Toxic Chemicals in the Great Lakes Basin Ecosystem: -Some Observations

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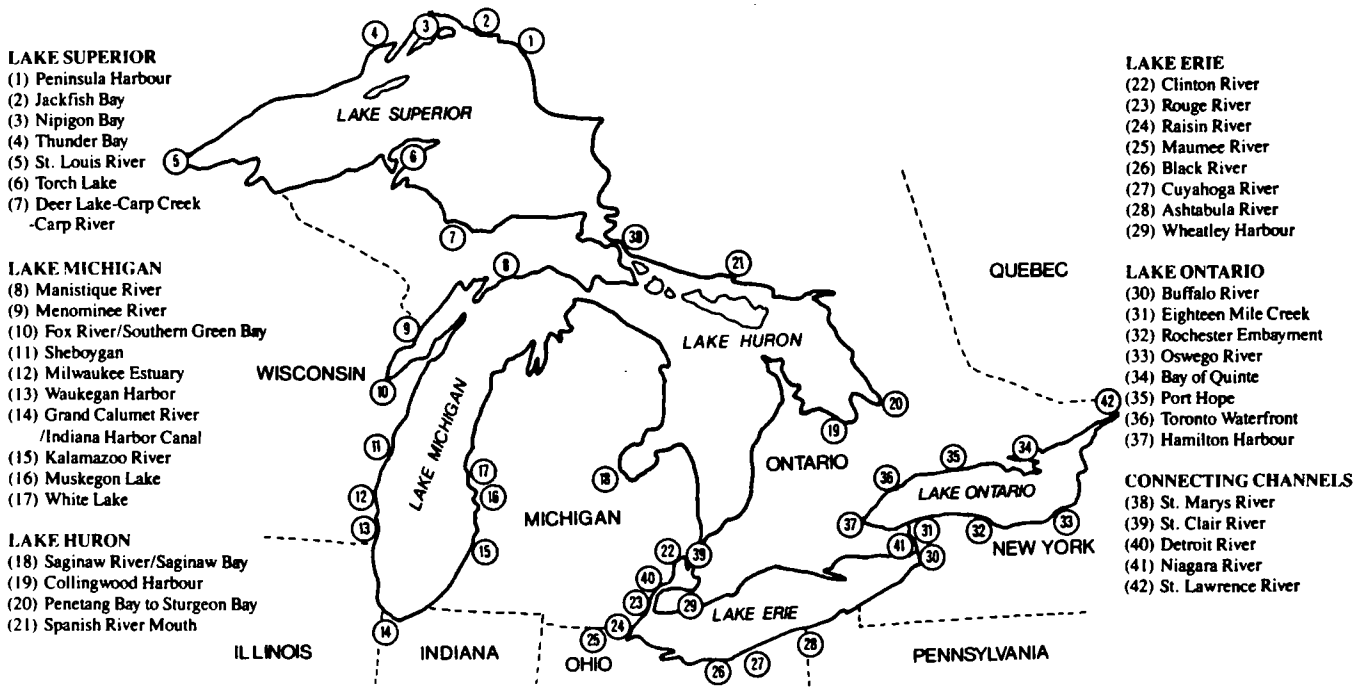
Great Lakes Areas of Concern



AUTHORS' NOTE

This report is about humans and their ecosystem, and involves the disciplines of physics, chemistry, biology, ecology, biochemistry, toxicology, sociology and economics. No one person can be a specialist in all these fields and as a result, this report is not written for the specialist. It is written by and for the generalist who has a little knowledge in all these areas, and perhaps specialist knowledge in some, but who wishes to see the totality of the interrelationships that make up the ecosystem.

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TOXIC CHEMICALS IN THE GREAT LAKES ECOSYSTEM: SOME OBSERVATIONS

EXECUTIVE SUMMARY

INTRODUCTION

We, began this project with the question "What are the socio-economic impacts of toxic chemicals in the Great Lakes Basin?". Motivated by a steady stream of information on the toxic chemical issue and its ramifications which came to us from many sources (discussions with colleagues, scientific journals, the mass media, and personal experience), we had a sense that something important was happening in the ecosystem.

It soon became evident that we could not even begin to assess the social and economic impacts of toxic chemicals until we had a clear idea of their effects on people and other life in the basin. This is a very complex issue and our investigations led us into many scientific disciplines. While we cannot claim to be experts in most of these disciplines, we had the advantage of being located at the Canada Centre for Inland Waters where many scientists are working on various aspects of the toxic chemicals issue. This gave us a unique opportunity to become familiar with the work, the results, the concerns, and the language of the natural scientists.

This report is not a conventional scientific study in the usual sense of the term. We did not begin with a hypothesis, carry out experiments, and report our results. Our starting point was the observation stage, where what we were observing were the results of many scientific studies done by others. We have attempted to integrate and interpret, from our own perspective, a diverse array of facts on toxic chemicals and ecosystem health and we have ended up with a general hypothesis that the two are connected.

CONCENTRATIONS OF TOXIC CHEMICALS IN THE ECOSYSTEM

The similarities in levels and types of toxic chemicals in all parts of the ecosystem emphasize the physical connections between air, water, land and life, including humans.

Time Trends

The levels of toxic substances in sediments of the Great Lakes generally reflect the production and use of persistent toxic substances in and around the Great Lakes Basin. Dated sediment cores provide a historical record of water pollution which in some instances may also imply deposition rates of pollutants from air to water and from air to land over the general area. The general pattern is a progressive increase in concentrations of persistent toxic substances from about 1915, with highest levels occurring from the late 1950's to the early 1970's, and subsequent declines.

Similar trends as seen in the sediments have been observed for Great Lakes fish, herring gull eggs, Ontario beef and pork fat, Ontario mothers' milk, and human fatty tissue over the period for which data exists, from the early 70's to the present.

Geographic Patterns

The concentrations of toxic substances in sediments show that even the more remote sites in the basin receive pollutants from atmospheric transport. Nevertheless, local sources can be very important and sediment samples taken close to urban-industrial centres and river mouths have much higher levels.

Great Lakes fish and herring gulls which live in or near the more contaminated parts of the Great Lakes system generally have higher concentrations of persistent toxic substances in their tissues. In the St. Lawrence River, contaminants have been found in snapping turtles, eels and Beluga whales. Contaminant levels in whales' blubber are very high for PCBs and DDT and even higher in their milk.

The data on concentrations in humans often raise interesting questions. People living in Kingston have been found to contain significantly higher levels of several contaminants than the levels found in people from Ottawa. This may reflect the higher concentrations of these substances found near the downstream end of the Great Lakes system.

Concentrations of toxic substances in the life of the Great Lakes ecosystem also show that these substances are passed on to future generations. The concentrations in herring gull eggs are direct evidence of this. It is suspected that in mammals, toxic substances are transferred to offspring through the placenta during pregnancy and through milk. Female Beluga whales in the St. Lawrence River have lower levels of PCBs than males; and in Kingston women have lower levels of PCBs and several other chemicals than their male counterparts. Females in both species may be losing some of their toxics to the next generation through pregnancies and lactation.

ECOSYSTEM HEALTH

Indicators of ecosystem health can also be useful indicators of the risk to human health. Individual indicators are not, in themselves, conclusive evidence of this relationship, but a spectrum of indicators, taken together can provide a strong basis for linking ecosystem contamination and human health. We believe that the material synthesized in this report constitutes a reasonable reflection of the growing body of sometimes circumstantial, but convincing, evidence of the importance of these linkages.

Cancer

Seemingly unrelated and disconnected events in this whole issue of toxic chemicals may be sending us an important message. Although in many ways each species of life is unique and humans are certainly very different from fish, all life forms have some things in common. In terms of biochemistry, there are many similarities. There are also similarities in the way that the eggs develop into adults. Diseases too can affect a wide variety of life forms, cancer being one example.

The U.S. cancer mortality rates for humans are high in the same five locations where high rates of fish cancers have been observed (Black River, Ohio; Buffalo River, N.Y.; Hudson River, N.Y.; Puget Sound, Washington; and Torch Lake, Michigan). It could be just coincidence, or it could be that a common factor is involved, such as exposure to toxic chemicals. In Canada, high rates of human cancer are observed along the St. Lawrence River. Beluga whales living in the St. Lawrence River also appear to have a high incidence of cancer. Another coincidence, or could there be a common link?

North American cancer and heart disease rates are high in large urban centres where population density and environmental contamination are high. Disease rates also seem to be high at the mouths of major continental watersheds (the St. Lawrence and Mississippi being the most obvious examples). Another general observation is that cancer rates are higher in the east than in the west. Air pollution , as measured by acid and metal deposition, is also higher in the eastern part of North America, particularly the northeast.

Reproductive Impairment

Reproductive problems and deformities in wildlife may also be giving us important signals. For example, deformities in freshwater insects have been linked to environmental contaminants. These insects spend the larval stage of their life cycle in the sediments at the bottom of lakes and rivers. A recent study found that the incidence of deformities in Chironomus larvae in Port Hope Harbour, Lake Ontario was much higher in the more heavily polluted inner harbour than in the outer harbour. Similarly, analysis of the fossil remains of this group of insects in sediments of the Bay of Quinte indicate that the incidence of deformities has increased substantially since about 1950.

Studies of fish in the Great Lakes show some instances of reduced reproduction, reduced viability of eggs and young fish, deformities, and abnormal development. Laboratory studies have also shown that fish sperm and sperm processes are damaged by toxic substances.

Problems have also been observed in birds that eat Great Lakes fish. An outbreak of severe and often fatal birth defects, and reproductive failure occurred in herring gulls living in the Great Lakes area during the early seventies. This was at the same time and same place as high levels of toxic contaminants were being deposited in the sediments of the lakes. As the levels of toxic chemicals in the ecosystem declined, the reproductive success of these birds improved dramatically.

More recently, reproductive problems have been observed in a colony of Forster's terms on Green Bay in Lake Michigan. Experiments in which contaminated adults were given uncontaminated eggs to hatch and vice versa indicate that toxics may not only be affecting the eggs' ability to develop and hatch, but also the parents' ability to care for the eggs.

Mink on commercial ranches who were fed PCB-contaminated fish from Lake Michigan suffered a high incidence of reproductive failure and kit mortality. Toxic chemicals may be hindering reproduction in Beluga whales living in the St. Lawrence River. These whales are not increasing in numbers even though hunting was stopped 25 years ago. By contrast, an uncontaminated Arctic population of whales recovered after hunting was stopped.

Many of the chemicals that are known or suspected causes of reproductive problems in humans are also found in various parts of the Great Lakes Basin ecosystem, including the tissues of humans. There have also been specific instances where exposure to toxic chemicals has been linked to reproductive problems in humans. Women who ate PCB-contaminated fish from Lake Michigan gave birth to babies who were born earlier, weighed less, had smaller heads, and reduced neuromuscular maturity as compared to the babies of women who did not eat such fish. Women who lived near Love Canal during the period of toxic dumping had significantly more low-birthweight babies than women in the rest of upstate New York.

In Canada, there is some evidence that death rates due to birth defects are high along the St. Lawrence River, a pattern similar to the cancer rates and toxic contamination. And, if we take a broad look at the time trends of indicators of human reproductive health, some general parallels emerge. The rates of most birth defects in Ontario were higher in the early seventies than they are now. This observation generally corresponds with the data on birth defects in fish-eating birds and with the higher loadings of toxics observed in the early seventies as compared to the present.

Birth rates declined rapidly from 1960-1976 and have been relatively stable since then. Although many social factors contributed to this decline, some portion of it might have been due to the higher levels of toxic chemicals in the ecosystem during that time period.

Toxic chemicals may have contributed to the finding that sperm counts of U.S. men have significantly declined over the last 30 to 50 years. Studies have also shown that human sperm density and motility (swimming ability) are sensitive to toxic substances. Another general trend which may have relevance here is an apparent increase in human infertility in industrialized countries. The number of North American couples that have difficulty conceiving is currently estimated at 15% to 20%.

Other Health Problems

Numerous persistent toxic chemicals and metals have also been linked to other human health problems such as allergies, heart disease, and chronic degenerative conditions. Exposure to lead has been found to lower intelligence levels in children.

Exposure to toxic chemicals can even affect mental health. Most of the social and psychological effects of toxics appear to result from fears and anxieties about future health impacts. This anxiety can lead to long term stress and depression which are related to numerous other diseases.

Mechanisms of Action

In addition to these population and organism level observations, we also looked for information on direct effects of toxic chemicals at the cellular and subcellular levels. Several mechanisms exist whereby toxic chemicals can interact with and damage living systems at the cellular and subcellular levels. These mechanisms are often very complicated, but the ultimate effects are genetic errors and genetic diseases, cancer, and other degenerative health problems.

SOCIAL AND ECONOMIC ASPECTS OF THE TOXICS PROBLEMS

Causes

The social and economic causes of the toxics problem in the Great Lakes basin ecosystem are relatively straightforward. Toxic chemicals are released into the ecosystem from a variety of industrial, commercial, and residential activities. Chemical wastes released into the air, water, or land, reduce or eliminate treatment costs and thereby cut production costs and increase short-term profit. Also, because the social and environmental costs of these products are not included in the prices, they appear deceptively cheaper than the things which they have replaced.

But the economic roots of the toxics problem go deeper than this. Although careless waste disposal is clearly the source of much of the toxics that we see now in the ecosystem, many of the products produced and used by our society are themselves toxic. So consumers who purchase, use, and often carelessly dispose of these products are also contributing to the toxic chemical problem.

Some chemicals are useful and valuable to people, but many of them are produced, not because they have any inherent social value, but because money can be made by producing them and a market exists or can be created for them.

Consequences

Our economy is just as intricately connected to the ecosystem as we are and long term economic well-being is dependent on a healthy ecosystem. Conversely, a contaminated and impaired ecosystem leads to economic disbenefits.

Some of the economic and social costs of toxic chemicals in the Great Lakes Basin ecosystem are direct and measurable; others are indirect, hidden, and not easily measured. Examples of direct costs are fishery losses due to toxics, money spent on cleaning up hazardous waste sites and toxic spills, forestry and crop damage from acid and toxic rain, and the costs of human illnesses related to toxic chemicals (both treatment costs and lost human productivity). An example of indirect costs is the reduction in property values near hazardous waste sites.

Industrial society now has the capacity to contaminate and deplete resources on a global scale. Ozone depletion, carbon dioxide accumulation in the atmosphere and long range transport of air pollutants are well-known examples of global effects of human activities. This change from a local to a global context has initiated a shift in some parts of society from growth and material affluence to more fundamental goals like ecosystem sustainability, environmental quality, health and human fulfillment.

CONCLUSIONS

1. Humans are part of the ecosystem and are connected to the rest of the environment. The levels of toxic chemicals in the water, air, lake sediments, fish and wildlife and people reflect these connections.

2. Fish and wildlife in the Great Lakes basin have been hurt by toxic chemicals and the information on human health summarized in this paper indicates that people are being affected as well. The scale of the effects of toxic chemicals on human health cannot be determined based on this review, but we feel that it is significant and warrants concern.

3. Toxic chemicals are having negative impacts on the social and economic welfare of the people living in the Great Lakes basin. While these impacts are difficult to quantify, we believe that major initiatives to reduce our reliance on products and processes which involve toxic chemicals would yield important social and economic benefits.

