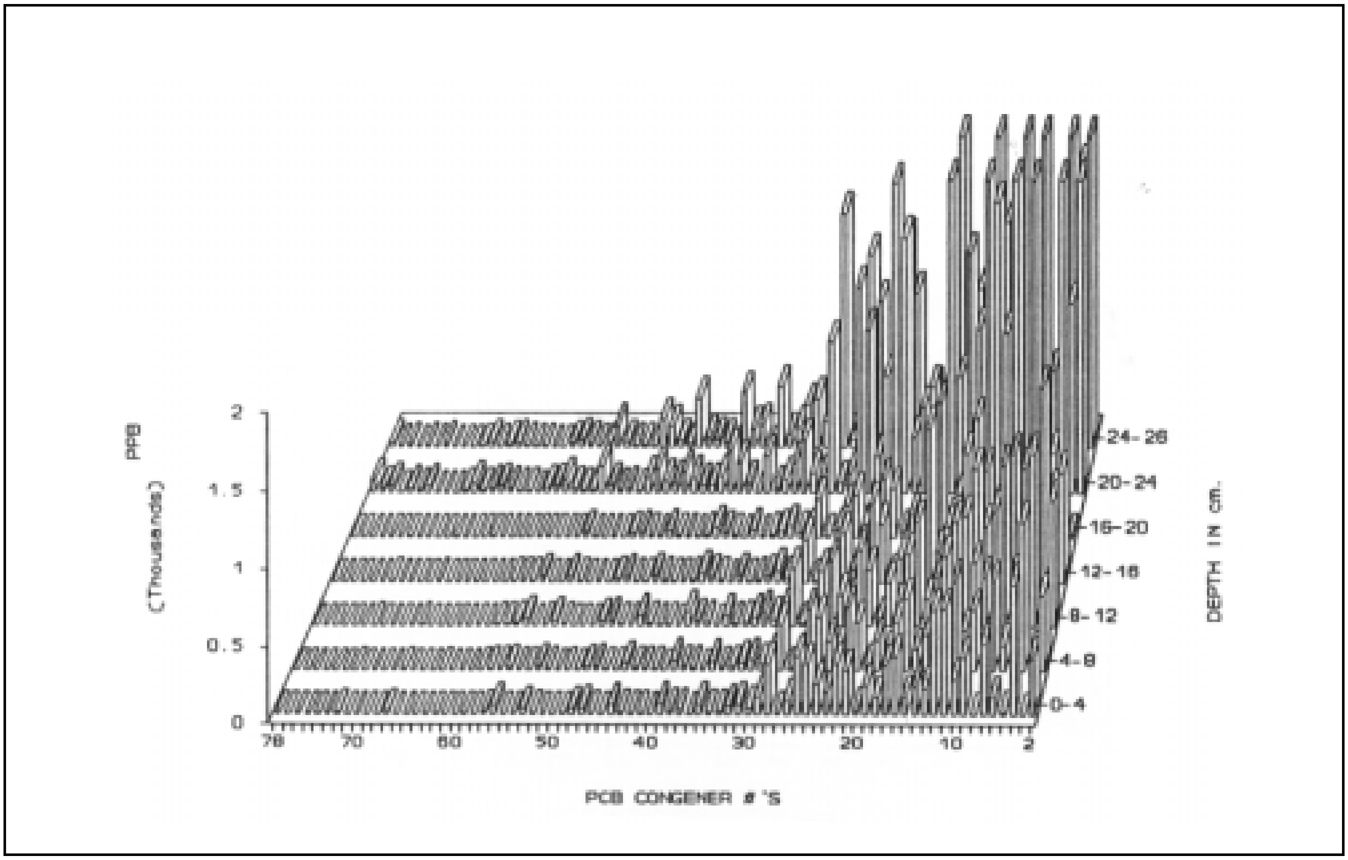

Figure 1. PCB congener patterns from a 26 cm core taken at Griffin Island in the upper Hudson River.

similar pattern has also been produced in water by slow passage of water over PCB contaminated sediment, vis: by purely physicochemical means (Wood,1987; Sokal, 1992). Profound PCB pattern changes occur when unpolluted lake sediment is suspended in an aqueous solution of PCB (Bush, 1990) so that physicochemical pattern modification cannot be ignored. The relative contribution of physicochemical pattern distortion, in which the most soluble PCB congeners gain predominance, or microbial processes where a similar predominance of lower chlorinated congeners is produced, is not presently clear.

Water

Early examination of PCB congener patterns in water was again carried out first, on the upper Hudson River. The greatest congener concentration was that of 2,2'-dichlorobiphenyl comprising along with 2-chloro and 26-dichloro-biphenyls, one third of the total PCB present in the water (Bush et al., 1985). The concentrations of successive congeners diminish, being well correlated with the octanol/water partition coefficient of the congeners.

The water pattern was replicated in the laboratory using a sediment release reactor, where a very slow stream of pure water is passed over a measured surface of PCB contaminated sediment (Wood et al., 87). Later, water was passed through a cartridge packed with PCB-coated glass beads and a similar pattern distortion in the water chromatogram vis a vis the original PCB mixture pattern was produced (Sokal et al., 1992).

Although the transport of contaminated sediment has long been considered to be the major PCB transport mechanism and much environmental modelling has been carried out on that basis, now that accurate measurements have been made of water concentrations, transport in aqueous solution appears increasingly important, especially when enormous flows are considered as in the Niagara River and the Hudson River.

For example, zebra mussels were collected from the Niagara river at Niagara on the Lake, Ontario, shortly after they had established their first colonies in 1990. They had already become contaminated at the mg/kg level with a residue closely resembling Aroclor 1254, indicating

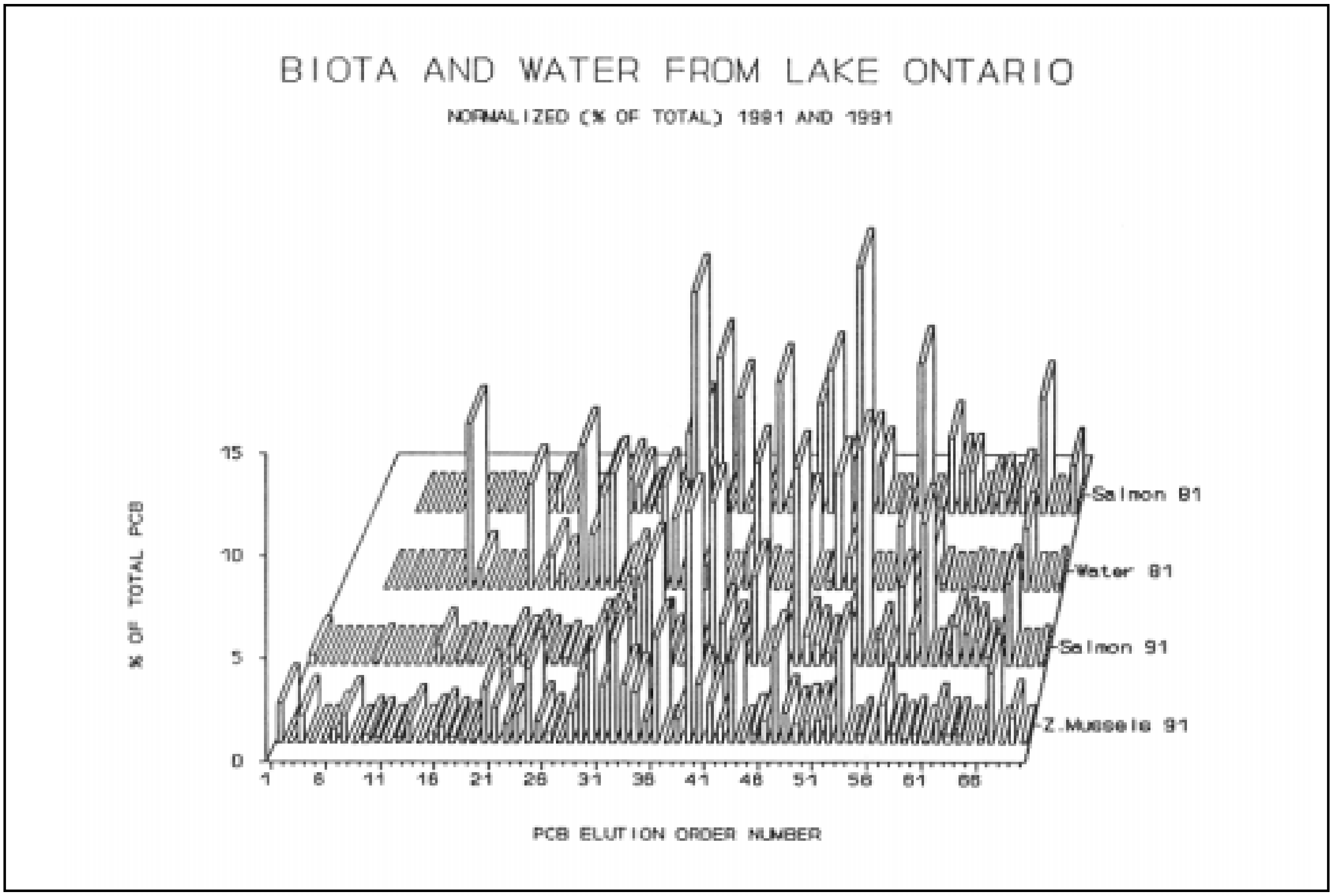

Figure 2. Patterns of PCB pollution from Lake Ontario. 1981 data are from Oliver and Nimi (1988) reordered to match data from this laboratory.

that PCB are still being actively transported by the river at nearly undetectable concentrations. Between April 1991 and March 1992, forty-eight samples were taken at Fort Erie at the Lake Erie source of the Niagara River and at Niagara on the Lake at its mouth in Lake Ontario using a high volume continuous centrifuge similar to that reported by Oliver and Nimi (1988).