TABLE OF CONTENTS

		PAGE
1.0	INTRODUCTION	1
2.0	HISTORICAL OVERVIEW OF ECOSYSTEM CONTAMINATION	2
	2.1 Trends in Specific Areas	2
	Historical Loadings to Lake Ontario	2
	Present Loadings to Lake Ontario	7
	Detroit River - St. Clair River Area	9
	2.2 Trends Reflecting General Ecosystem Contamination	10
	2.3 Factors Acting in General Ecosystem Contamination	20
	2.4 Synchronous Contaminant Pattern in the Life Forms of the Ecosystem	21
	Herring Gull Eggs	21
	Fish	22
	Human Tissues, Mothers' Milk and Human Food	22
	Other Life Forms	40
3.0	STATES OF HEALTH IN THE ECOSYSTEM: NON-HUMAN	40
	Birds	40
	Fish	45
	Other Aquatic Life	47
	Mammals	48
4.0	STATES OF HEALTH IN THE ECOSYSTEM: HUMAN	49
	Cancer	49
	Reproduction	61
	Toxic Chemicals and Reproductive Health	61
	Case Studies	64
	Measurements of Reproductive Health	68
	Infertility	68
	Fertility as Measured by Birthrate	68
	Sperm Counts	70
	Congenital Anomalies and Adverse Reproductive Outcomes	72
	Allergies and Asthma	78
	Degenerative Conditions	79
	Psycho-social Conditions	82

TABLE OF CONTENTS (continued)

		PAGE
5.0	UNIFYING FACTORS AND MECHANISMS OF ACTION	82
	Unifying Factors 37	
	Mechanisms of Action	88
6.0	DISCUSSION AND PRINCIPLES OF CAUSALITY	89
	Principles of Causality	92
7.0	CONCLUSION AND RECOMMENDATIONS	93
8.0	APPENDIX - MECHANISMS OF ACTION	95
REFERENCES		103

LIST OF FIGURES

		Page
Figure 1	Total concentration of di- through hexachlorobenzenes versus depth in sediment core (bottom axis) and approximate Pb210 dating (top axis).	3
Figure 2	Total chlorotoluenes (2,4,5-TCT and 2,3,6-TCT), octachlorostyrene (OCS), and hexachlorobutadiene (HCBD)concentration versus sediment depth in core and date.	4
Figure 3	Mirex concentration versus sediment depth in core (bottom axis) and sediment age (top axis). Mirex sales are superimposed.	5
Figure 4	Total PCB's versus sediment depth in core (bottom axis) and sediment age (top axis). Sales figures for PCB's are superimposed.	6
Figure 4b	Average biannual concentrations of a fluorinated hydrocarbon for the Lake Ontario cores, normalized to the maximum concentration in each core.	8
Figure 5	PAH profiles in four sediment cores.	11
Figure 6	Metal concentrations (by dry weight) as a function of depth in the Lake Michigan core.	12
Figure 7	Average lead deposition by precipitation over the continental United States, September 1966 to March 1967.	13
Figure 8	Sulfate in precipitation, 1980.	15
Figure 9	Surface wind flow across North America based on July resultant surface winds.	16
Figure 10	U.S. production of synthetic chlorinated organics compared to the total PCDD and PCDF in the four Lake Huron cores as a function of time.	18
Figure 11	Total flux of PCDD and PCDF to Siskiwit Lake and Lake Erie sediments.	19
Figure 12	Toxics in St. Lawrence River sediments and industrial point sources.	23
Figure 13	Total PCB's in the sediment core and herring gull eggs of Lake Ontario.	25
Figure 14	Mean organochlorine contaminant concentrations (mg/kg wet weight) in herring gull eggs 1974-1983	26
Figure 15	Residues of PCDDs in herring gull eggs	27

LIST OF FIGURES (continued)

		Page
Figure 16	PCB concentrations in Bloater Chubs (left verticle) and calculated historical loads of PCB's (right verticle) in Lake Michigan.	28
Figure 17	Mean annual dieldrin, total DDT, and PCB concentrations in whole fish samples of lake trout collected from eastern Lake Michigan.	29
Figure 18	PCB concentrations in Rainbow Smelt 1981.	30
Figure 19	Decrease in total DDT, dieldrin and PCB residues in bovine fat between 1969 and 1981, Ontario.	33
Figure 20	Decrease in total DDT, dieldrin and PCB residues in porcine fat between 1969 and 1981, Ontario.	34
Figure 21	Contaminants in Human adipose tissue; micrograms/g wet wt.	35
Figure 22	Contaminants in Human milk; microgram/g fat basis	37
Figure 23a	Cancer mortality map of Canada 1966-76: Males.	51
Figure 23b	Cancer mortality map of Canada 1966-76: Females.	53
Figure 24	Cancer mortality map of U.S. 1950-69.	55
Figure 25	Toxic Hot Spots in the Great Lakes Basin	57
Figure 26	Congenital anomalies mortality map of Canada 1975-77.	75
Figure 28	Congenital anomaly rates in Ontario 1973-83	77
Figure 29	Sperm density distributions as compared over time.	73
Figure 30	Low birth weight and residence near Love Canal swales.	65
Figure 31	Dose-response relationships for birth weight, gestational age, head circumference, and neuromuscular maturity by overall contaminated fish consumption.	66
Figure 32	Limitation of Activity in U. S. Residents due to Chronic Conditions.	81
Figure 33	Mortality Map: Diseases of the Circulatory System - Males.	83
Figure 34	Mortality Map: Diseases of the Circulatory System - Females.	85
Figure 35	Overview of absorption, fate and disposition of xenobiotics in mammals and fish.	90

LIST OF TABLES

		Page
Table 1.	PCBs in North American Food	32
Table 2.	Trends in Contaminants in Human Adipose Tissue	36
Table 3.	Trends in Contaminants in Human Milk	38
Table 4.	Organochlorine residues (ng/g) in adipose tissue.	39
Table 5.	Organochlorine residue levels versus Herring Gull reproductive success in Lake Ontario.	42
Table 6.	Incidents of toxic chemical effects on wildlife in the Great Lakes.	43
Table 7.	Chemicals that are Considered to be Proven or Potential Reproductive Hazards in Humans	63
Table 8.	Reported Sperm Counts of Unselected Men	71

1.0 INTRODUCTION

This report began as a survey of information and evidence on changes in the quality and health of the Great Lakes ecosystem for use in an evaluation of the social and economic dimensions of toxic chemical use and pollution. There are sound practical and theoretical reasons for undertaking such a study. There is a substantial amount of literature on the state of the Great Lakes ecosystem, as well as its physical, chemical and biological history. There is strong evidence and some consensus that chemical pollution of the aquatic, terrestrial, and atmospheric environments is causing stress on ecosystems; transforming and degrading them. There is also strong evidence and some consensus that chemical pollution is toxic to fish and wildlife in the Great Lakes ecosystem, causing a variety of health effects.

There is also evidence that humans suffer a significant amount of disease stemming from genetic errors and that the environment contains many chemicals that induce all known kinds of genetic damage in experimental systems including human cells (64, 107, 126, 289, 304). That environmental chemicals do, in fact, cause a significant proportion of genetic disease afflicting humans is a fundamental premise of genetic toxicology and of regulatory and legal attitudes (289).

This report is not the first attempt to show a link between ecological changes over the past 40 years or so, and their possible consequences for humans. An investigation of a perceived drop in the quality of military manpower in the United States concluded "...that there has been a serious and continuing decline in human quality in recent years, and the military quality decline is but one manifestation of this larger problem." After a substantial literature review, this study proposed that the quality decline is, perhaps, an inevitable consequence of the accumulation of ecological changes and biological stresses that individuals born in the United States during the last several decades have been exposed to (310).

The notion that some human diseases may be caused by chemicals, together with the fact that toxic pollution and exposure to it are preventable, means there are sound social and economic reasons to evaluate the effects toxic chemicals have upon the quality and health of the Great Lakes ecosystem. This report proposes to make the beginnings of such an evaluation.

Substantial use is made of data to illustrate synchronisms or patterns of phenomena in such areas as pollutant sources, ecosystem contamination and states of health. Where available, relevant and comparative toxicological and epidemiological data and evidence are introduced. Factors that may serve to illustrate fundamental processes that link the various physical, chemical and biological components are discussed. General principles for assessing possible causal relationships are presented.

2.0 HISTORICAL OVERVIEW OF ECOSYSTEM CONTAMINATION

Awareness and concern regarding the toxic chemicals issue in the Great Lakes ecosystem have been slowly emerging for almost two decades. However, man-made contamination has been occurring since the beginning of the industrial revolution, growing with it, and then accelerating with the buildup of the chemical industry. In general, the historical patterns of pollution show a synchronous relationship with this growth process. There is a substantial literature on this pollution history, and large data and information collections on numerous components of the ecosystem are assembled, compiled, and maintained by the International Joint Commission, Environment Canada, including Inland Waters/Lands Directorate, the National Water Research Institute, and the Canadian Wildlife Service, (including seabirds and the arctic marine ecosystem) and the Department of Fisheries and Oceans. A detailed review of this large information base exceeds the scope of this paper, and is properly a task in itself that needs to be done in the near future. Therefore, representative examples of this historical record, preserved in lake sediments, and in the tissues and health of the life that inhabits the ecosystem, are presented below.

In this paper, three classes or groups of pollutants (each containing a substantial number of individual compounds) are selected as representative of the chemicals of major concern: PCBs and other halogenated organic compounds including chlorinated dibenzo-dioxins and chlorinated dibenzo-furans; polynuclear aromatic hydrocarbons (PAH); and trace metals, their salts, and metal complexes, e.g. mercury, lead, cadmium, aluminum, and organic tin. While these chemicals do not exhaust the list of concern, their resistance to biodegradation (metals don't degrade), toxic properties, widespread distribution in the ecosystem, and the tendency of many to bioaccumulate warrant close attention.

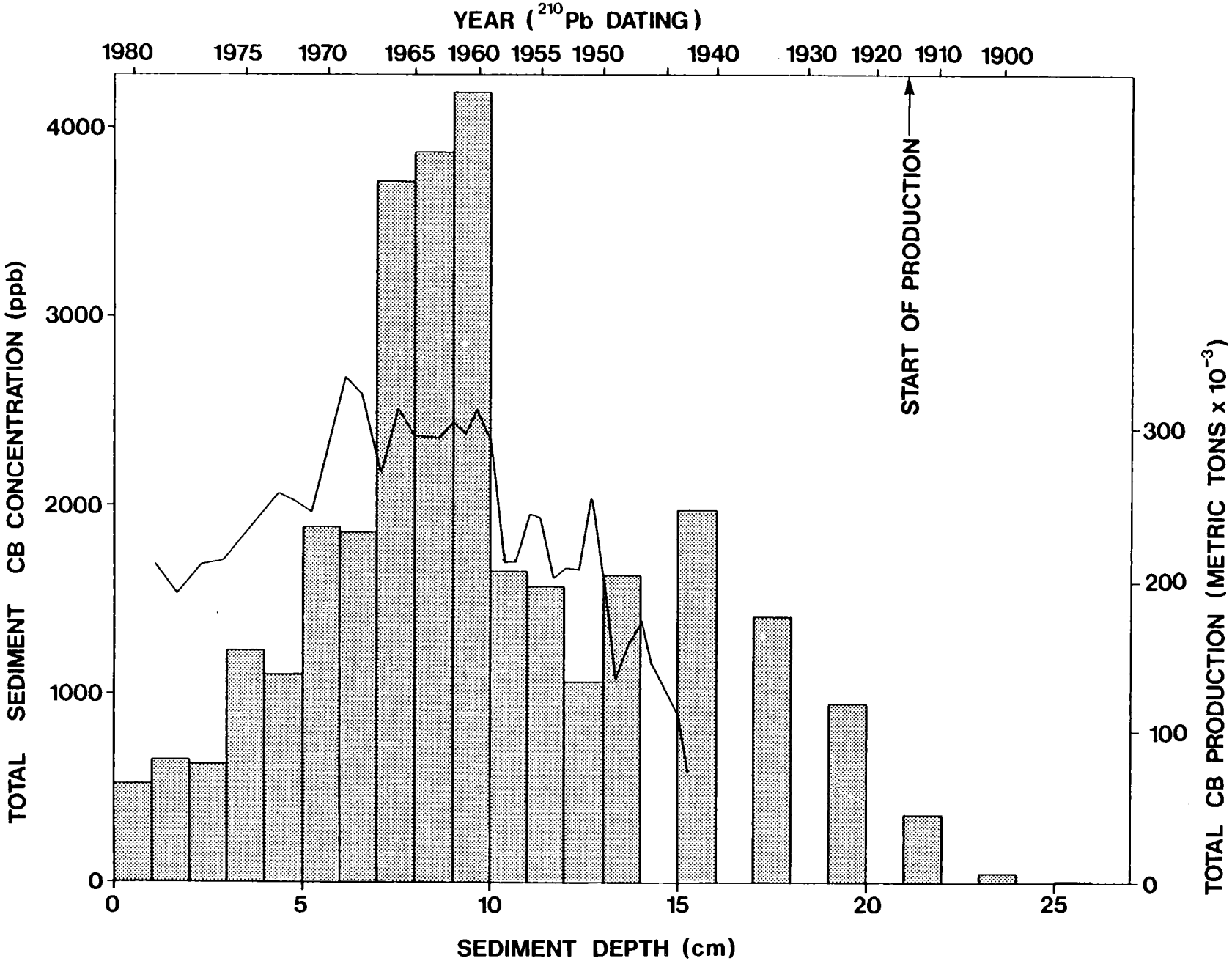
2.1 Trends in Specific Areas

Historical Loadings to Lake Ontario

The pollution of the Lake Ontario ecosystem from major sources along the Niagara River, and elsewhere, is documented in a number of reports (88, 28, 29, 154, 1, 229, 300). Evidence of historical loadings of organochlorine chemicals to this system was derived from a radiodated sediment core taken about 3 km. from the mouth of the Niagara River (48). Other dated cores from Lake Ontario's four sedimentation basins provide evidence of historical loadings of a group of fluorinated aromatic compounds. The historical sediment record of these fluorinated compounds agrees with the pattern of use of the Hyde Park dump which is reported to be the major source (109).

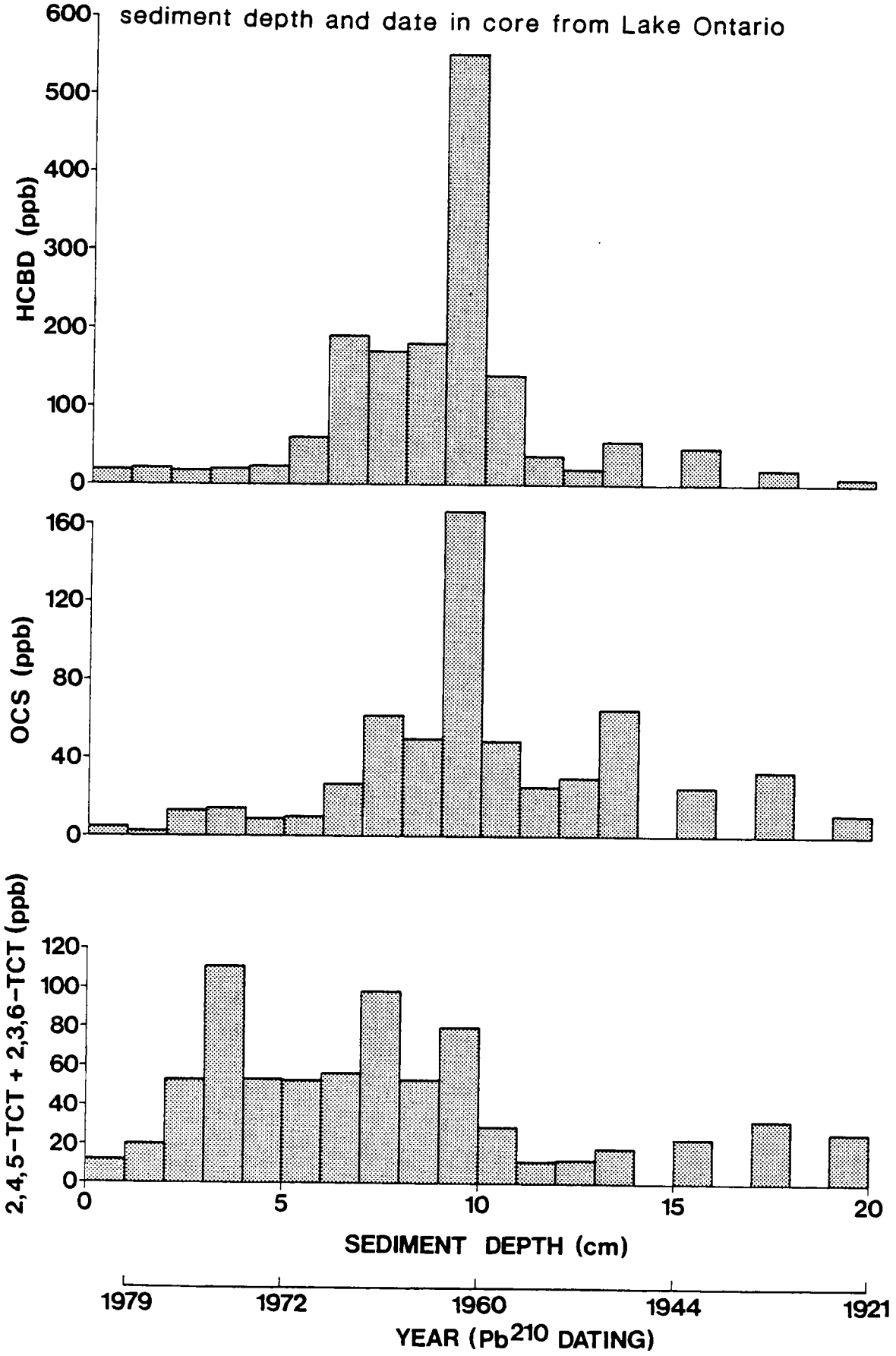
Figures 1 to 4 summarize sediment core data for chlorinated benzenes, chlorotoluenes, octachlorostyrene (OCS), hexachlorobutadiene (HCBD), mirex, and PCBs. These data in these figures parallel the production and usage patterns (where known) superimposed (48).

Figure 1. Total concentration of chlorobenzenes vs. sediment depth and age in Lake Ontario (bar graph) and total U.S. production figures for chlorobenzenes (line graph).



Source: Durham, R W and Oliver, B G. 1983. History of Lake Ontario contamination from the Niagara River by sediment radiodating and chlorinated hydrocarbon analysis. J. Great Lakes Research 9: 160-168.

Figure 2. Total Chlorotoluenes, OCS, and HCBD concentration versus sediment depth and date in core from Lake Ontario



Source: Durham and Oliver, 1983

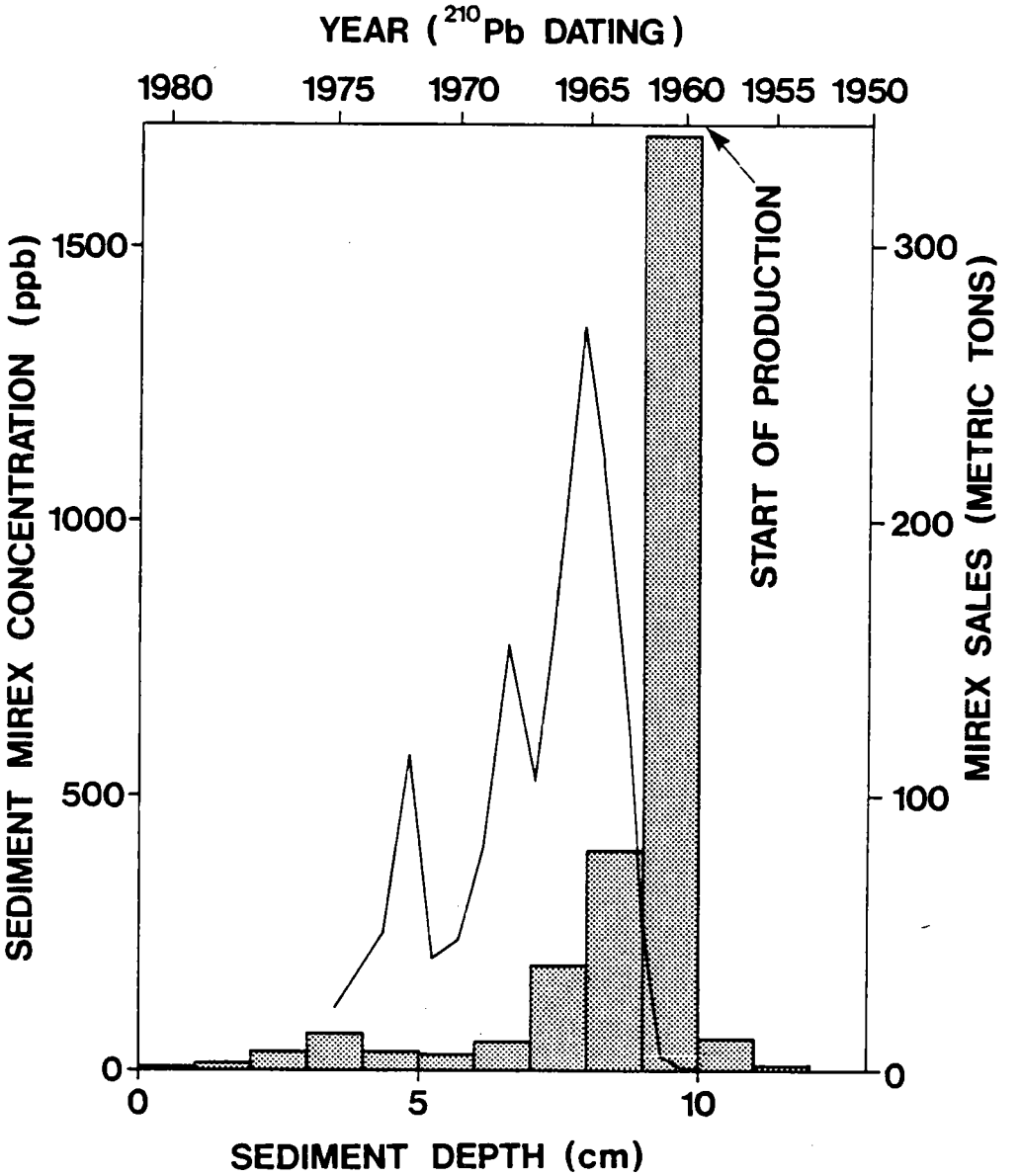


Figure 3 Mirex concentration versus sediment depth and age in core from Lake Ontario (bar graph). Mirex sales are superimposed (line graph).

Source: Durham and Oliver, 1983

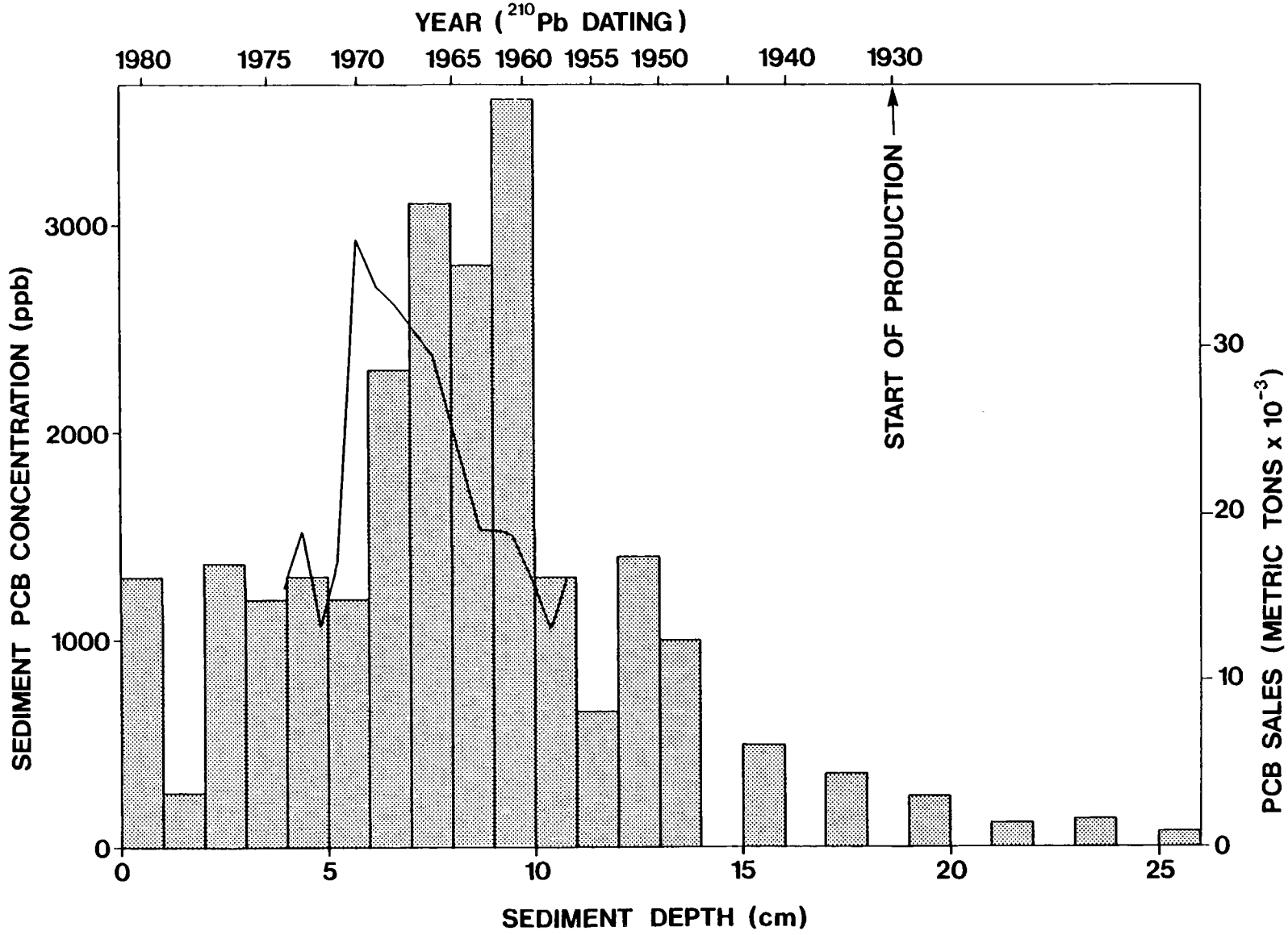


Figure 4. Total PCBs vs. sediment depth and age in core from Lake Ontario (bar graph). Sales figures for PCBs are superimposed (line graph).

Source: Durham and Oliver, 1983

Taken together, these results show the progressive increase in contamination from about 1915, with the highest levels occurring in the late 1950's through the early 1970's. Figure 4b illustrates the historical record of sediment data for one of the fluorinated aromatic compounds. Overall, these data show that increasing sales were accompanied by ecosystem contamination exemplified by occurrence and buildup in sediments.

These figures indicate that some industrial source loadings of certain chemicals (note that there are a great many chemicals not indicated here and possibly not measured) to Lake Ontario reached a peak and show relatively rapid and significant reductions. This is due mainly to production bans and/or use restrictions. However, there is a substantial, accumulated burden of numerous persistent contaminants in the Lake Ontario ecosystem, and loadings (large in absolute terms and relative to the goal and philosophy of zero discharge of persistent toxic chemicals as specified in the 1978 Canada-U.S. Agreement on Great Lakes Water Quality) continue from a variety of sources upstream, outside, and within the Lake Ontario basin, including the Hyde Park dump, and an unknown number of other leaching dumpsites along the Niagara River (214, 109, 242, 154).

This residual chemical burden, together with continued loadings, exerts a chronic stress on the Lake Ontario ecosystem. Furthermore, there is no known method for the establishment of a "no-observed-effect" level or threshold level for human exposure to chemical or other carcinogens, even one agent at a time (208, 253, 309, 281, 320). Thus, while the situation appears improved relative to past conditions for certain measured chemicals, the problem of chemical contamination certainly has not passed. Moreover, these data relate only to Lake Ontario, and cannot be used as general indicators of pollution reduction.

Present Loadings to Lake Ontario

Other studies provide evidence of continuing contamination of Lake Ontario from upstream (including Lake Erie), from a variety of point sources, occasional slugs (e.g. chlorinated benzenes, PCBs (160, 214)) that could be due to spot dumping, spills, or direct industrial discharges, and from a number of steadily leaching waste disposal sites (51, 214, 160, 161, 109, 110, 242). It should be noted that these measurements show large variations. How well they represent actual loadings is subject to review and refinement. These data serve an immediate practical value to the surveillance and monitoring of toxic chemical discharge to the ecosystem. Moreover, in combination with the data records for sediments, fish, herring gulls, and land-based plants, animals, and humans, these data may prove useful in the ongoing development of environmental models of contaminant pathways, fate, and effects (279). These models may be used to backcast the historical levels of loadings of contaminants to the ecosystem, and together with other data and epidemiological models, measure and predict the general ecosystem fate and effects of hazardous chemicals, both past and future.

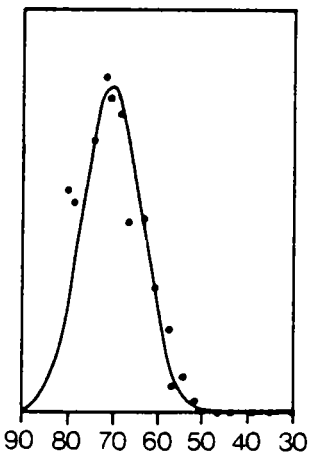


Figure 4b. Average, biannual concentrations of α, α -difluorodichlorotrifluoromethyl diphenylmethane for the Lake Ontario cores, normalized to the maximum concentration in each core.

Source: Jaffe, R and Hites, R A. 1986. Fate of hazardous waste derived organic compounds in Lake Ontario. Environ. Sci. Tech. 20: 267-274.

Recent published estimates of loadings entering the Niagara River from upstream (means of measurements taken at Fort Erie) are: 400 grams/day of chlorinated dibenzofurans; 35 grams/day of chlorinated dibenzodioxins; 39 kg/day of other chlorinated organics; 95 kg/day of PAHs; 961 kg/day of phthalates; 40 kg/day of pentachlorophenols; 6 kg/day of phenol; 9.2 tonnes/day of volatiles (benzene and dichloromethane (methylene chloride)); and 255 tonnes/day of metals (e.g. 57 tonnes/day of aluminum, 0.4 tonnes/day of arsenic, 0.6 tonnes/day of cadmium, 0.8 tonnes/day of lead, and 1.5 tonnes/day of zinc) (214).

Mean loadings entering Lake Ontario at Niagara-on-the-Lake are estimated at: 69 grams/day of chlorinated dibenzofurans; 47 grams/day of chlorinated dibenzodioxins; 70 kg/day of chlorinated organics; 184 kg/day of PAHs; 2448 kg/day of phthalates; 28 kg/day of pentachlorophenols; 26 kg/day of phenol; 9.9 tonnes/day of volatiles; and 402 tonnes/day of metals (e.g. 84 tonnes/day of aluminum, 2.5 tonnes/day of zinc, and 1.0 tonnes/day of chromium). There are a number of factors and processes (e.g. volatilization) at work along the length of the Niagara River, and the difference between these averages (Fort Erie and Niagara-on-the-Lake) cannot be the only basis used to infer loadings due to sources along the river (214). For instance, the dibenzofuran mean loading estimates show a drop from upstream to downstream that is inconsistent with the other estimates.

Estimates of a number of organic pollutant and metals loadings to the Lake Ontario ecosystem from the Welland Canal, Welland River and Twelve Mile Creek also exist. These range from 7.2 kg/day of aliphatic hydrocarbons, and 38 kg/day of dissolved zinc, to 177 kg/day of benzene related compounds (230). These estimates are based on small samples relative to the Niagara River loading estimates, for example. In assessing the significance of all these loadings, it is worthwhile to recall the goal and philosophy of zero discharge, and the need for accurate surveillance and monitoring data for all such loadings.