At Fort Erie, dissolved total PCB were 1.3ng/L and sediment born PCB were 0.3ng/L and the total loading was 0.6kg/day via water and 0.2kg/day via sediment. At Niagara on the Lake, dissolved PCB were 1.1ng/L and sediment born were 0.9ng/L, total load was 0.5 kg/day and 0.2kg/day respectively (Joint Study, 1994).

It can be fairly stated that as on the Hudson River more PCB is transported via aqueous solution than via sediment transport and also that most seems to originate in Lake Erie, although the mussels also contained substantial quantities of mirex, indicating a probable load from somewhere on the river itself.

Biouptake

Polychlorinated biphenyls (PCBs) have long been known to accumulate from the water column into the tissues of biota exposed to contaminated aquatic ecosystems (Shaw & Connell, 1972). Whether the majority of exposure to PCBs occurs from bioconcentration from the water column (Shaw & Connell, 1987; Davies & Dobbs, 1984; McKim et al., 1985; Barron, 1990) or biomagnification through the food chain (Gobas et al., 1988; Oliver & Nimi, 1988; Rasmussen et al., 1990) is a topic of considerable interest and much debate.

Numerous attempts have been made to quantify the variables influencing PCB uptake from the water (bioconcentration) and the food web (biomagnification) on a fish's total PCB burden (bioaccumulation) (Barron, 1990). Disagreement exists over whether the majority of a fish's PCB bioaccumulation comes from the surrounding water column or via the food it eats, with species which breath air such as the turtle or seal, both of which are badly contaminated by PCB in the waters of the

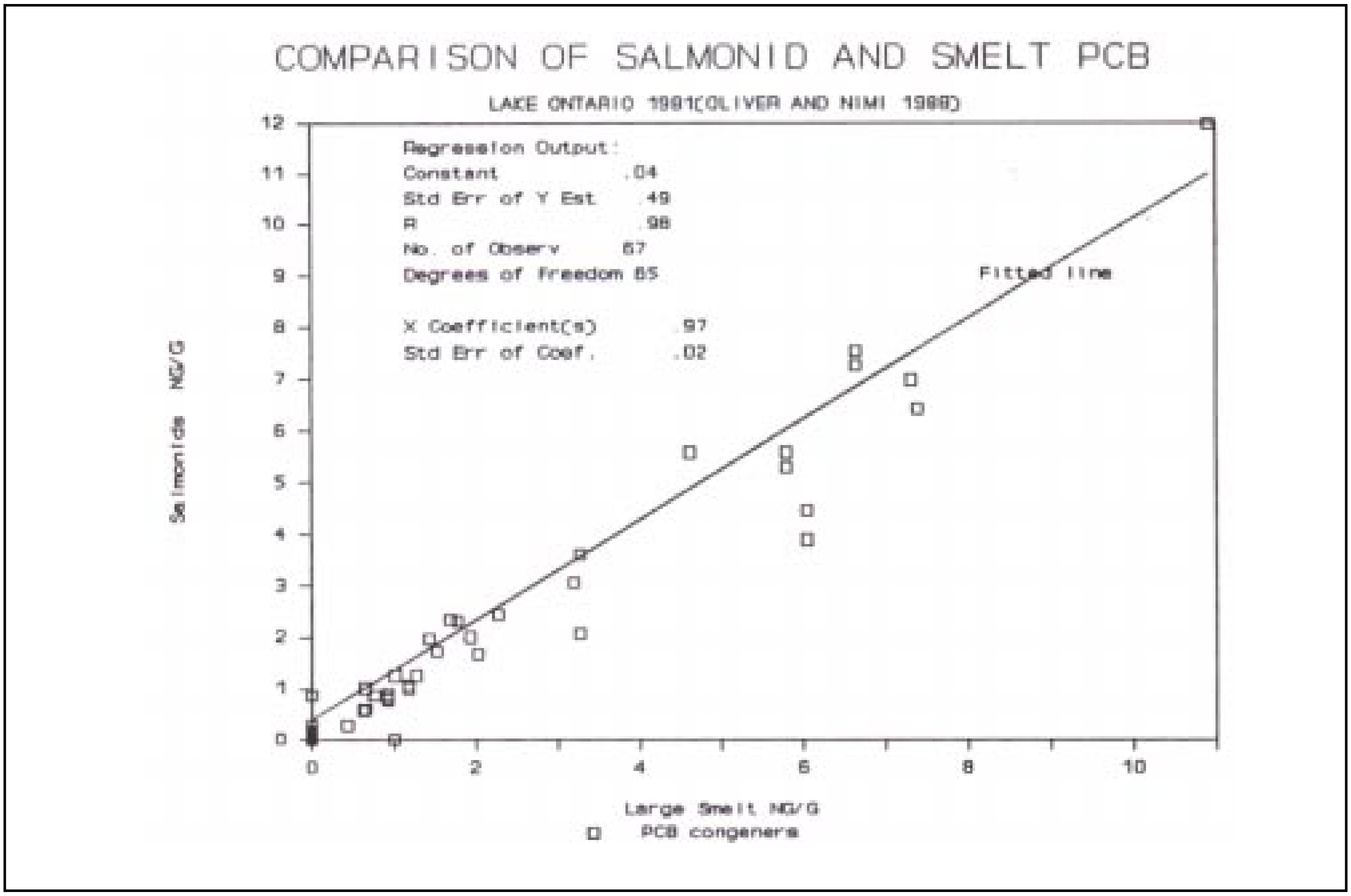

Figure 3. Comparison of the PCB congener concentrations in large smelt and salmonids reported by Oliver and Nimi (1988) from Lake Ontario in 1981 .

USA, uptake is from food (Olafsson et al., 1983; Hong et al., 1993). An accurate interpretation of the factors determining bioconcentration of PCB congeners from the water is an essential component of environmental risk assessments. It was shown clearly by Wood et al. (1987) that chironimid larvae accumulated PCB in the stream of water from a sediment release reactor producing a pattern transformation similar to that observed in the field in wild chironomids (Bush et al., 1985). The former could only have accumulated PCB either from water solution directly.

Novac et al. (1990) exposed laboratory raised chironomids in cages and were able to determine in the river the uptake curves of the major PCB congeners present in the water, some congeners (2,2', 26 and 26,2') reached 90% of equilibrium in 2-4 hours whereas 2,4,5,2',5'-pentachlorobiphenyl and other more chlorinated congeners took more than 5 days to reach 90% of equilibrium and reached eventual concentrations 10 - 50 times higher than the less chlorinated congeners. This demonstrated clearly the disparate tropodynamic rates and equilibrium concentrations of the different PCB congeners.

. . .The zebra mussels had already become contaminated at the mg/kg level with a residue closely resembling Aroclor 1254, indicating that PCB are still being actively transported by the river at nearly undetectable concentrations. . .

The factors which determine the uptake of PCBs from a contaminated media to the flesh of fish have been quantified in several experiments (Vieth et al., 1979; Spacie & Hamelink, 1982; Shaw & Connel, 1984; Schuurmann & Klien, 1988; Barron, 1990; Sijm et al., 1992). Oliver and Nimi (1988) report the use of high volume continuous centrifuge to separate particles from Lake Ontario water to determine concentrations of dissolved PCB congeners.