Detroit River - St. Clair River Area

Further upstream, the Detroit River - St. Clair River region is the focus of more recent scientific investigation and public concern (34, 53, 52, 229). A number of study methods show that active sources of significant loadings of a variety of toxic metals and persistent organic chemicals exist within both of these river basins. It was reported that analysis of surface water (Thames River), ground water (drinking wells), and municipal drinking water supplies by provincial authorities identified 'high levels' (52) of a number of pesticides (unidentified) used extensively in agriculture (52).

Specific petrochemical industries on the Canadian side of the St. Clair River are major sources of a variety of chlorinated organics (e.g. vinyl chloride, hexachlorobenzene, hexachlorobutadiene,

hexachloroethane, chlorophenoxy herbicides) and volatile organics (e.g. acrylonitrile, styrene, ethylbenzene, benzene, carbon tetrachloride and percloroethylene). The loadings of volatile organics to the St. Clair River from four companies alone total more than 450 kg/day. Loadings of chlorinated organics were not estimated. These loadings are shown by chemical concentrations in sediments in Lake St. Clair that are elevated relative to southern Lake Huron. Fish downstream of these industries show elevated levels compared to control sites upstream. Elevated levels of some compounds were found in treated drinking water taken from St. Clair River sources (53, 52, 229).

Other measurements detected major sources of PCBs, particularly the higher chlorinated and more persistent types, entering the Detroit River. Loadings from the U.S. side of the river reportedly dominate the Lake Erie sport and commercial fish contaminations (203). These sources appear to have been identified in the 1978 and 1979 intensive sampling of herring gull eggs from the Detroit River and Lake Erie. The colony on Fighting Island in the Lower Detroit River was more heavily contaminated with PCBs and other industrial chemicals than colonies in Lake Erie (259). There was also a significant regression between decreasing PCB levels in eggs and increasing colony distance from the Detroit River (259). These loadings are reported to exert a major impact on the PCB sediment concentrations in the western basin of Lake Erie and, in turn, the other basins of the lake (34), and possibly further downstream (e.g. Niagara River and Lake Ontario). Other contaminants of concern for which inputs have been documented, include the continuing inputs of lead, cadmium, and zinc, the presence of the highly toxic tri-n-butyltin species, and alkyllead compounds (34).

Once again, the usefulness of this data may extend beyond the immediate need for surveillance and monitoring, to general ecosystem modelling. There is some historical data for some chemicals in fish from Lake St. Clair (52, 53) and Lake Erie, and for herring gull eggs from colonies in the general area. If dated sediment core data can be developed (it may not be necessary, but it would be better to have it) all the data may prove useful in complementing and connecting with the ecosystem modelling noted above for the Niagara River/Lake Ontario system, and other areas in the Great Lakes.

2.2 Trends Reflecting General Ecosystem Contamination

Dated sediment cores indicate historical fluxes of pollutants to various sites in the Great Lakes, and neighbouring regions. They can also imply deposition rates to water and land over the general area.

It should be noted that there is no comprehensive surveillance program and network for monitoring, estimating, and compiling data on loadings of toxic organic chemicals and metals to the atmosphere from point sources. For instance, what proportion of loadings to the ecosystem from steel-making, pulp and paper, refineries and tank farms, and petrochemical plants, just to

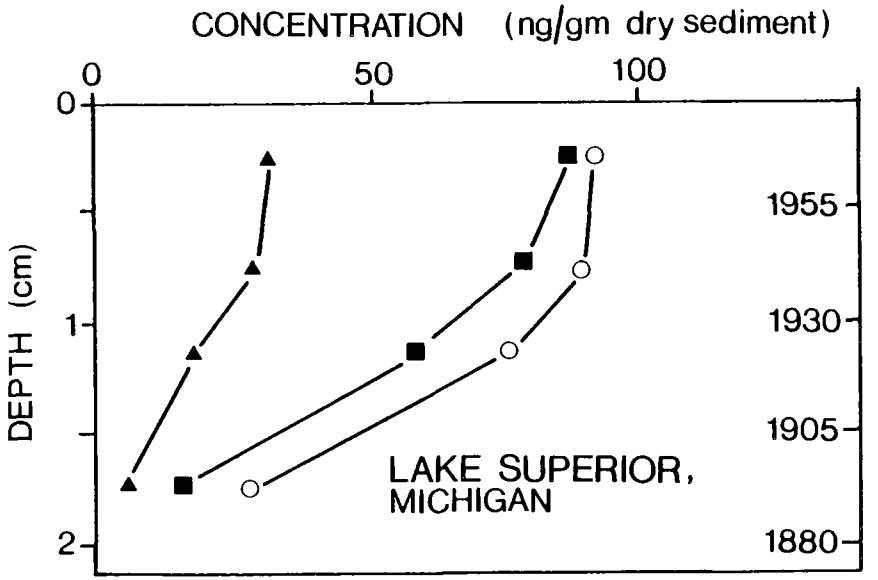


Figure 5 PAH profiles in four sediment cores. Symbols: ▲ benzo(a)pyrene; ○ chrysene and triphenylene; ■ pyrene.

Source: Gschwend,P M and Hites, R A. 1981. Fluxes of polycyclic aromatic hydrocarbons to marine and lacustrine sediments in the northeastern U S. Geochim. Cosmochim. Acta 45: 2359–2367.

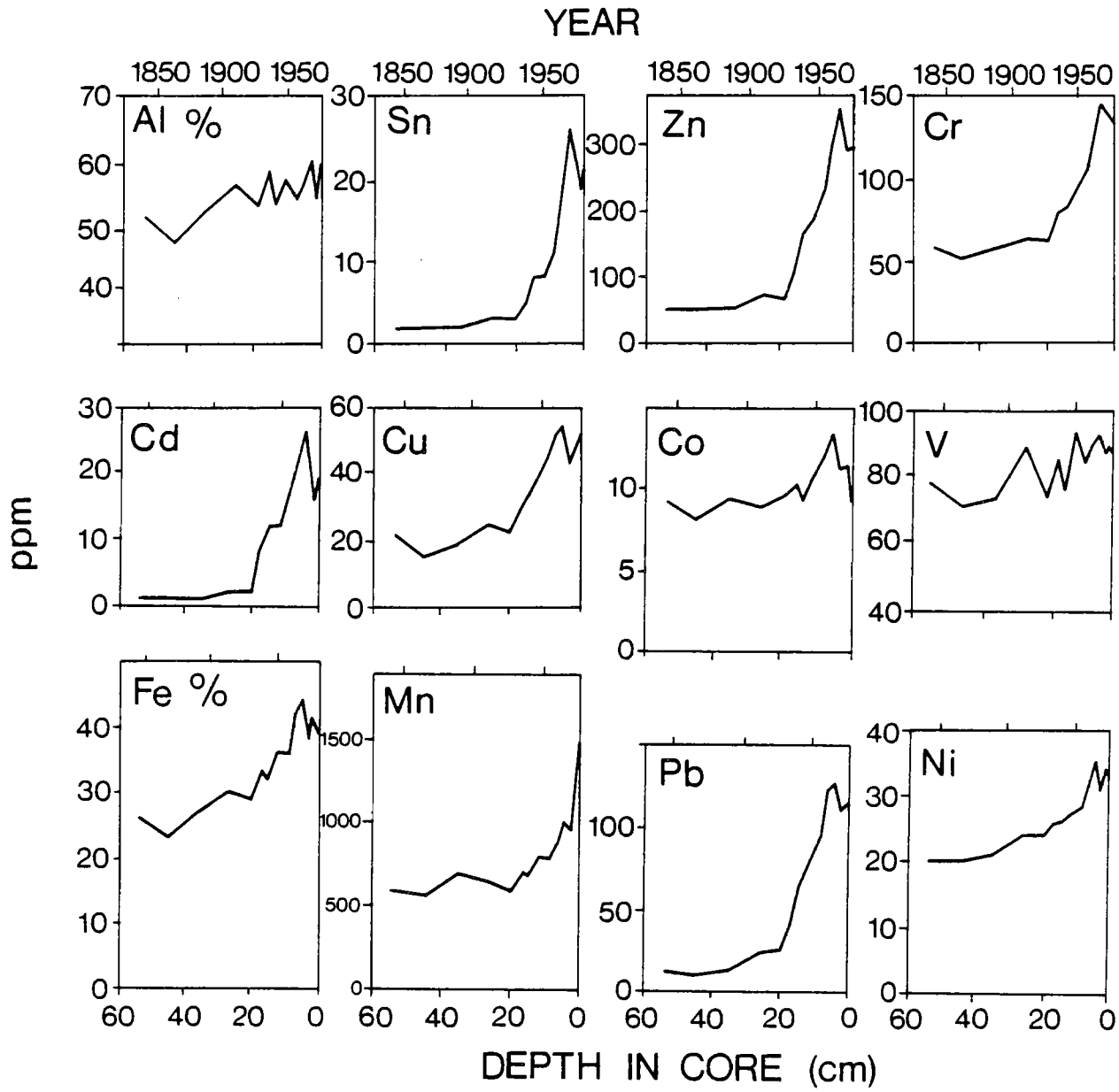


Figure 6. Metal concentrations by dry weight as a function of depth in the Lake Michigan core

Sources: 191 and 240

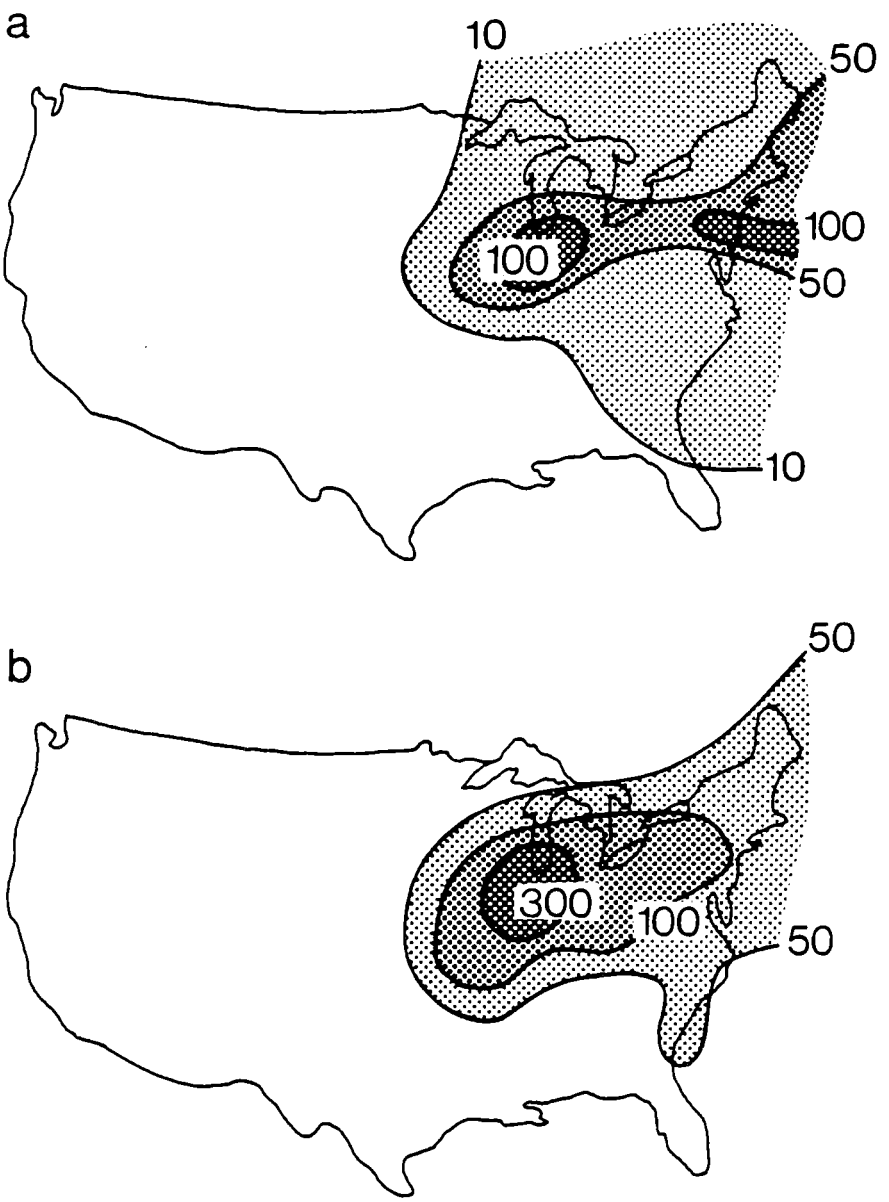


Figure 7 a. Average lead deposition by precipitation over the continental United States, September 1966 to March 1967 (in grams per hectare per month).

b. Average zinc deposition by precipitation over the continental United States, September 1966 to March 1967 (in grams per hectare per month).

Source: 191 and 241

mention a few important ones, goes directly to the atmosphere rather than into water? Further, what emissions are of the so-called "fugitive" type, escaping from production processes, storage areas, and retention ponds? Monitoring of water is important, however, industrial production, and other processes, require the venting to the atmosphere of a wide variety of toxic chemicals.

There are many reasons to think that loadings to the atmosphere are substantial, and far greater than loadings directly to water. The fact that humans are obligate breathers and are connected to the atmosphere as fish are to water, suggests that exposures to these emissions may be important (301, 317). A program of research and development for comprehensive monitoring of background levels and loadings is required to assess and manage the problem. While reductions in loadings at the source may proceed without this information, long-run cost effectiveness dictates the need for such a program.

Polycyclic aromatic hydrocarbons (PAH) are generated on land by the combustion of various fossil fuels and wood, by both stationary and mobile sources, as well as by industrial processes like coke production, aluminum reduction, and petroleum cracking (149). Results of analysis of a sediment core (83) from a Lake Superior site appear in Figure 5. This profile, and others for Northeastern U.S. sites (83), show the influx of PAH to the environment over the last century. In general, remote sites appear to receive a uniform deposition (flux) from atmospheric transport (83). Other cores, not shown here, indicate that sites nearer to urban centres have much higher inputs, probably augmented by runoff delivery (83). There is more data on cores and surficial sediments for PAH by other authors, however, this data is illustrative of the history.

In core sections dated at about 100 years ago, the inputs of PAH are nearly undetectable. Generally, the current deposit rate or flux is 5-10 times greater than that of 80 years ago, but has diminished by a factor of about 2 to 3 since about 1950. This decline probably reflects greater use of oil and gas relative to coal, since coal-derived energy produces much more PAH. Also, this PAH pollution 'reflects the strength of the same combustion sources as those producing acid rain' (83). In other words, many of the sources of acid rain are also sources of PAH (among other substances).

The IJC Pollution From Land Use Activities Reference Group (PLUARG) report (168) indicated that significant amounts of heavy metals, and other materials like PCBs, are deposited in the Great Lakes by the various atmospheric mechanisms. Other studies consistently document the long and short range transport and deposition of metals, other trace elements, PCBs, and other organic pollutants, in dry fallout, rain, and snow, throughout the Great Lakes (e.g. Toronto, Windsor, and Essex county) and downstream, including the island of Montreal (123, 159, 34). Selected metal concentrations as a function of depth in a Lake Michigan sediment core appear in Figure 6 (191, 240). Areal deposition maps for lead and zinc over the eastern continental United States and into Canada appear in Figure 7 (191, 241).

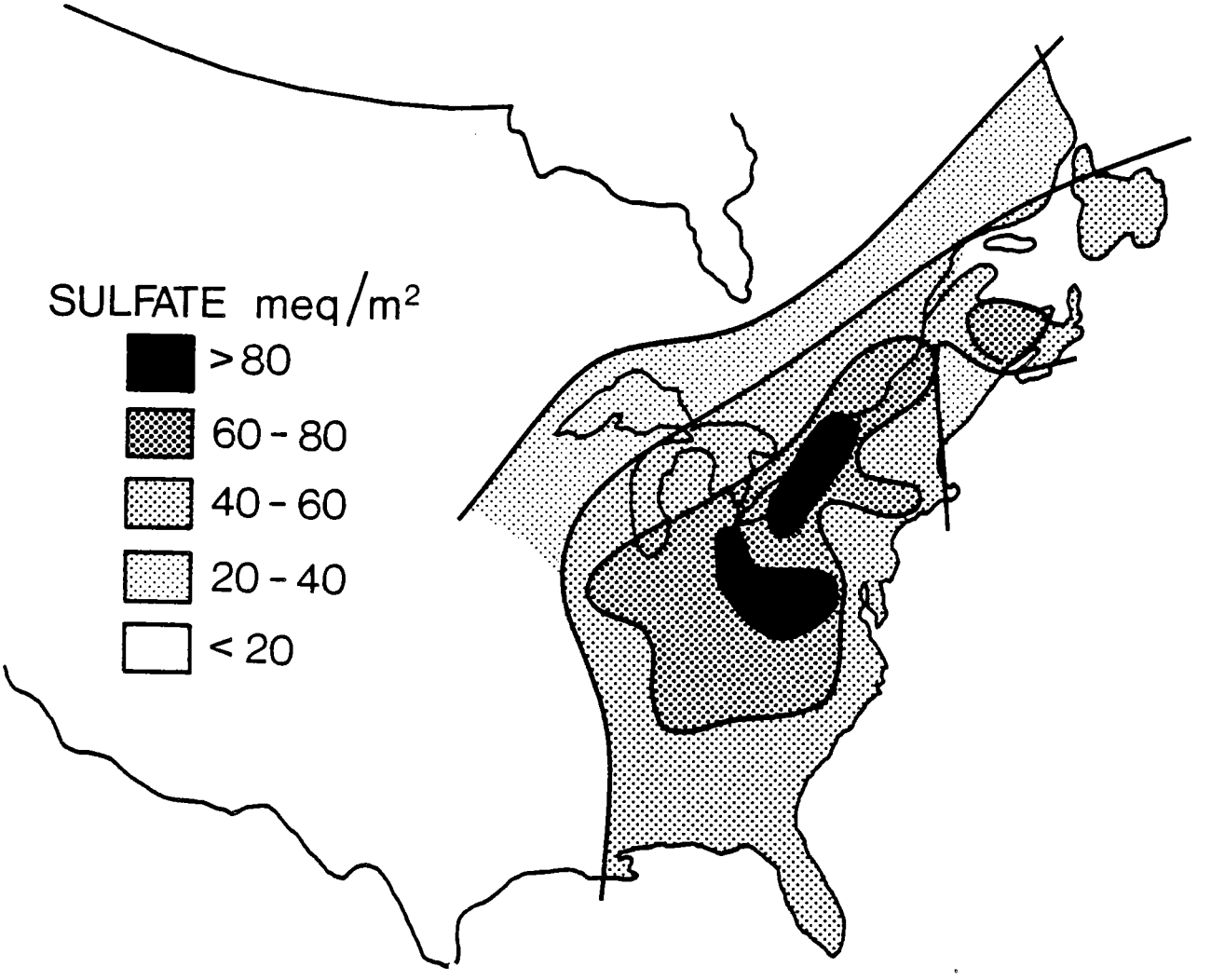


Figure 8. **Sulfate in Precipitation, 1980**

Source: Impact Assessment. Work Group 1. U.S.–Canada Memorandum of Intent on Transboundary Air Pollution. final report. 1983.

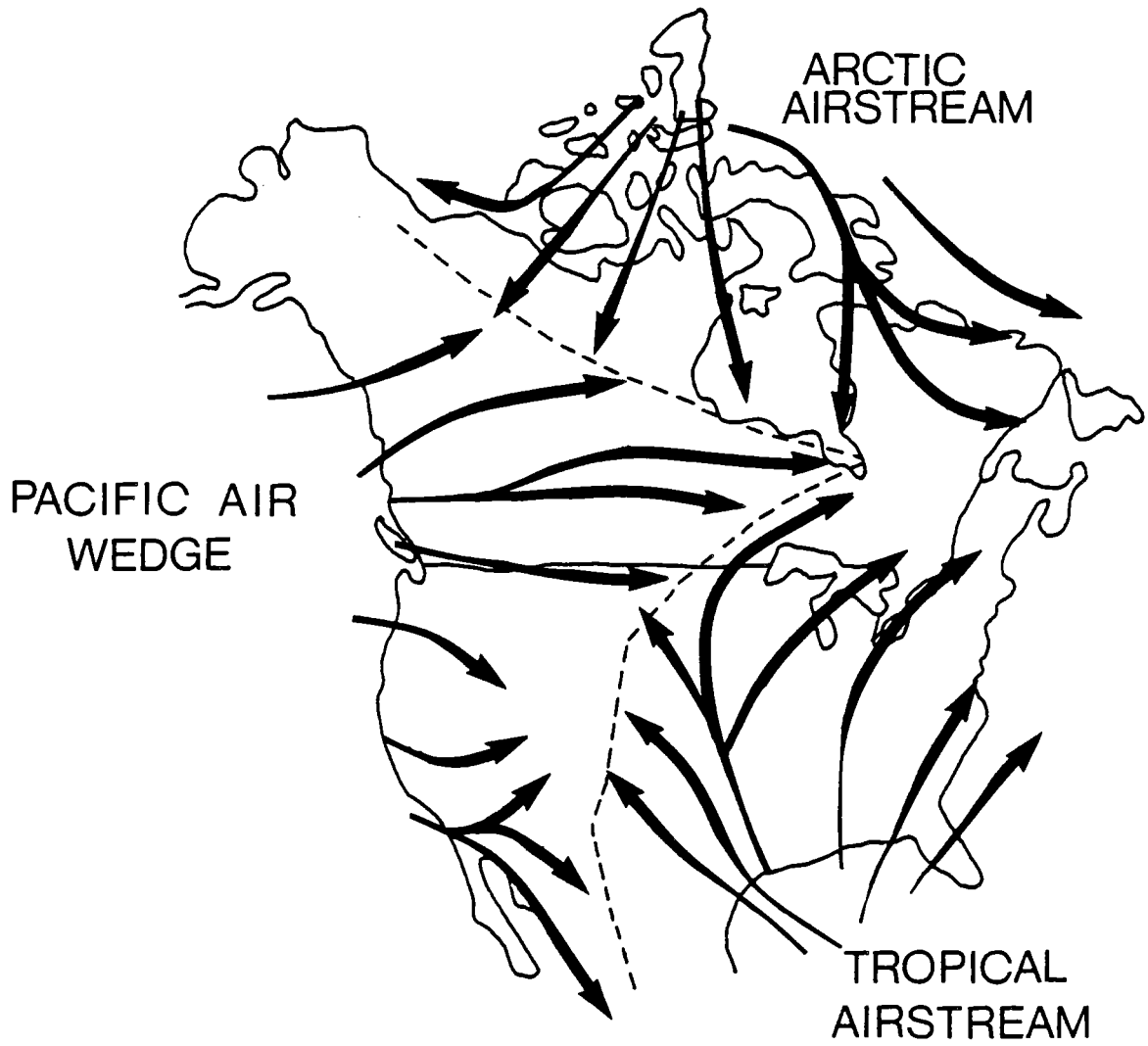


Figure 9 SURFACE WIND FLOW ACROSS NORTH AMERICA BASED ON JULY RESULTANT SURFACE WINDS

Source: Subcommittee on Acid Rain. 1981. Still Waters: The Chilling Reality of Acid Rain . Ottawa.

These data and figures closely resemble the profiles of PAH deposition, and acid precipitation (shown below). This is not surprising since source-areas and often even the sources are the same. For example, smelters and coal-fired power plants are major sources of acidifying substances, photochemical oxidants, trace metals and organic pollutants, visibility obscuring aerosols (fine particulates), and climate change gases (e.g. CO_2) (191, 317). This comparability with sulfate deposited in or by precipitation is shown in Figure 8. The predominant summer wind flow directions that transport and disperse these substances appear in Figure 9.

The historical record of dioxin and furan deposition, both as widespread environmental contaminants, and as particular sources and/or areas, also resides in the lake sediments. Figure 10 contains two graphs plotted over time: one shows the concentrations of polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF) in four Lake Huron cores; and the other shows U.S. production (the Great Lakes region accounts for more than a quarter of North American chemical production (33)) of selected synthetic chlorinated organics (40). The inputs of these same compounds to Lake Erie and Siskiwit Lake (Isle Royale, Lake Superior) appear in Figure 11. Siskiwit Lake is in a location that can only receive atmospheric inputs (41, 42). The historical deposition records of PCDD and PCDF in sediment cores agree well with the production of chlorinated aromatic compounds.

The Lake Huron and Siskiwit Lake sites indicate quite low levels of total PCDD and PCDF prior to 1940, and steep increases since then. It should be noted that the levels of these compounds consist of mostly octa-, hepta-, and hexa-CDDs, and octa-, hepta- and hexa-CDFs. In the Siskiwit Lake site these compounds were nearly absent from sediments prior to 1940. The chlorinated organics production statistics (Figure 10) also show that the chemical industry grew greatly beginning in 1940. Moreover, the patterns in the sediment records don't match the historical patterns or records of wood burning, coal combustion, and natural combustion (42). The conclusion (40) is that the most significant input of the noted higher chlorinated dioxins and furans to the sedimentary environment in the locations measured, and over the period studied, was 'probably' (40) due to the combustion of wastes containing chlorinated compounds in municipal and chemical company incinerators (40, 41, 42).

Other evidence shows that specific PCDD and PCDF forms or structures, indicative of other important sources, are superimposed on the combustion background. These present major problems in certain areas. For example, the concentrations of the most potent dioxin, 2, 3, 7, 8-TCDD, in fish and birds are greatest in regions producing chlorinated organic chemicals, or near hazardous waste sites (197). Other evidence from Lake Ontario sediment cores indicates octa-CDF contamination from pentachlorophenol production (42). While PCB production has been banned, there are still large quantities of dibenzofuran tainted PCBs in use and in storage, and they are widespread in the environment (265). Pentachlorophenol and other chlorinated phenol production, use, and contamination still occurs (214). Direct dumping of these materials to the environment also continues to be reported (E.T. Wagner, personal communication), and the legacy of improper disposal has appeared in the form of leaching and degassing waste sites.

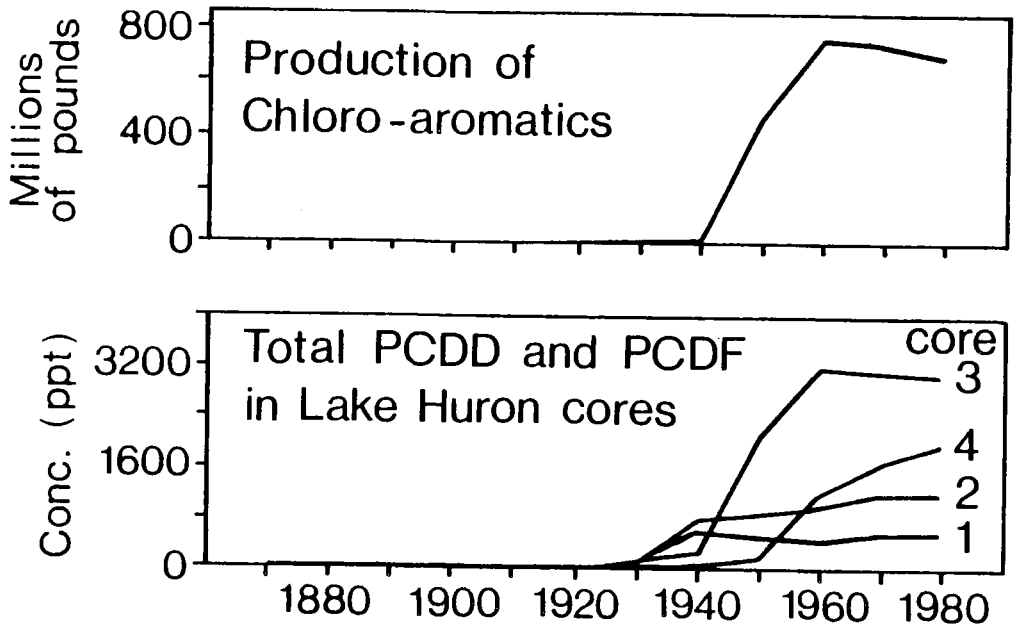
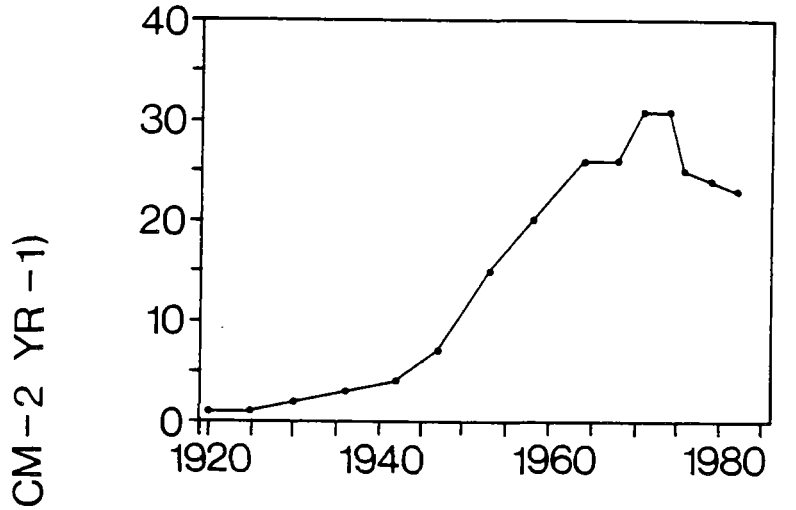


Figure 10 U.S. production of synthetic chlorinated organics (includes chloro- and dichlorobenzenes, 2,4-dichloro- and 2,4,5-trichlorophenoxyacetic acid, esters and salts, and pentachlorophenol) compared to the total PCDD and PCDF in the four Lake Huron cores as a function of time (all are plotted on a decade basis).

Source: Czuczwa, J M and Hites, R A. 1984. Environmental fate of combustion-generated polychlorinated dioxins and furans. Environ. Sci. Technol. 18: 444-450.



Flux of PCDD and PCDF to Siskiwit Lake (SL). Total flux (pg cm^{-2} $year^{-1}$) is plotted vs. average year of deposition.

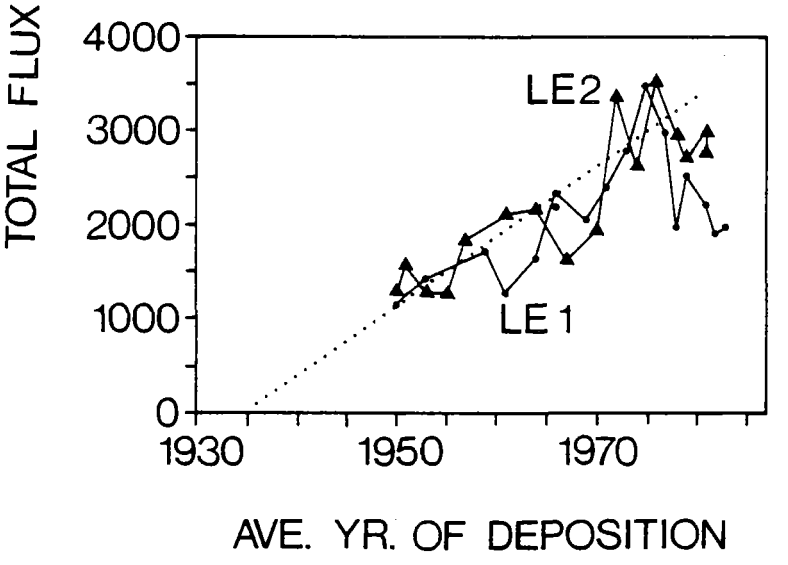


Figure 11 Total flux of PCDD and PCDF to Lake Erie sediments: Lake Erie 1 (●) and Lake Erie 2 (▲). Total flux (pg cm^{-2} $year^{-1}$) is plotted vs. average year of deposition. The linear regression line for the flux data from the two cores for the years 1950-1977 is shown (r = 0.867; a = -134 100; b = 69.3).