They also analyzed bottom sediment, suspended sediment, plankton, mysids, oligocheates, amphipods, sculpin, small and large smelt and salmon. Their data are shown in Fig.2 where the PCB congeners they measured are ordered the same as the PCB congeners we measure on DB-5 type capillaries.

Also shown is a chromatogram of salmon composite collected at Oswego, NY for toxicological studies by Helen Daly and a composite of zebra mussels collected when they first started colonization at Niagara on the Lake, Ontario, by Ronald Scrudato (both of the NY State University at Oswego). There is a clear resemblance between the water pattern and the salmonid and mussel patterns. Using the pattern regression approach (Bush et al., 1994) we have examined the correlation between the patterns of the Oliver and Nimi's various analyses. Figure 3 shows the large smelt chromatogram plotted against the salmonid chromatogram. It is obvious that the patterns are very strongly associated ($R^2>0.95$) and also that the concentrations in the two species are very similar (x coefficient=.97)

The regression coefficients of each of Oliver and Nimi's species, suspended sediment, bottom sediment and water are shown in Table 1. There is a very close resemblance between all the fish species and also mysids (R>.94) but there is a discernible resemblance between all the observations made (R>0.6). To clarify uptake by fish on a congener by congener basis, and to provide data for a proposed aquaculture project by the Mohawk nation at Akwesasne near Massena, NY, aquaculture-raised rainbow trout (Oncorynchus mykiss) were caged in the water column at a site with a water concentration of 900ng/ near a PCB-containing landfill and at two less polluted sites with water concentrations of approximately 40 ng/L of total PCB.

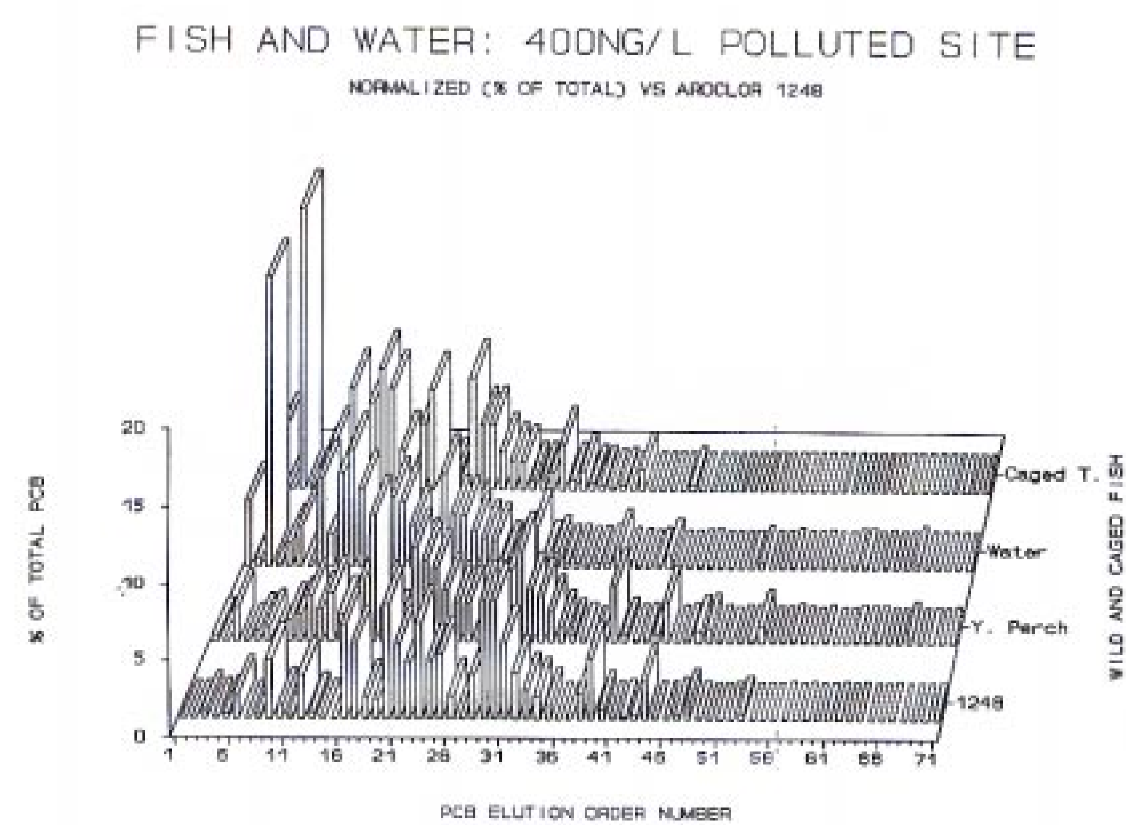

Figure 4. Comparison of PCB patterns in caged trout, wild fish (yellow perch) and water from Contaminant Cove, Akwesasne on the St. Lawrence River and Aroclor 1248.

Table 1.
Correlation coefficients of PCB patterns of various Lake Ontario samples versus salmonids (Oliver and Nimi, 1988)

Fish vs:	R
Large smelt	0.99
Small smelt	0.99
Alewives	0.94
Sculpin	0.95
Oligocheats	0.67
Amphipods	0.82
Mysids	0.95
Plankton	0.80
Susp. Sediment	0.84
Bottom Sediment	0.73
Water	0.62

Normalizing the data again showed clear trends (Fig.4).

The pattern of PCB in water resembles water solutions generated by passage over Aroclor 1248 supported on glass beads (Sokal et al., 1993) and the pattern taken up by the fish also resembles this, whereas the pattern in wild fish shown by a composite of 10 yellow perch taken from the 900ng/L site resembles the pattern of Aroclor 1248 which is known to contaminate the site. Regression coefficient values greater than 0.95 were obtained for fish patterns from the three sites.

At the most contaminated site (Contaminant Cove) a pattern of congeners almost exactly resembling the water PCB pattern was accumulated (R = .7) on two occasions, December 1992 and June 1993. Since the fish were hand fed uncontaminated fish food this is a clear demonstration of the importance of PCB uptake directly from the water column.

Bioconcentration factors of 2400 ± 50 were observed at 3^{O}C from water containing 900 ng/L with an uptake rate of 60 ± 18 ng/g/day and from 470 ng/L water at 17^{O}C 8,000 ± 270 with an uptake rate of 109 ± 29 ng/g/day. At 40ng/L and 17^{O}C the factors were 8000 ± 400 with an uptake factor of 13 ± 3 ng/g/day.

Because these factors were arrived at by regressing all the congeners against each other in the different media, the variance indicates the differential behavior of the individual congeners; the correlation coefficient being highly significant in all the regressions, confirms that the lipophilic property of the PCB congeners is the driving factor in the uptake. No evidence of attainment of equilibrium between fish and their aquatic environment was apparent after 30 days. The work of Novak et al. (1990) with a much smaller organism would predict that equilibrium might eventually be attained, but the labor intensive design of the caged fish experiment precluded continuation beyond 30 days.

Careful examination of the patterns in the fish did indicate a shift in pattern toward the more chlorinated congeners as time progressed, but it appeared that a long time would be required to reach the pattern shown by resident wild fish which closely resembled Aroclor 1248, the dominant pollutant in the area. By contrast, the congener pattern of fish from Lake Ontario, which were wild and so had probably reached equilibrium with their ecosystem resembles a mixture of Aroclors 1254 and 1260. It is probable that as the water concentration lowers, food chain contribution to the fish residue becomes more important. But at the relatively high concentration of 40ng/l observed near Akwesasne and in the Hudson River, direct uptake is certainly of predominant importance.

Conclusions

PCBs are a continuing problem in the waters of the NE United States. Input (or load) has not been reduced appreciably in the last 20 years. Enough PCB is still leaking into the Niagara River to produce mg/kg concentrations in freshly established zebra mussels at its mouth. They are still seeping into the Hudson River and moving to the Atlantic ocean at 1kg/day. Smaller sources such as the Fox river and the aluminum industry on the St. Lawrence seaway continue to load their receiving water bodies. Air transport to the Arctic is probably a result of this water pollution. Only when the political will is generated to remove PCB sources, will the problem of these ubiquitous compounds begin to diminish.

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In Vitro Neurotoxicology of Great Lakes Fish - Borne Contaminants

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Introduction

Consumption of fish from the Great Lakes by pregnant women is associated with elevated PCB body burdens and long-term deficits in cognitive function in their children (Jacobson *et al.* 1984; Jacobson *et al.* 1990; Humphrey 1988). However, the fish also contain other potentially neurotoxic contaminants that may exacerbate the neurological effects thought to be due to perinatal exposure to PCBs. At present, little information exists on which contaminant or contaminants may be responsible for the observed decreases in cognitive function, the mechanisms by which these contaminants might alter higher central nervous system (CNS) function or if the contaminants interact to produce a greater total response than would be predicted by the action of single toxicants.