Source: Czuczwa,J M and Hites, R A. 1986. Airborne dioxins and dibenzofurans: sources and fates. Environ. Sci. Tech. 20: 195-200.

The Great Lakes system ultimately drains a proportion of its contaminant load into the St. Lawrence River, where it joins the inputs from numerous sources of similar materials within the downstream drainage area. The locations of known contaminated sediments in the river, and major industrial, municipal, and other sources that discharge into it appear in Figure 12. Moreover, the St. Lawrence River valley is not only at the mouth of a major continental watershed that is indicated, in a report by the Royal Society of Canada and the National Research Council (181), to be one of the most contaminated in North America. It is also at the mouth of a major continental airshed, an airshed that may be equally contaminated by the wide variety of toxic substances it transports, processes, and deposits as dustfall, rain and snow - "toxic rain" (see reference 123; Figures 7, 8, and 9; and discussion above).

2.3 Factors Acting in General Ecosystem Contamination

Depending upon a compound's physical and chemical properties (e.g. water solubilities and volatility), and upon the particulate density and particle properties (e.g. surface structure and area, and organic content) of the receiving body, some compounds can substantially and rapidly volatilize from the water to become sources of atmospheric pollution, and possibly land and soil pollution (161, 34). For example, while measurements are not available, the turbulent mixing action of Niagara Falls is believed to be causing substantial losses (from water to air) of volatile compounds entering the river from upstream (214). These volatiles, and compounds associated with the water droplets in the "mist" or plume of spray which is spread high and wide for some distance on both sides of the Canada-U.S. border by the action of the falls, may enhance the geographical extent and consequent human exposure. These factors indicate that water pollution cannot in general be separated from overall ecosystem contamination. There are numerous kinds of interaction between water, atmosphere and land. A chemical's residence in water may be temporary and periodic, because it can move and/or cycle through the ecosystem in processes that both dilute and concentrate.

There is other evidence indicating that sediments are not necessarily the final resting place for contaminants (162, 105, 181, 148, 179, 279). Certain physical and chemical properties (molecular weight, vapour pressure, solubility, octanol-water partition coefficient) and processes (partitioning, reaction, and transport (279)) result in a tendency for the atmosphere to become the physically preferred phase (place) for some chemicals. Through a number of pathways and processes, these substances can be released from the sediments into the water column and possibly to the atmosphere, where they can be recycled onto land and into water. This review did not consider the kinetics of this phenomenon. On a more visible scale, the constant forces of wind, lake currents and river flow disperse and spread the contaminants even more.

2.4 Synchronous Contaminant Patterns in the Life Forms of the Ecosystem

If one set out to demonstrate the intrinsic unity of all life, and the biospheric "systems" of the earth (16, 17, 100, 206, 46), one would be hard pressed to improve upon the unity shown by the variety and scale of persistent toxic pollutants and products freely released into the ecosystem by certain industrial sectors, economic activities, consumer products, and human practices. The evidence presented below is a sample of measurements indicating that the persistent and bioaccumulated pollutants are almost everywhere (157, 265, 257, 243). Mobilized by the wind and water, they have joined the natural, elemental cycles of the biosphere, and bioconcentrate and/or bioaccumulate in life forms (265, 157).

Indeed, these toxic industrial chemicals are even passed on to the next generation (and an unknown number of future generations) through contamination of the germ line (26, 47, 319), placental transfer (170, 318) and breast milk (164, 210, 318). Although not intended for humans, many of these compounds are made specifically to kill and/or sterilize (126). Others have similar structures or properties (158, 319).

Long term (30 or 40 year) trend data on levels of toxicants in the life forms of the Great Lakes ecosystem are nonexistent, as monitoring for toxics was not done, nor was the technology developed, until more recently. It wasn't until the late 1960's and early 1970's, when ecosystem pollution was generally at its worst (as measured in sediments), that severe biological effects and reproductive failure were showing up in fish-eating birds. As technical capability developed, systematic surveillance and measurement began (72, 73, 259, 271, 264).

There are now some 15 years of trend data on levels of halogenated organic chemicals and some metals in herring gull eggs and fish (Canadian Wildlife Service, Fisheries and Oceans Canada, 105). Also, there are more limited data on levels in humans, and certain items in the human food chain. While none of these data records covers the historical record of production and discharge in the ecosystem, they do show some of the history of ecosystem contamination. The data presented below are a small but illustrative sample of this record.

Herring-gull Eggs

The history of PCB loading to Lake Ontario as reflected in sediment, and the contamination (where measured) of Herring Gull eggs from colonies living on the lake, is shown in Figure 13. These gull egg concentrations clearly parallel, with a lag, the loading and resultant sediment buildup and decline of PCBs. Figure 14 shows a nine year record of mean organochlorine contaminant concentrations in Herring Gull eggs from Lakes Erie and Ontario for selected compounds. Figure 15 shows the locational variation in residues of chlorinated dibenzo-p-dioxins in Herring Gull and Forster's Tern eggs collected from the Great Lakes region in 1983. The inset in the figure shows the trend in PCB and 2, 3, 7, 8-TCDD residues in Lake Ontario herring gull eggs from 1971 to 1984.

These patterns of bioaccumulation reflect and parallel the spatial and temporal patterns of contamination observed in the sediment cores, as discussed above. For example, the gull colonies with the greatest mean levels of DDE and PCBs in each lake are in locations that appear to correspond with the locations of major sources of these contaminants (259). These sources are indicated by areas of elevated residue levels in sediments (259), and by estimates of loadings and sources as discussed above.

Fish

Figure 16 shows the data record in PCB concentrations in Bloater Chubs superimposed on calculated historical loads of this compound in Lake Michigan, from 1972 to 1980. Figure 17 shows a thirteen year record of mean annual residues of dieldrin, total DDT, and PCBs in whole Lake Trout from Eastern Lake Michigan. Figure 18 compares 1981 PCB concentrations in Rainbow Smelt for Lakes Ontario, Erie, Huron and Superior. The inset graph shows a six year pattern in these residues for Lake Ontario. These data are a small sample of the substantial data available to show the spatial and temporal variation in contaminant levels in various species and trophic levels of fish (e.g. lake trout, walleye, rainbow smelt, spottail shiners) and other aquatic life. (105, Fisheries and Oceans Canada). This data base contains a substantial amount of information that may prove useful in the modelling and prediction of contaminant fate and effects in ecosystems and life forms.

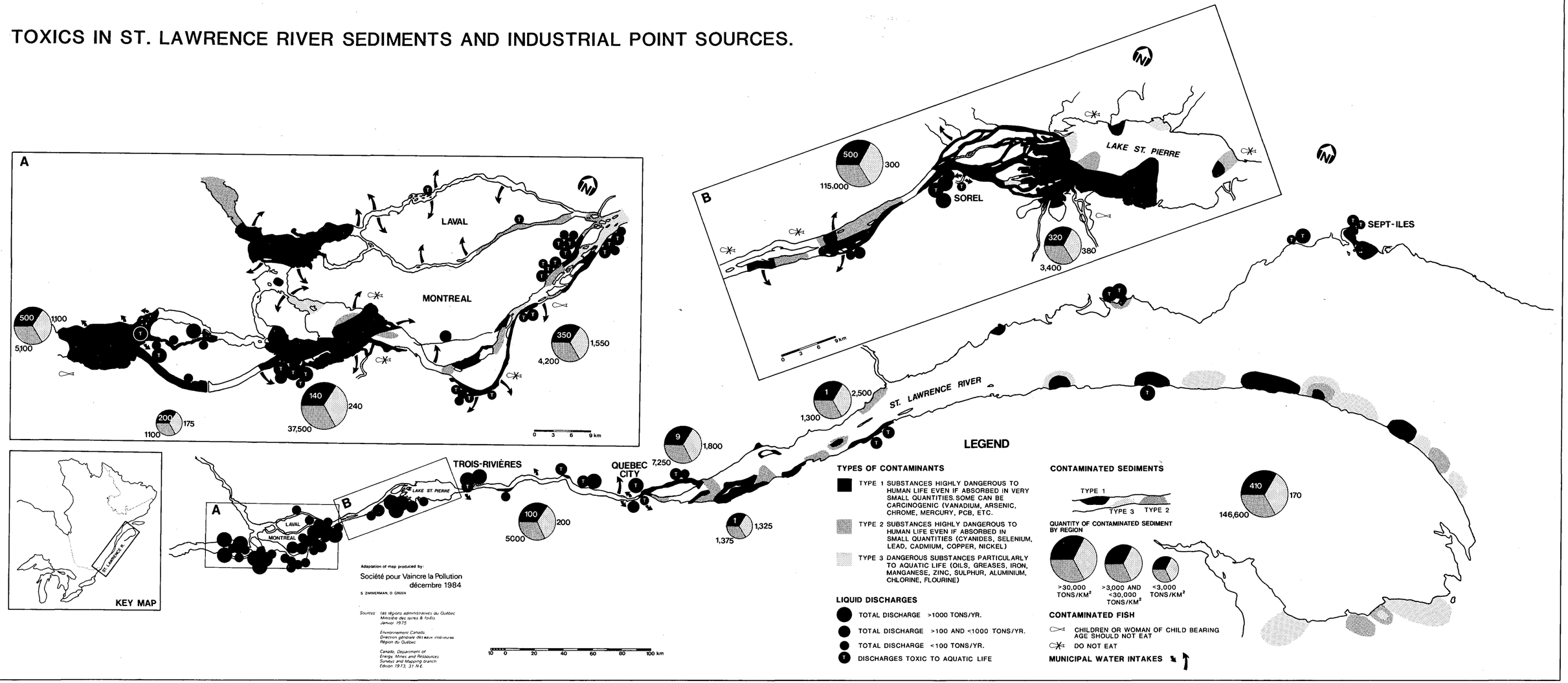
Human Tissues, Mother's Milk, and Human Food

Humans and their surrounding environment must be considered as a single entity. The use of radioisotopic techniques to trace the chemicals that enter and leave the body have revealed that about 98 percent of the 10^{28} atoms of the body are replaced annually (46). This replacement of body substances with the food, drink, and air is a part of the normal ecosystem exchange processes. Since many man-made contaminants are known to be in the ecosystem, these too are incorporated into the body by these exchanges.

Residues of a variety of contaminants have been found throughout the human food chain, both in the Great Lakes region, North America, and in other countries. A number of studies have documented the contamination of fish, meat, poultry, eggs, milk, root vegetables including potatoes, fresh fruit, and leafy and other above ground vegetables (190, 184, 66, 67, 178, 187, 226, 156, 115, 231). Other studies have demonstrated experimentally (PCBs added to soils to show plant uptake) the uptake of contaminants by both root and leaf vegetables under conditions analogous to field practices and situations (106, 188, 4, 6). Figures 19 and 20 show the data record of total DDT, dieldrin, and PCB residues in beef and pork fat between 1969 and 1981, for Ontario marketings. Table 1 shows examples of PCB residues

FIGURE 12

TOXICS IN ST. LAWRENCE RIVER SEDIMENTS AND INDUSTRIAL POINT SOURCES.



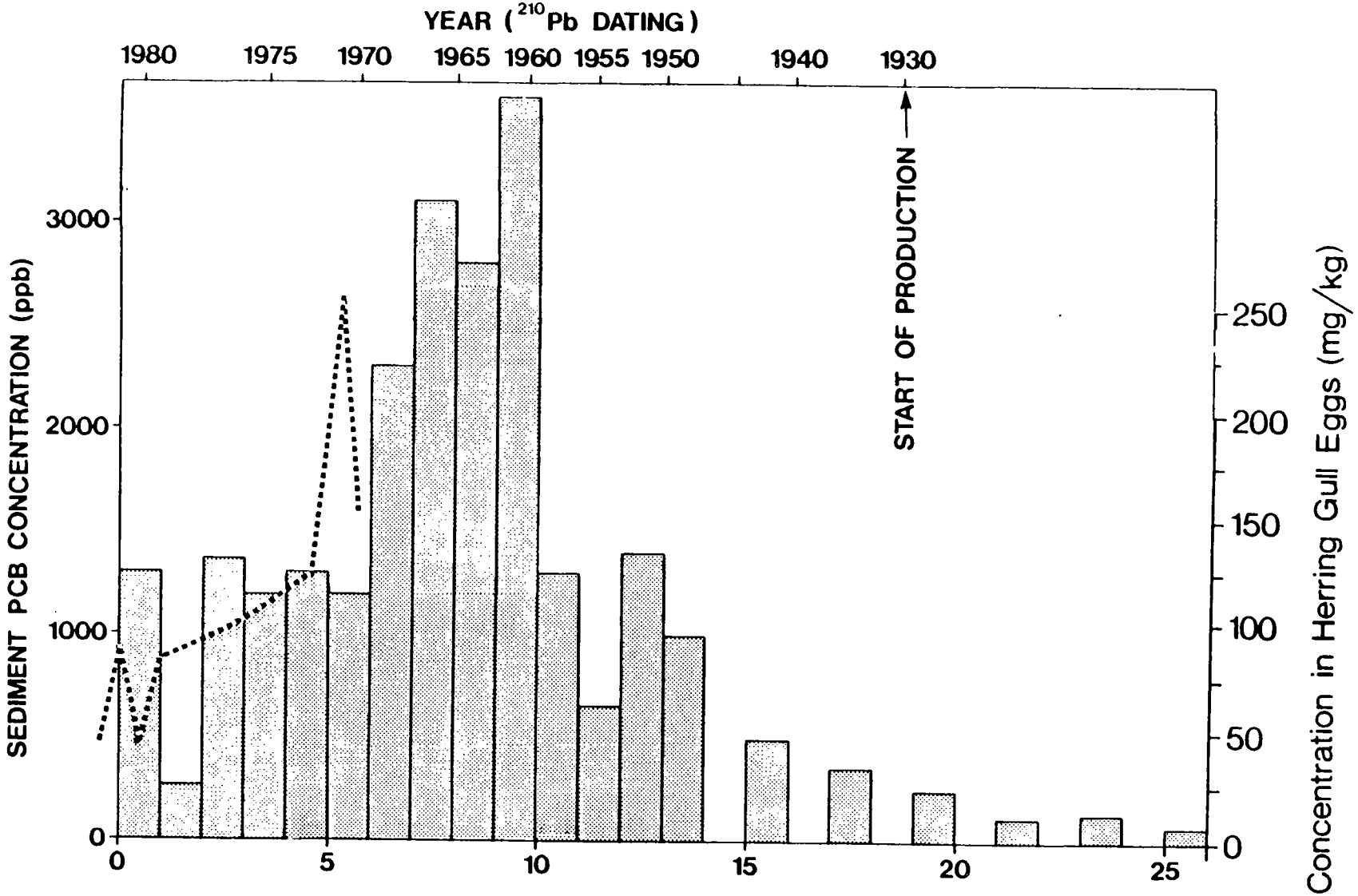


Figure 13. Total PCB's in the sediment core (bar graph) and herring gull eggs (line graph) of Lake Ontario

Source: D. Hallett, Personal Communication

1971 - 1980 — Gull eggs from Scotch Bonnett Island
1981 - 1984 — Gull eggs from Snake Island

Sediment Data (Durham & Oliver 1983)

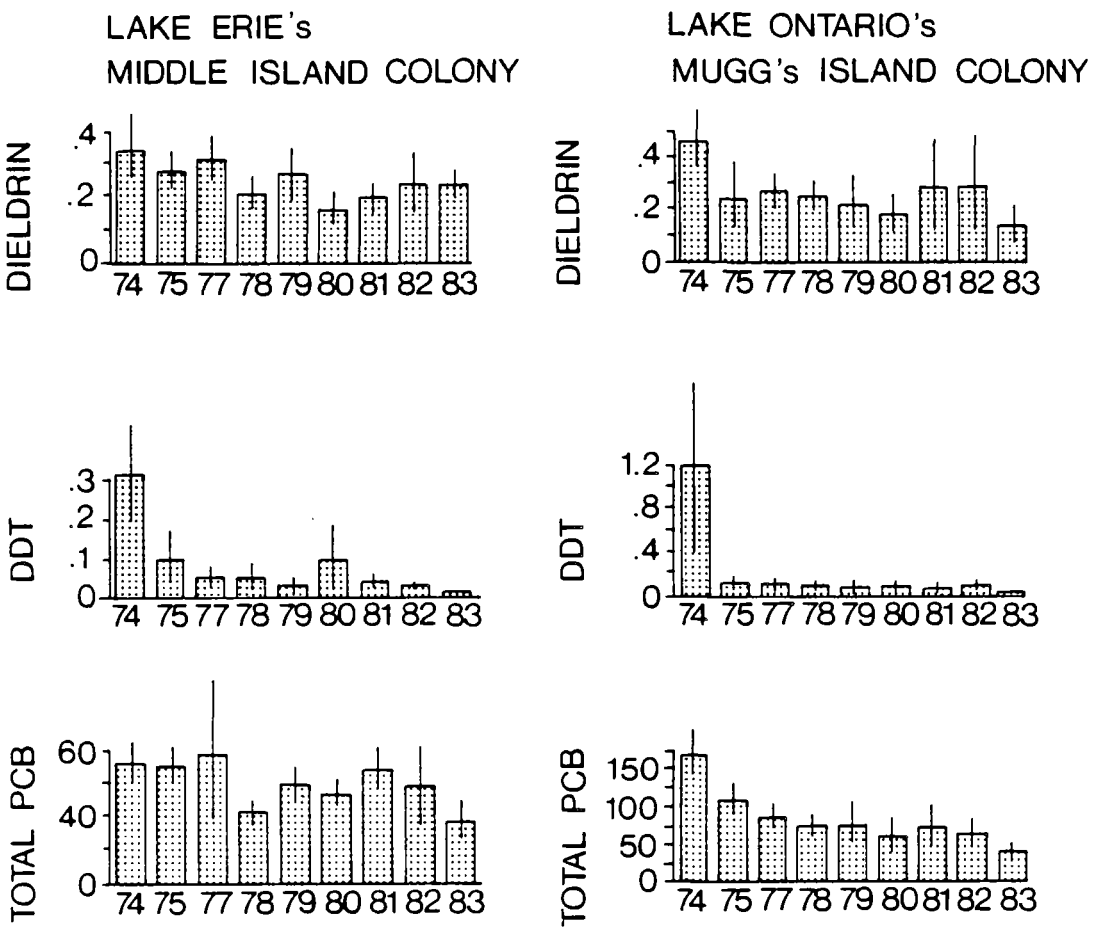


Figure 14 Mean Organochlorine Contaminant Concentrations (mg/kg wet weight +/— S.D.) in Herring Gull Eggs 1974-1983.
Data from the Canadian Wildlife Service.

Source: IJC. 1985. Report on Great Lakes Water Quality.

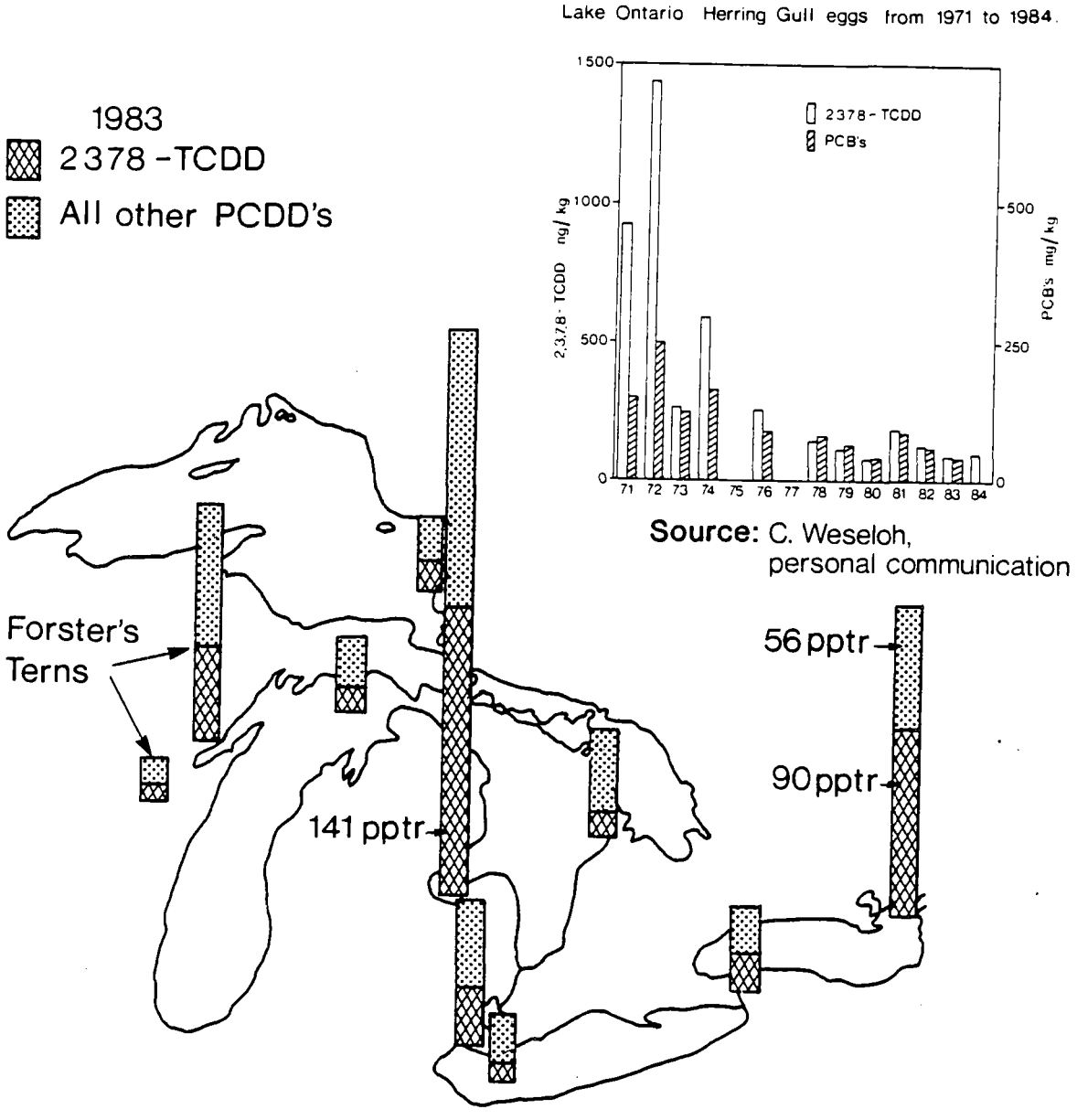
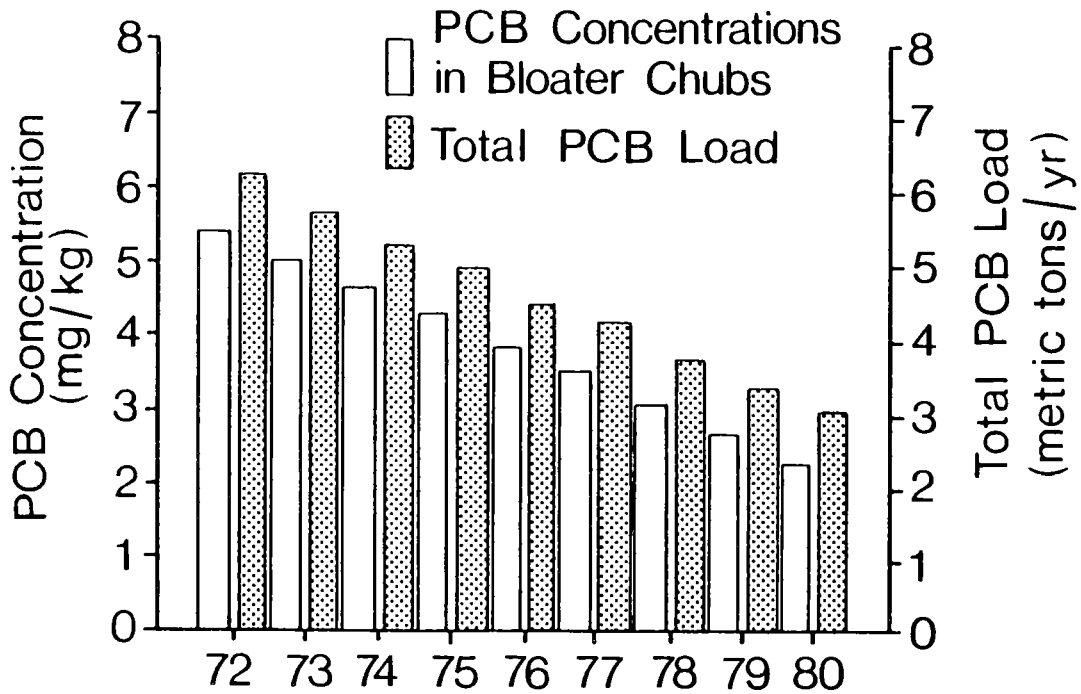


Figure 15 Residues of Chlorinated Dibenzo-p-dioxins in Herring Gull and Forster's Tern Eggs Collected from the Great Lakes Region. (pptr = ng/Kg).
Source: Stalling, D. L., Norstrom, R. J., Smith, L. M., and Simon, M. 1985. Patterns of PCDD, PCDF, and PCB contamination in Great Lakes fish and birds and their characterization by principal components analysis. **Chemosphere** Vol 14 No 6/7, p. 627-644.

Figure 16



Source: Rodgers, P.W. and Swain, W.R. 1983
Analysis of polychlorinated biphenyl
(PCB) loading trends in Lake Michigan.
Great Lakes Research 9(4): 548-558

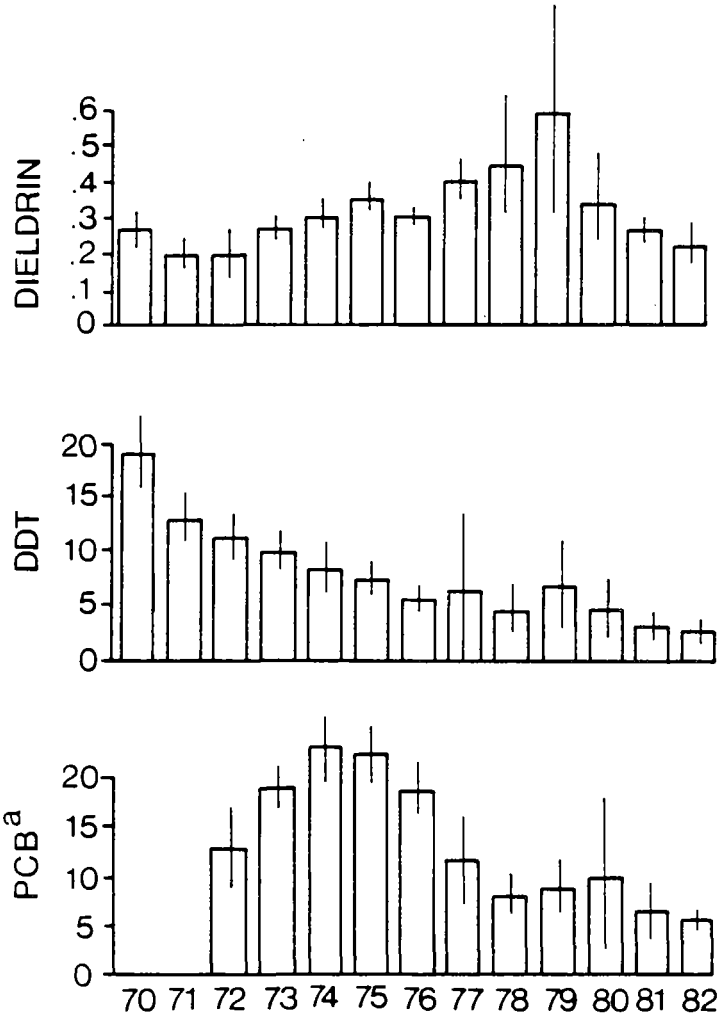


Figure 17 Mean Annual Dieldrin, total DDT, and PCB concentrations (mg/kg wet weight; with 95% confidence intervals) in whole fish samples of lake trout collected from eastern Lake Michigan.

a. From 1972-76 quantified using 1:1:1 Aroclor 1248, 1254, 1260 and beginning in 1977 only Aroclor 1254.

Source: IJC. 1985. Report on Great Lakes Water Quality.

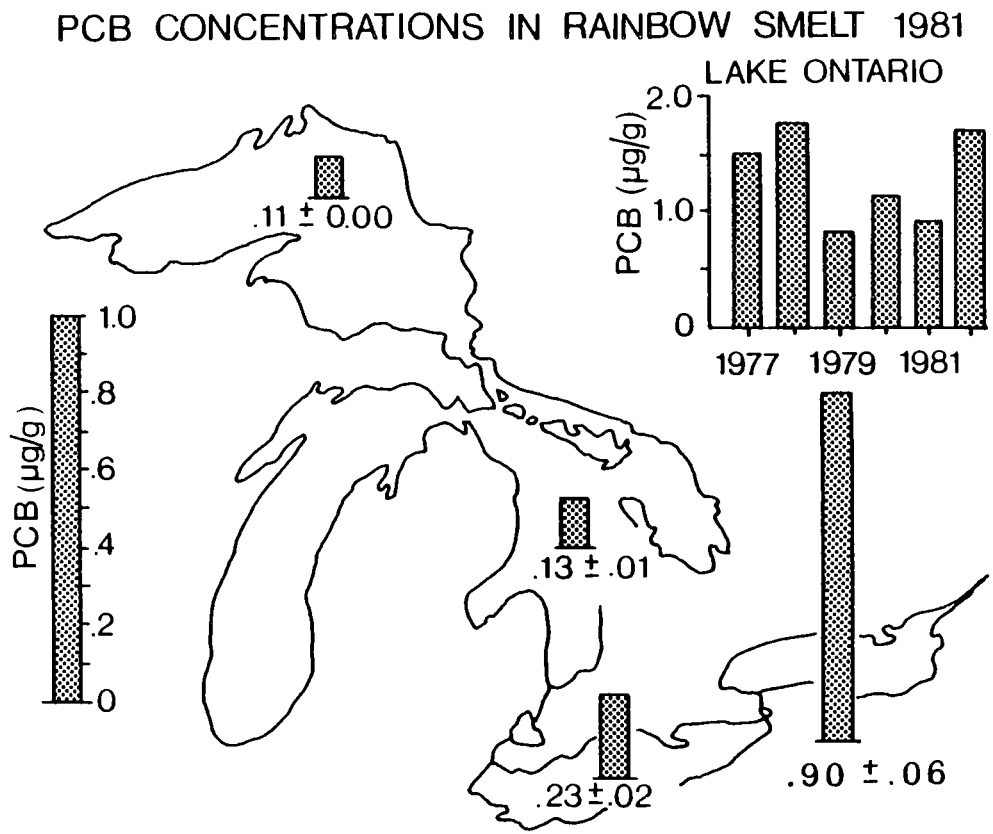


Figure 18

Source: 105

contained in foodstuffs, as reported in field and experimental studies. It should be noted that Table 1 is a mixture of data types and units, and is meant primarily as illustrative. It is not meant to show what is actually in food. What is needed is an estimate of what is in an ordinary shopping basket, and the amount of toxicants that people are really ingesting.