In this study we examine the effects of: (i) florisil column-fractionated hexane extracts of Lake Ontario and Pacific Ocean salmon and (ii) individual toxicants, found by chemical analysis, to be present in the salmon, on dopamine (DA) function in pheochromocytoma (PC12) cells. We chose these cells because they synthesize, store, release and metabolize DA in a manner similar to that observed in the mammalian CNS (Greene *et al.* 1977; Kittner *et al.* 1987). Indeed, we have previously demonstrated that PC12 cells can be used to study the neurotoxicity of PCBs (Seegal *et al.* 1989; Shain *et al.* 1991) and, therefore, may be useful for describing the possible interactions between PCBs and other potential neurotoxicants. Furthermore, because alterations in *in-vivo* DA function are associated with changes in cognitive function (Brozoski *et al.* 1979; Lidow *et al.* 1989), information gathered from these *in-vitro* experiments should aid in understanding the neurochemical mechanisms responsible for the observed cognitive deficits seen in children whose mothers consumed contaminated fish from the Great Lakes.

Methods

Lake Ontario and Pacific Ocean salmon were lyophilized, extracted with hexane and treated with sulfuric acid to remove fatty acids which might otherwise interfere with the normal functioning of the PC12 cells. This extract, which contained the majority of the solvent-extractable organic contaminants present in the Lake Ontario salmon, was then loaded onto a 4% deactivated florisil column to separate the PCBs, mirex, *p,p'*-DDE and hexachlorobenzene (HCB) (40 ml of hexane, FRAC1) from the pesticides (lindane, dieldrin, heptachlor), dioxins and dibenzofurans (40 ml of methylene chloride, FRAC2). Each fraction was characterized by gas chromatography with electron capture detection and mass spectrometry (Bush *et al.* 1989; O'Keefe *et al.* 1984).

PC12 cells were grown in mass cultures and seeded at a density of 10^5 cells per well in 24-well trays five to seven days before each experiment. On the day of the experiment the growth medium was replaced with medium containing the fraction of interest dissolved in DMSO (DMSO concentrations in the media were 0.2%). Cells were exposed for one hour and then harvested (Seegal *et al.* 1989). In additional experiments, cells were exposed to: (i) a synthetic mixture of PCB congeners that approximated the congeners found in the salmon (*e.g.*, a 1:1 mixture of Aroclors 1254 and 1260); (ii) mirex, HCB, *p,p'*-DDE or (iii) the above contaminants in combination with the synthetic PCB mixture. Cellular DA concentrations were determined by HPLC with electrochemical detection (Seegal *et al.* 1986). Detection limits, defined as twice baseline, were $\leq$50pg/injection.

Results

Chemical Analyses of Contaminants in Lake Ontario and Pacific Ocean Salmon.

PCBs are the major contaminant in Lake Ontario salmon and were present at a concentration of approximately 2.0 ppm, expressed on a wet-weight basis. The PCB concentration in Lake Ontario salmon was more than 100-fold higher than in the Pacific Ocean salmon. Mirex, HCB, p,p'-DDE, 2,3,7,8-TCDD and 2,3,7,8-TCDF concentrations are presented in Table I. Six PCB congeners accounted for 40% of the total PCB content of the Lake Ontario salmon (Table II). The congener make-up of Pacific Ocean salmon was different from Lake Ontario salmon.

Table I. Organic Analysis of Fish Oil Extracted from Lake Ontario and Pacific Ocean Salmon

Contaminant	Lake Ontario Salmon[1]	Pacific Ocean Salmon[1]
FRAC1		
PCBs	237.1	2.39
p,p'-DDE	45.4	0.14
Mirex	16.0	0.07
HCB	0.35	0.044
FRAC2		
PCBs	2.18	0.0017
p,p'-DDE	n.d.	n.d.
Mirex	n.d.	n.d.
HCB	n.d.	n.d.
2,3,7,8-TCDD	1.31[3]	n.a.[4]
2,3,7,8-TCDF	0.67[3]	n.a.

[1]expressed as ppm [2]not detected
[3]expressed as ppb [4]not analyzed

Table II. Major PCB Congeners Found in Hexane Extracts of Lake Ontario and Pacific Ocean Salmon

Congener	Lake Ontario Salmon[1]	Pacific Ocean Salmon[1]
2,4,5,2',4',5'	10.4	4.5
2,3,4,2',4',5'	10.0	6.0
2,4,5,2',5'	6.2	4.3
2,3,4,5,2',4',5'	5.1	2.2
2,3,6,2',4',5'	4.5	3.4
2,4,5,2',4'	2.7	2.2

[1]expressed as a percent of the total

Effects of Salmon Extracts on DA Content in PC12 Cells

The quantity of florisil column-prepared extract needed to produce a final medium PCB concentration of 200 ppm was determined from gas chromatographic analysis of PCB concentrations in the Lake Ontario H_2SO_4-treated extract. This concentration of PCBs was chosen based on our previous studies with exposure of PC12 cells to PCBs. Changes in PC12 cell DA content following exposure of these cells to Lake Ontario and Pacific Ocean FRACS1 & 2 were analyzed statistically using the non-parametric Mann-Whitney U test. Results,

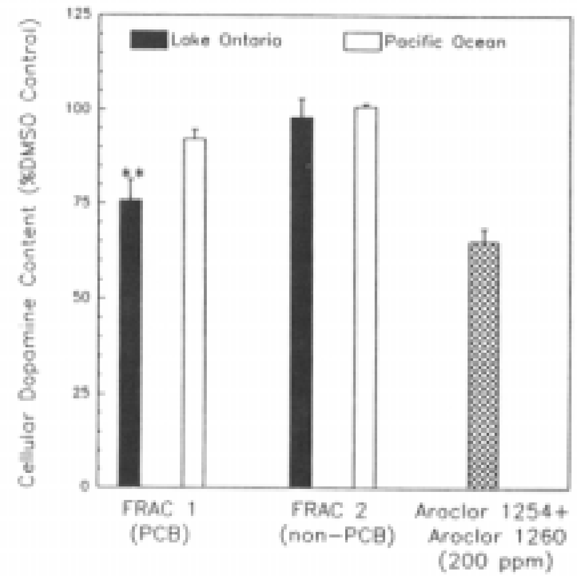

Figure 1. PC12 cells were exposed for 1 hr to media made using Lake Ontario FRAC1 or the same volume of Lake Ontario FRAC2, Pacific Ocean FRAC1 or Pacific Ocean FRAC2. The Lake Ontario FRAC1 medium was prepared to have a final PCB concentration of 200 ppm. Cell responses are presented as a percent of the vehicle (DMSO) control. N=4-8 wells/data point; **Significantly different from DMSO-vehicle control using Mann-Whitney U test ($p \leq 0.01$).

shown in Figure 1 and observed in replicate Lake Ontario and Pacific Ocean salmon experiments, varied by no more than 3-4%.

The hexane-eluted material (FRAC1) from Lake Ontario salmon significantly reduced cell DA content by 24% ($p \leq 0.01$) while FRAC1 of the Pacific Ocean salmon reduced cell DA content by only 8%, a nonsignificant difference compared to DMSO vehicle-exposed cells. The methylene chloride-eluted material (FRAC2) from both the Lake Ontario and Pacific Ocean salmon did not significantly alter PC12 DA content. Exposure of cells to 200 ppm of the synthetic PCB mixture, produced a 30% decrease in cell DA content—an effect similar to that produced by exposure of cells to the Lake Ontario FRAC1. These results suggest that the significant reductions in PC12 cell DA content following exposure to Lake Ontario FRAC1 are due to the PCBs present in this extract. Indeed, when we exposed cells in culture to several concentrations of Lake Ontario FRAC1 and the synthetic

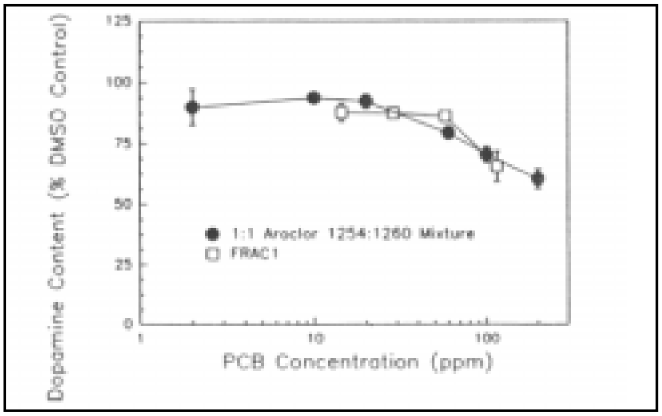

Figure 2: PC12 cells were exposed to media containing varying concentrations of a mixture of Aroclor 1254:1260 (2-200 ppm) or amounts of FRAC1 yielding varying concentrations of PCBs (13-100 ppm) for 1 hr before analyzing for cellular dopamine content.

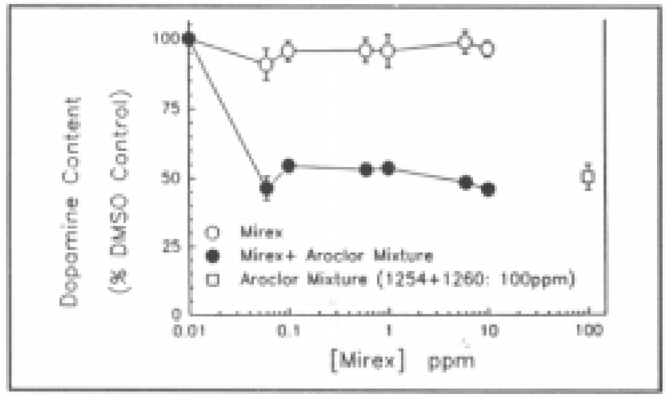

Figure 3. PC-12 cells were exposed to media containing varying concentrations of Mirex (60 ppb-10 ppm) alone or in combination with a 100 ppm mixture of Aroclor 1254/1260 for 1 hr before analyzing for cellular dopamine content.

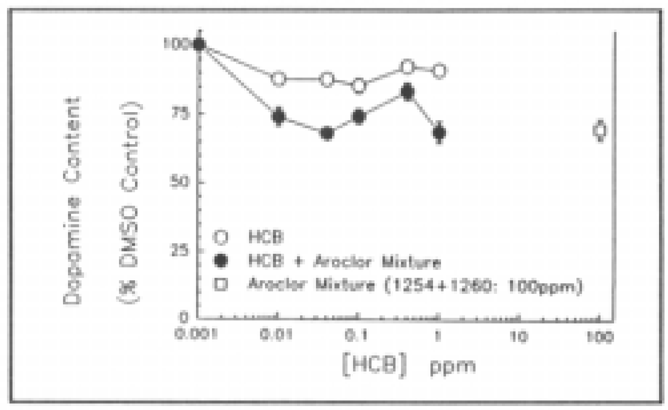

Figure 4. PC-12 cells were exposed to media containing varying concentrations of HCB (10 ppb-1 ppm) alone or in combination with a 100 ppm mixture of Aroclor 1254/1260 for 1 hr before analyzing for cellular dopamine content.

Aroclor mixture, the reductions in cellular DA concentrations were virtually identical (Figure 2). These results further support our hypothesis that reductions in cellular DA concentrations are due to the PCB congeners and not to the additional contaminants present in Lake Ontario FRAC1.

In order to directly test the above hypothesis, PC12 cells were exposed to the other major contaminants present in FRAC1 (*e.g.*, mirex, HCB or *p,p'*-DDE) either alone, or in combination with 100 ppm of the Aroclor 1254/1260 mixture. The reductions in cellular DA concentrations were compared with those seen following exposure to a 100 ppm mixture of Aroclors 1254 and 1260.

Mirex concentrations in the fish-oil extract were 16 ppm (Table I). PC12 cells were exposed to mirex at concentrations in medium of 60 ppb to 10 ppm either alone or in the presence of a 100 ppm mixture of Aroclor 1254/1260. Mirex, either alone, or in the presence of the synthetic Aroclor mixture, failed to alter cellular DA concentrations (Figure 3).

HCB concentrations in fish-oil extracts were 350 ppb (Table I). PC12 cells were exposed to either HCB only, in doses ranging from 10 ppb to 1 ppm, or identical concentrations in the presence of 100 ppm Aroclor 1254/1260. As was seen with mirex, HCB had no discernible effects on cellular DA content. Simultaneous exposure to PCBs and varying concentrations of HCB did not reduce cellular DA content to a greater extent than exposure to the Aroclor 1254/1260 mixture only (Fig.4).

p,p'-DDE is a major contaminant in Lake Ontario salmon and is present in the fish-oil extracts at concentrations of 45 ppm. We exposed PC12 cells to 4, 20 or 100 ppm of *p,p'*-DDE either alone or in the presence of a 100 ppm of Aroclor 1254/1260. PC12 cellular DA content was reduced at the highest *p,p'*-DDE concentration (which is approximately twice the concentration found in the fish-oil extract), although neither of the two lower doses of *p,p'*-DDE altered cellular DA content. When PC12 cells were exposed to *p,p'*-DDE in the presence of a 100 ppm mixture of Aroclors 1254/1260, there was no evidence of an interaction with PCBs (*e.g.*, reductions in cellular DA content were no greater than those seen following exposure to the synthetic PCB mixture only). These results are shown in Figures 5A-C.

Discussion

Chemical analysis of Lake Ontario and Pacific Ocean salmon indicated that the former samples contain 50-fold or more of each of the solvent-extractable putative neurotoxicants identified in Table I than were found in Pacific Ocean salmon. These results supported our initial experimental approach, *i.e.*, that extracts of Pacific Ocean salmon could be used as a biological control for Lake Ontario salmon. When florisil fractions of these extracts were tested, only the hexane-eluted fraction from Lake Ontario salmon had any significant effect on PC12 cell DA content.

This observation has several important consequences. First, the lack of activity in the Pacific Ocean fractions indicate that the contaminants in Pacific Ocean salmon were not present at concentrations sufficient to alter PC12 cell DA content and thus the Pacific Ocean salmon can be used as a control for the Lake Ontario salmon.

Second, since the percent reduction in cellular DA content following exposure to the hexane-eluted fraction (FRAC1) of the Lake Ontario extract was similar to that seen with a 200 ppm concentration of a 1:1 mixture of Aroclors 1254 and 1260, which closely approximates the congener patterns found in the Lake Ontario salmon, we conclude that the active components in this fraction are the PCBs. This statement is further supported by comparing the effects of varying concentrations of FRAC1 and the synthetic mixture of PCBs on cellular DA content. The dose response curves for both FRAC1 and the

Aroclors were virtually identical indicating that the PCBs are the major contributor to the observed decreases in cellular DA content (Figure 2). Finally, the lack of significant reductions in cellular DA content, following exposure of PC12 cells to the other major toxicants found in Lake Ontario FRAC1, either alone or in combination with exposure to PCBs, strongly suggests that the PCBs present in Lake Ontario FRAC1 are responsible for the observed reductions in cellular DA content.

Third, since no effect was seen with the methylene chloride-eluted fractions (FRAC2), which contains the more planar contaminants including dioxins and dibenzofurans and the more polar pesticides, we conclude that these contaminants do not play a significant role in reducing cell DA content.

What are the implications of these findings? First, sub-chronic exposure of the adult nonhuman primate to Aroclors 1016 and 1260 resulted in PCB accumulation in

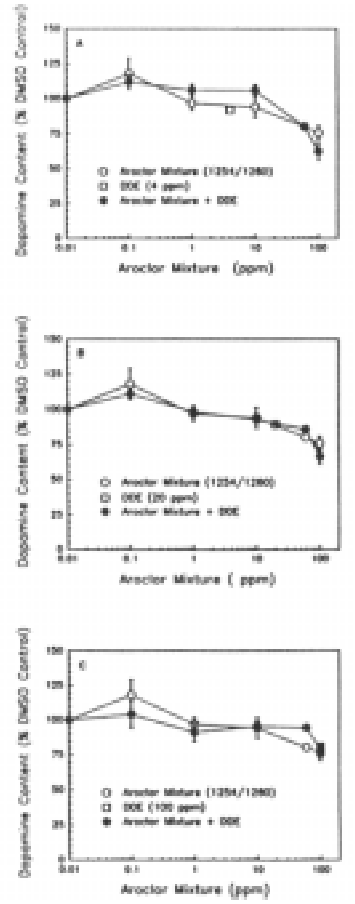

Figure 5A-C. PC12 cells were exposed to varying doses of a mixture of Aroclor 1254/1260 in the presence of a constant amount of *p,p*'-DDE: 4 ppm (A); 20 ppm (B); and 100 ppm (C), for 1 hr before analyzing for cellular dopamine content.

the brains of these animals and decreases in CNS DA concentrations (Seegal *et al.* 1991; Seegal *et al.* 1994). Thus, prolonged exposure to low doses of PCBs can result in significant accumulation that is associated with changes in neurochemistry. Exposure of PC12 cells to artificial PCB mixtures mimicking brain concentrations produces decreases in cellular DA content (Seegal *et al.* 1990).

Thus, we can expect that prolonged *in-vivo* exposure to low levels of PCBs can result in toxicological consequences since alterations in CNS DA concentrations and function are associated with deficits in cognitive function (Brozoski *et al.* 1979). Furthermore, Levin *et al.* (1988) have demonstrated that perinatal exposure of non-human primates to Aroclor 1016 (0.25 and 1.0 ppm) and Aroclor 1248 (2.5 ppm) results in behavioral deficits.

Animals exposed to Aroclor 1248, which is similar in its congener makeup to the congeners found in Lake Ontario salmon, demonstrated significant deficits on a delayed spatial alternation task. Thus, perinatal exposure to PCBs, at levels similar to those found in Lake Ontario salmon, are sufficient to induce long-lasting deficits in recognized measures of cognition.

In summary, our *in-vitro* data clearly demonstrate that the PCBs, and not other identified contaminants present in Lake Ontario salmon, produce significant reductions in PC12 cellular DA content. We thus tentatively conclude that the observed association between maternal consumption of contaminated Great Lakes fish and cognitive deficits in children may be explained on the basis of the PCB content of the fish.

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Fish Consumption Health Advisories: Who Heeds the Advice?

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Abstract

Various objectives exist for fish consumption health advisory programs. Two primary objectives are (1) enabling potential fish consumers to make their own, informed decision about whether or not to eat fish; and (2) reducing public health risks by reducing human exposure to chemical contaminants via fish consumption. Achieving either of these outcomes requires that potential consumers of sport-fish are aware of and understand the health advice provided. Several studies that focused on human understanding of and response to health advisories in the Great Lakes Basin are summarized. Key findings indicate (1) advisory experts may not understand the specific information needs of their audiences; (2) advisory awareness and knowledge vary among target populations, emphasizing the need for communication strategies specific to each target audience; and (3) achieving advisory understanding will not guarantee compliance with advisory recommendations.

Introduction

Fish consumption health advisories have been issued by each of the Great Lakes States for almost 20 years. Advisories were developed in response to concerns about potential negative human health consequences from consuming fish, caught recreationally (or for subsistence purposes), affected by chemical contaminants in the Great Lakes. This article reviews key concepts and findings related to human attitudes and behaviors associated with fish consumption health advisories.

Health Advisory Objectives

Advisories are a risk management tool designed to inform fish consumers about how to minimize exposure to chemical contaminants. Alternative risk management tools include closure of contaminated fisheries, or bans on the possession of fish affected by contaminants. Such a tool was implemented for the New York portion of Lake Ontario in the mid-1970's, when the New York State Department of Environmental Conservation banned the possession of seven species of highly-valued sport-fish. The ban was greeted by a public outcry (Brown 1976), which emphasized the importance of involving the affected public in risk management strategies to protect human health.

Implementing an advisory that can adequately protect human health is a challenging and complex task. On one hand, advisories are voluntary. Advisories are intended to enable people to make their own, informed decision about fish consumption, and thus their likely exposure to chemical contaminants through eating fish (Knuth 1990). On the other hand, advisories are created with the intent of reducing public health risks. Achieving this outcome requires that consumers of contaminated sport-fish receive, understand, and comply with the recommendations in the advisory (Knuth 1990).

Several government agencies may be involved in the development and dissemination of an advisory, even within one state. Each agency may put greater emphasis on one of the two outcomes noted above, or may emphasize different outcomes altogether.

In the Great Lakes States, policy objectives to be achieved via fish consumption health advisories have varied among health, fishery management, and environmental quality agencies, each of whom is involved in some aspect of the health advisory process (Knuth and Connelly 1991); Knuth 1994). Health agencies have emphasized reducing public health risks; enabling people to make their own, informed decision about eating Great Lakes fish; helping people select a variety of risk-reducing behaviors that may include fish cleaning and cooking procedures, fishing for less-contaminated species, and fishing in less-contaminated locations; and informing people about the health benefits of eating fish. Fishery management agencies have also emphasized these objectives, in addition to encouraging public support for toxic cleanup programs; and encouraging public enjoyment and use of sport-fishery resources. Environmental quality agencies have out most emphasis on promoting risk-reducing behavior.

While few of these objectives are totally at odds with one another, they do send mixed signals about health advisory program priorities. Is success based on (1) reducing public health risks (e.g., ensuring strict compliance with the recommendations in the advisory); or rather, (2) ensuring people are making their own, informed choice, whether that choice is to abide by the recommendations or not? The agencies involved in the health advisory programs must engage in this debate, if success of health advisory programs is to be measured.

Common to either of these approaches is the requirement that potential consumers of sport-fish are aware of and understand the advice provided. Research on human understanding of and responses to Great Lakes health advisories can help inform discussions about health advisory program success. Several studies that focused on human response to health advisories in the Great Lakes Basin are summarized below.

What Determines Response to Advisories?

Disseminating health advisories to achieve human health protection objectives is a form of risk communication. Risk communication is an interactive process of information exchange among individuals and groups and institutions, a process that involves multiple messages about the nature of risks (National Research Council 1989). These multiple messages may received and processed by those audiences who are targeted in the advisory communication program. Advisory communicators must understand their target audiences to ensure that they are meeting their needs, and not just the needs perceived by the communicators (Slovic et al. 1981).

Through a series of studies focused on target audience characteristics, attitudes toward advisories, and behaviors in response to advisories, we developed a conceptual model of the social-psychological process influencing response to advisories (Figure 1) (Connelly et al. 1992; Knuth et al. 1993; Velicer and Knuth 1994). The model suggests several factors must be considered in communication programs that seek to influence either people's understanding of advisories or adoption of the recommendations contained within. External variables include the characteristics of the audience itself that influence which health advisory information sources will be used, and how information may be interpreted in an individual or societal context. A variety of beliefs influence how advisory information will be processed, including beliefs about the source of the information, the importance of fish and fishing, and the probable reactions of other people who are important to that individual. Ultimately, health advisories target behavior, including general fish-eating habits, and fish-catching practices. The extent to which these behaviors must change to comply with advisory recommendations, are critical factors influencing response to advisories.

Can Experts Design Effective Advisories?

Health advisories are developed, written, and disseminated by a variety of individuals with training in public health, toxicology, fisheries management, and sometimes risk communication. How well can the collective efforts of these experts address the in information needs of the audiences they are trying to reach?

To address this question, we focused on three target audiences in seven New York State counties bordering Lake Ontario (Jefferson, Monroe, Niagara, Oswego, Cayuga, Wayne, and Orleans), and experts charged with developing and communicating health advisories. Audiences included (1) opinion leaders among recreational anglers and charter boat operators; (2) migrant farm workers; and (3) low-income individuals (Velicer and Knuth 1994). Methods involved a combination of in-person individual and group interviews, and mail survey techniques.

In this study, experts and target audiences differed in their assessments of important information to include in an advisory. Opinion leaders among angling and charter boat associations differed from experts in placing greater importance on information about changes in health advisory recommendations over time and the reasons for those changes, risk-reducing fish cleaning methods, comparisons of fish consumption risks with other dietary risks, and details about fish sampling methods. Experts however, placed lower importance on including these types of information within a health advisory. Low-income individuals tended to receive their information from mass media sources. Advisory experts often felt they had little influence over the content of mass media coverage regarding advisories. Migrant farm workers had little access to mass media or the government documents describing the advisory. Rather, farm workers required interpersonal advisory dissemination mechanisms, and information communicated in a language (e.g., dialect, difficulty) they could understand. Such interpersonal advisory communication programs were quite limited in number at the time of this study.

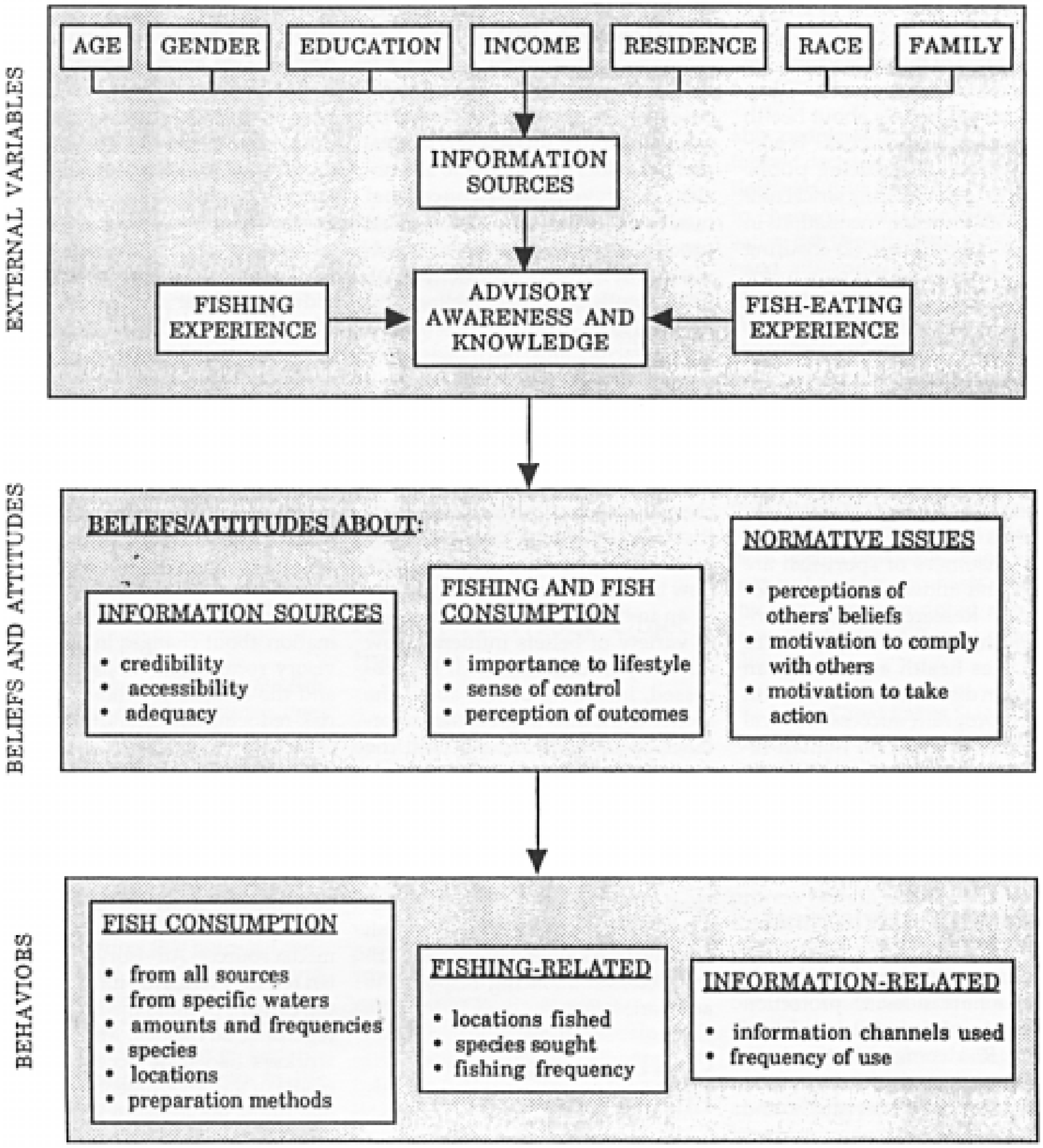

Figure 1. Conceptual diagram of the socio-psychological process determining reponse to fish consumption health advisories (based on Knuth et al., 1993)

Messages delivered in the preferred communication style of the target audience have a greater chance of success than those constructed to meet the communication styles preferred by the communicator (Johnson and Petcovic 1987). Our findings, however, indicate that the target audiences differed from advisory experts regarding preferred communication styles and desired information (Velicer and Knuth 1994).

Who Do Advisories Reach? Who Do They Miss?

Health advisory target audiences include any potential fish consumer who may eat fish from waters covered by an advisory. We have conducted a series of studies addressing the extent to which various target audiences have been aware of and/or knowledgeable about advisories, and have adopted behaviors adhering to health advisory recommendations. These studies have focused on low-income individuals and migrant farm workers (Velicer and Knuth 1994), licensed anglers in New York State (Connelly et al. 1992, 1993), and licensed anglers throughout the Great Lakes Basin (Connelly and Knuth 1993). Most have used the mail survey research techniques.

Awareness of Great Lakes health advisories among these audiences ranged from 9% among migrant farm workers who were interviewed (Velicer and Knuth 1994) to almost 95% among licensed angler respondents who fished Lake Michigan (Connelly and Knuth 1993). Typically, 75% to 85% of licensed angler respondent groups have been aware of advisories. Awareness of advisories has differed however based on location fished, age of respondent, years of education, income, gender, and ethnicity. In general, awareness has been lower among those fishing smaller bodies of water (e.g. St. Mary's River, Niagara River) vs. the larger lakes; younger groups vs. older; less-educated vs. more-educated; lower vs. higher income; women vs. men; and nonwhites vs. whites.

Specific knowledge about health advisories and health effects associated with fish consumption has been more variable than awareness. Accurate knowledge of specific advisory recommendations among those claiming to be aware of advisories has ranged from about 25% to 55% of respondents indicating the correct information. Among New York licensed angler respondents, about 53% could correctly identify the recommended maximum number of fish meals for women of childbearing age and children under 15, and about 26% could correctly identify the recommended maximum number of fish meals any individual should eat from any New York State water (Connelly et al. 1992, 1993). Other low-knowledge areas included the negative health effects associated with eating contaminated fish, and the time-frame over which negative health effects would be exhibited. In general, knowledge scores tended to increase with increasing age, income, and education, and men generally had higher knowledge scores than did women.

Behavioral compliance with advisory recommendations, based on reported fish consumption patterns, has varied from about 45% to 80% of various populations keeping their fish consumption within levels recommended in health advisories. About 34% of migrant farm workers interviewed lived with women and children who ate sport-caught fish recommended against consumption in the advisory (Velicer and Knuth 1994). Throughout the Great Lakes Basin, about 25% of licensed angler respondents ate fish that advisories recommended should not be consumed (Connelly and Knuth 1993). About 54% of licensed New York Lake Ontario anglers of childbearing age (men and women ages 18-40) ate fish above levels recommended in the advisory.

Awareness of advisories ranged from 9% to 95% ... Compliance varied 45% to 80%.

In New York State, 20% of licensed anglers statewide exceeded the advisory recommendations (Connelly et al. 1992). This group, however, tended to be as knowledgeable about the advisory as other fish consumers, but more likely than others to (1) believe that the health risks associated with fish consumption are minor compared to other risks, (2) believe the health benefits are greater than the risks, and (3) have adopted risk-reducing fish cleaning and cooking methods.

Implications and Conclusions

Until recent years, most advisory communication strategies in the Great Lakes States were based on disseminating information via (1) fishing regulations guides; (2) specially prepared government brochures available by request; and (3) simplified information in general media releases. Recently however, Great Lakes States are placing greater efforts on implementing communication strategies targeted toward specific groups.

These include brochures targeted toward women of childbearing age that are distributed at health care clinics (e.g., Michigan, Minnesota), tip sheets specific to individual bodies of water and local populations (e.g., Minnesota, New York), multilingual posters and brochures distributed to ethnic audiences known to be frequent fish consumers (e.g., Minnesota, Wisconsin), and individual personal outreach at fishing access sites (e.g., New York). With the implementation of these more specific communication strategies, it is likely that advisory awareness and knowledge will increase among those low-awareness, low-knowledge groups noted above.

Even if advisory awareness and knowledge increase, however, it is uncertain what effects will be evident in fishing and fish-eating behaviors. These behaviors are affected by a host of factors (see Figure 1), only some of which are under any influence by agencies communicating health advisory information.

If successful health advisory programs are judged by individuals' abilities to make their own, informed decisions, perhaps these renewed efforts to reach out to specific target audiences who have specific information needs will be sufficient. These specifically-targeted efforts are, at the very least, necessary to achieve the objective of informed decisions by all potential fish consuming populations.

If, however, successful health advisory programs are judged by percent compliance with the fish consumption recommendations contained within advisories, agencies will need to understand better the link between awareness/knowledge and ultimate behavior. Results from the New York statewide study (Connelly et al. 1992) indicate advisory awareness and knowledge by themselves do not predict compliance with advisory recommendations.

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Exposure Characterization, Reproductive and Developmental Health in the New York State Angler Cohort Study

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Development of the New York State Angler Cohort

The New York State Angler Cohort Study was initiated in 1991 when funding from the Great Lakes Protection Fund was awarded to the Department of Social and Preventive Medicine at the School of Medicine and Biomedical Sciences at the University at Buffalo. Subsequently, additional funding was obtained from the Agency for Toxic Substances and Disease Registry (ATSDR) in 1992 to expand the scope of the original project. This is a multidisciplinary study conducted in collaboration with the Department of Natural Resources at Cornell University, the Toxicology Research Center at the University at Buffalo, the Department of Environmental Conservation, and the New York State Department of Health.

The goals of the New York State Angler research are threefold: 1) to characterize exposure to persistent toxic contaminants through consumption of Lake Ontario sport fish; 2) to evaluate knowledge of fish consumption advisories and health risk perception; and 3) to conduct epidemiological studies of reproductive and developmental health.

The New York State Angler Cohort was designed to focus on Lake Ontario sport fish consumption. Lake Ontario sport fish have higher levels of polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs), mirex and other pesticides in comparison to fish from the other Great Lakes. Consumption of contaminated fish is a major source of PCB and organochlorine exposure in human populations. PCBs, PCDDs, PCDFs, DDE and other pesticides are known to cross the placenta and given their lipophilic nature, tend to concentrate in breast milk. Thus, both developing fetuses and breastfed infants are exposed to these contaminants.

Current advisories indicate that women of reproductive age and children under age 15 should eat no sport fish meals from Lake Ontario. Men are advised to consume only a limited amount of fish based on species and size. Prior to the inception of the New York State Angler Cohort Study, very little information was available about anglers' fish-consumption habits, risk perception and the potential health risks associated with eating contaminated fish from Lake Ontario waters.

The New York State Angler Cohort study employed a cross-sectional design to survey a stratified random sample of licensed anglers between the ages of 18 and 40 who resided in 16 counties in upstate New York that were in close proximity to Lake Ontario.

The 16 counties included in the study were Niagara, Erie, Orleans, Genesee, Monroe, Livingston, Ontario, Wayne, Seneca, Cayuga, Onondaga, Oswego, Oneida, Jefferson and St. Lawrence. The self-administered questionnaire was systematically mailed in four waves to 30,000 anglers with the number of anglers sampled in each county proportionate to the number of fishing licenses sold in each county.

After two mail follow-ups, an overall response rate of 40 percent was achieved. The cohort comprises 10,782 male anglers and 6,579 of their wives and partners as well as 934 female anglers. Although the response rates were rather modest: 39% for male and 49% for female anglers, a telephone interview with 100 randomly selected non respondents revealed that non respondents were less likely to be married and had lower levels of education and income.

However, most importantly, no differences were observed between respondents and non respondents with respect to fishing habits, knowledge of the fish consumption advisory and consumption patterns. Therefore, findings suggest that the cohort is representative of licensed anglers in terms of exposure to environmental contaminants through the consumption of sport fish.

Exposure Characterization and Methodology

The questionnaire used a retrospective food frequency dietary assessment method to elicit sport fish consumption histories. Questions focused on the number, species, and size of fish consumed, usual portion sizes and cooking methods. Female anglers and the wives or partners of male anglers were queried about their reproductive histories, with particular attention given to all children born between 1986 and 1991. Fish consumption habits prior to and during pregnancy, as well as information on smoking and alcohol consumption during pregnancy were also elicited from women. Income, marital status, race, and education were reported by anglers and baseline reports of a variety of physician-diagnosed conditions were reported by both anglers and wives and female partners. In sum, the questionnaire contains sets of questions on sociodemographics, sport fish consumption, knowledge of advisories, reproductive and medical histories, and other selected behavioral characteristics.

A second phase of exposure characterization was the conduct of a validation study which collected biologic specimens for empirical exposure assessment. The intent of this component of the study was to assess the correlation of self-reported exposures with biological measures of contaminant body burden. To this end, a stratified random sample of 321 respondents (191 men and 130 women), based on self-reported exposure level, completed an additional questionnaire and provided blood, hair and urine samples for a biologic measurement of their body burden of environmental chemicals. None of the respondents who consumed sport-caught duck or turtle meals were eligible for this validation study. Toxicologic analysis of serum and hair samples have been recently completed. Laboratory data include 68 congeners of PCBs, DDE, hexachlorobenzene (HCB), mirex and methyl mercury. Statistical models will be constructed and used to determine factors which predict body burden of contaminants for both male and female anglers.

A small number of anglers consumed turtle (3.6%) and high levels of waterfowl (10%). In order to characterize the exposure of cohort members who consume wild duck or turtle meals, a substudy is currently underway with five groups: (1) 31 anglers who consume low amounts of waterfowl and no Lake Ontario fish (≤ 1 meal per month); (2) 102 anglers who consume high amounts of waterfowl (≥ 2 meals per month) but no fish or turtle; (3) 65 anglers who consume high amounts of waterfowl and low to moderate amounts of fish; (4) 77 anglers who consume high amounts of both waterfowl and fish; and (5) 25 anglers who consumed the highest amount of turtle regardless of their consumption of fish and waterfowl. Letters and questionnaires were sent to 296 sportsmen with detailed questions on wildlife consumption habits. To date, questionnaires have been received from 117 respondents (40%) and biologic specimens have been collected from 105 consumers of turtle and waterfowl (90%). Toxicologic assessment of 68 PCB congeners, DDE, HCB, mirex and methyl mercury will be determined for participants in this substudy as well as clinical chemistries (e.g., glucose, cholesterol, triglycerides, and thyroxine (T4)).

A third exposure characterization substudy is the analyses of breast milk samples which have been collected from 213 lactating women in the cohort. Laboratory data similar to that described above will be available for these samples. In addition to the congener specific analysis, detailed analysis of coplanar PCBs may be possible considering the higher concentration of lipids in breast milk.

The analytic procedures for determination of PCB congeners, HCB, DDE and mirex; the QA/QC methods; and laboratory data reporting have all been carefully developed in conjunction with the New York State Department of Health and the Centers for Disease Control. In a recent multi-center quality control assessment involving laboratories across the Great Lakes Basin sponsored by ATSDR, the Toxicology Research Center at the University at Buffalo ranked first in accuracy of exposure assessment.

Reproductive and Developmental Health

A variety of reproductive and developmental endpoints will be assessed in the cohort using many data sources. Detailed information on 3,638 children born to cohort members between 1986 and 1991 was collected during the original survey of anglers. Birth certificate data were obtained from the New York State Health Department for children who were born in the state (n=3,258). In addition, hospital delivery records were obtained to abstract additional information pertaining to the intra- and postpartum period. These data will permit assessment of various factors known or suspected to influence infant growth and development to ensure proper control of confounding before assessment of the potential impact of exposure. Birthweight and measures of intrauterine growth retardation will be examined in relation to parental sport fish exposure estimates. Medical records of all newborns with either congenital anomalies or abnormal newborn examinations are being reviewed by either a developmental pediatrician or a dysmorphologist who are blind to exposure status.

Currently, all cohort members are being linked to vital registries (live birth and fetal death) maintained by the New York State Department of Health commencing with their age of majority to the present. These data will be used to construct standardized fertility ratios to compare the fertility of exposed and unexposed cohort members. This exhaustive matching process is currently underway.

Assessment of more specific fertility endpoints such as time to conception and fecundity impairments are being assessed in a subgroup of women who were contemplating pregnancy at the time of the original survey (n=2,987). Telephone interviews were conducted by trained nurse-interviewers with 2,454 of those women (82%) between February 1993 and March 1994. Preliminary analyses of these data are ongoing.

Summary

The New York State Angler Cohort Study has entered its third year and has been quite successful in meeting its stated goals and objectives due to the efforts of a multidisciplinary team of co-investigators and collaborators.

Dr. John Vena from Social and Preventive Medicine at the University at Buffalo is the Principal Investigator. Co-Investigators include Drs. Germaine Buck, Pauline Mendola and Maria Zielezny from Social and Preventive Medicine, Drs. Paul Kostyniak, Hebe Greizerstein and James Olson from the Toxicology Research Center, and Dr. James McReynolds from the Department of Biophysics at the University at Buffalo.

Other collaborators include Dr. Edward Fitzgerald from the New York State Department of Health Bureau of Environmental and Occupational Epidemiology, Dr. Brian Bush of the New York State Department of Health Wadsworth Laboratory, and Dr. Lowell Sever from Battelle Pacific Northwest Laboratories.

A large cohort of anglers and their families in New York State has been identified. These individuals are avid sportsmen and heavily utilize the resources of Lake Ontario. Ongoing study of the cohort will supplement previous and newly-begun health effects studies in other areas of the Great Lakes Basin.

Baseline data on exposure to environmental contaminants through consumption of Lake Ontario sport fish and wildlife has been collected on the cohort and validation of questionnaire measures is underway. Reproductive and developmental outcomes such as intrauterine growth are currently being evaluated in the cohort which is now of reproductive age.

Long term follow-up of the cohort for chronic disease endpoints is planned. Considerable information will become available through this investigation of a population-based cohort of anglers with exposure to environmental contaminants from Lake Ontario.

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