The data on toxicant residues in human tissues and food items, also demonstrate the unity through exchange (the web or net of life) of the elements of living things with each other, and with the earth itself. Those data indicate that some toxicant doses were significantly higher during the late 1960s and well into the 1970s, when ecosystem contamination was much worse. For example, the data in Figures 19 and 20 indicate that PCB and Total-DDT residues in pork and beef were both about 110 and 26 times higher, respectively, in 1969-70, than in 1981. There are no indications of what the peak residues were, when they occurred, or how long people were exposed at those higher levels.

It should not be surprising that human tissues also reflect the trend and state of ecosystem contamination. Findings regarding residues of DDT and its metabolites in the general population were reported as early as 1951 (170, 125). The storage of PCBs in man was not detected until 1966 (170, 112), after 40 years of extensive use. Of course, the general question remains whether any of these chemicals were looked for before 1951. Since then essentially all of the compounds of concern here have been identified in mother's milk, fat, liver, muscle, kidney, brain, gonads, blood, and so on, of humans. While the data are limited, they are similar to the patterns found in animals, as shown above.

Figure 21 and Table 2 show concentrations of residues of dieldrin, total DDT, and PCBs in human adipose tissue from residents of Southern Ontario and Canada (239, 221, 143, 141, 210). While these data are a sporadic comparison of different times and places, it is the only comparable data available. Figure 22 and Table 3 show concentrations for the same compounds in human milk (178, 210, 142, 164). There is a substantial range in body burdens that should be noted, as it (together with genetic variability and sensitivity differences) indicates the difficulty of using a single number or some average for exposure or other analysis, interpretation of significance, or standard (guideline) setting. There is a need to account for concentration variations in actual environmental data so that extremes of concentration and exposure, and their frequency are evaluated (254, 281).

Other more recent studies have identified dibenzodioxin, dibenzofuran, and other organochlorine residues in human tissues from the general population across Canada, the U.S., and in various locations within Ontario and upstate New York (80, 183, 221). Table 4 shows examples of these residues for two locations in Ontario (221, 238).

Table 1

PCBs in North American Food

Vegetables	Total PCBs	Total PCBs in Soil	Reference
Beet	66 ug/kg (dry wt.)	16,400 ug/kg	Sawhney and Hankin 1984 188
Turnip	66 ug/kg (dry wt.)	16,400 ug/kg	
Beans (pods & seeds)	181 ug/kg (dry wt.)	--	
Carrot (scrubbed not peeled)	68.7 mg/kg (fresh wt.)	386 mg/kg	Iwata et al 1974 106
Carrot (peeled)	1.34 mg/kg (fresh wt.)	386 mg/kg	
Cabbage	400 ug/kg (dry wt.)		Babish et al 1979 4
Leafy vegetables	0.14 mg/kg	17.1 mg/kg	Baker et al 1980 6
Meats			
Beef fat	9.5 ug/kg		Frank et al 1983 66
Pork fat	3.0 ug/kg		
Mutton fat	8.37 ug/kg		Saschenbrecker 1976 187
Fowl fat	3.0 ug/kg		
Lake Trout (1983 Data, Lake Ontario)	6.44 mg/kg (wet wt. whole fish)		IJC 1985 105
Carp (edible fillet)	1.58 mg/kg		Zabik et al 1982 226
Dairy			
Whole Milk (1985-86)	0.60 ug/kg		Environment Canada (1986) 238

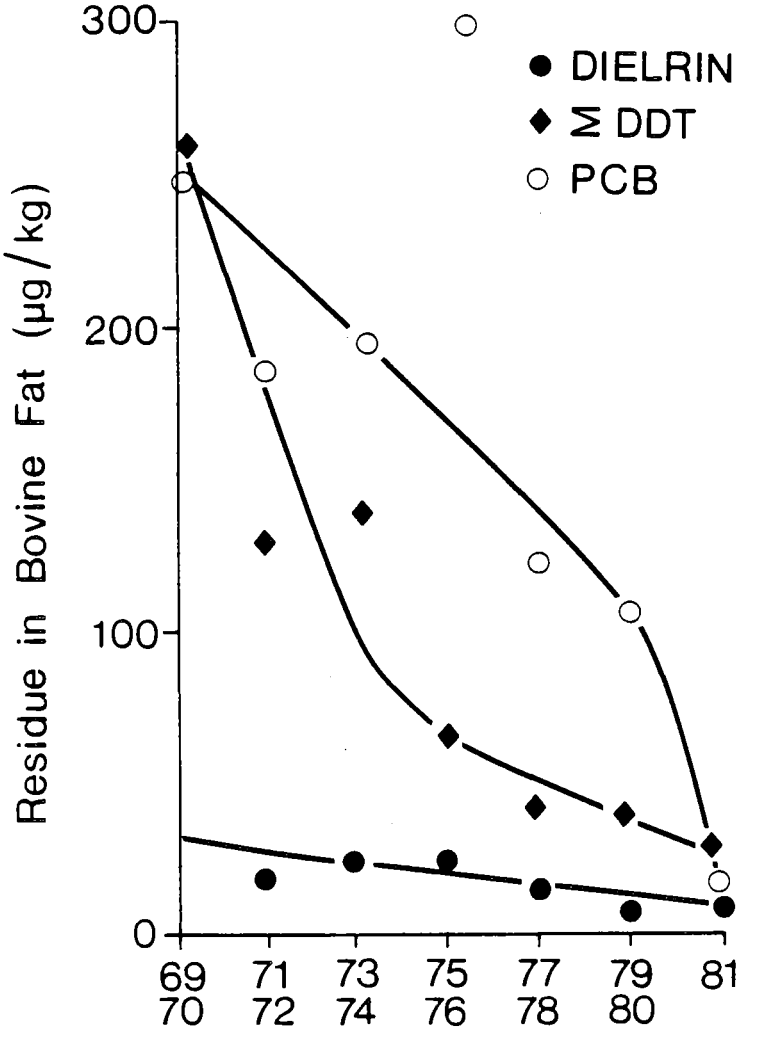


Figure 19 Decrease in ΣDDT, dieldrin and PCB residues in bovine fat between 1969 and 1981, Ontario, Canada.

Source: Frank, R et.al. 1983. Organochlorine and organophosphorus residues in fat of bovine and porcine carcasses marketed in Ontario Canada from 1969-1981. J. of Food Protection 46: 893-900.

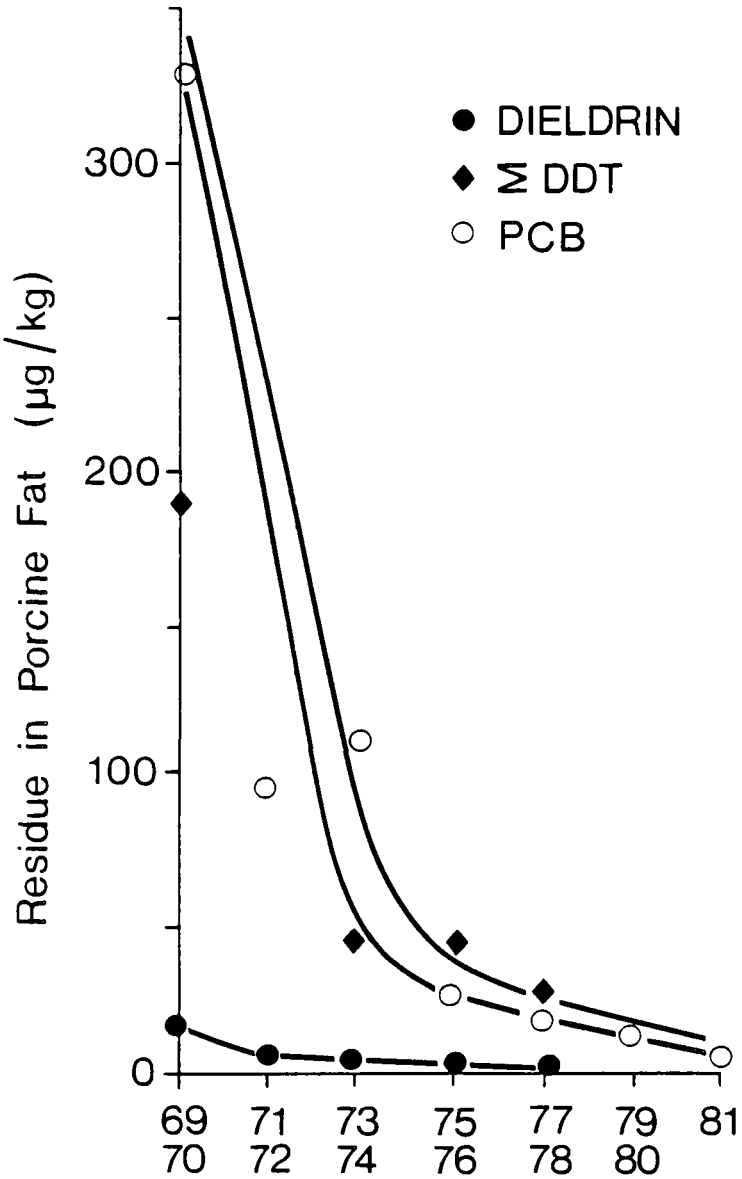


Figure 20 Decrease in ΣDDT, dieldrin and PCB residues in porcine fat between 1969 and 1981, Ontario, Canada.

Source: Frank, R et.al. 1983. Organochlorine and organophosphorus residues in fat of bovine and porcine carcasses marketed in Ontario, Canada from 1969-1981. J. of Food Protection 46 : 893-900.

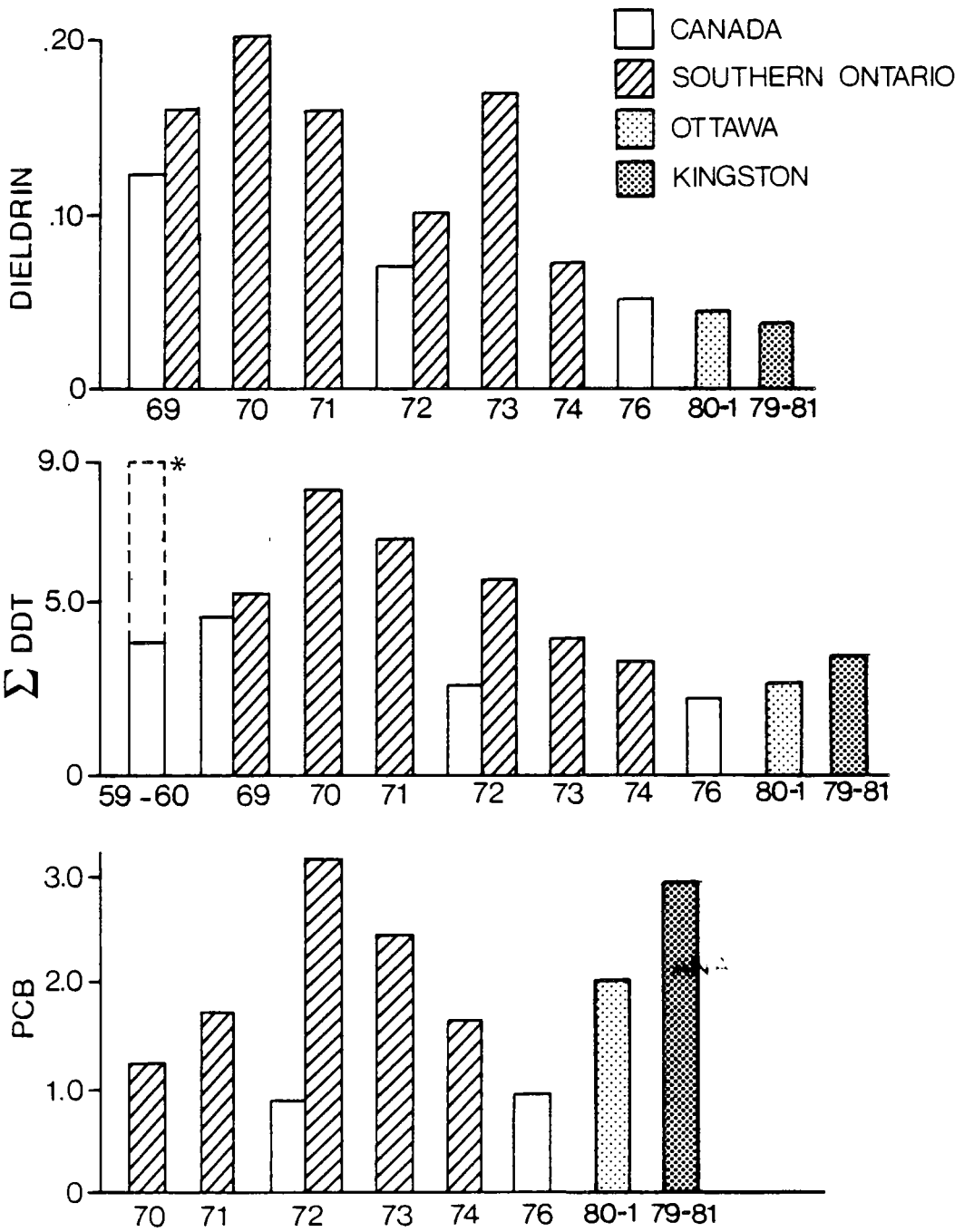


Figure 21 CONTAMINANTS IN HUMAN ADIPOSE TISSUE (µg/g wet weight)

Sources: see Table 2

*mean ranged from 4 to 9

Table 2 Contaminants in Human Adipose Tissue

ug/g wet weight

		DIELDRIN		DDT		PCB's		
Year	Place	Mean±S.D.	Range	Mean±S.D.	Range	Mean±S.D.	Range	Source
1959-60	Canada			4 to 9				176
1969	Canada	0.122±0.075	0.02 -0.46	4.543±2.732	0.18 -18.71			239
1969	Toronto	0.162±0.093	0.02 -0.46	5.330±3.583	0.32 -18.71			239
1970	S.Ontario	0.20	0.03 -0.56	8.06	1.32 -29.6	1.2	1.0 - 2.0	210
1971	S.Ontario	0.16	ND -0.88	6.69	0.50 -28.5	1.7	ND -10.0	210
1972	S.Ontario	0.10	ND -0.43	5.56	0.81 -18.8	3.2	0.6 -18.0	210
1972	Canada	0.069±0.055	0.001-0.353	2.571±2.101	0.075-18.22	0.907±0.817	0.106- 6.603	141
1973	S.Ontario	0.17	0.03-1.30	3.94	0.46-10.1	2.4	0.8 - 7.2	210
1974	S.Ontario	0.07	ND -0.16	3.12	0.47- 7.59	1.6	0.8 - 2.8	210
1976	Canada	0.049±0.030	0.003-0.211	2.064±1.941	0.055-12.395	0.944±0.902	0.040-6.801	143
1979-81	Kingston	0.036±0.028	ND -0.120	3.415±3.012	0.010-17.840	2.950+3.626	0.090-28.300	221
1980-81	Ottawa	0.043±0.028	ND -0.130	2.685±2.120	0.080-10.940	2.001±0.873	0.450- 4.760	221

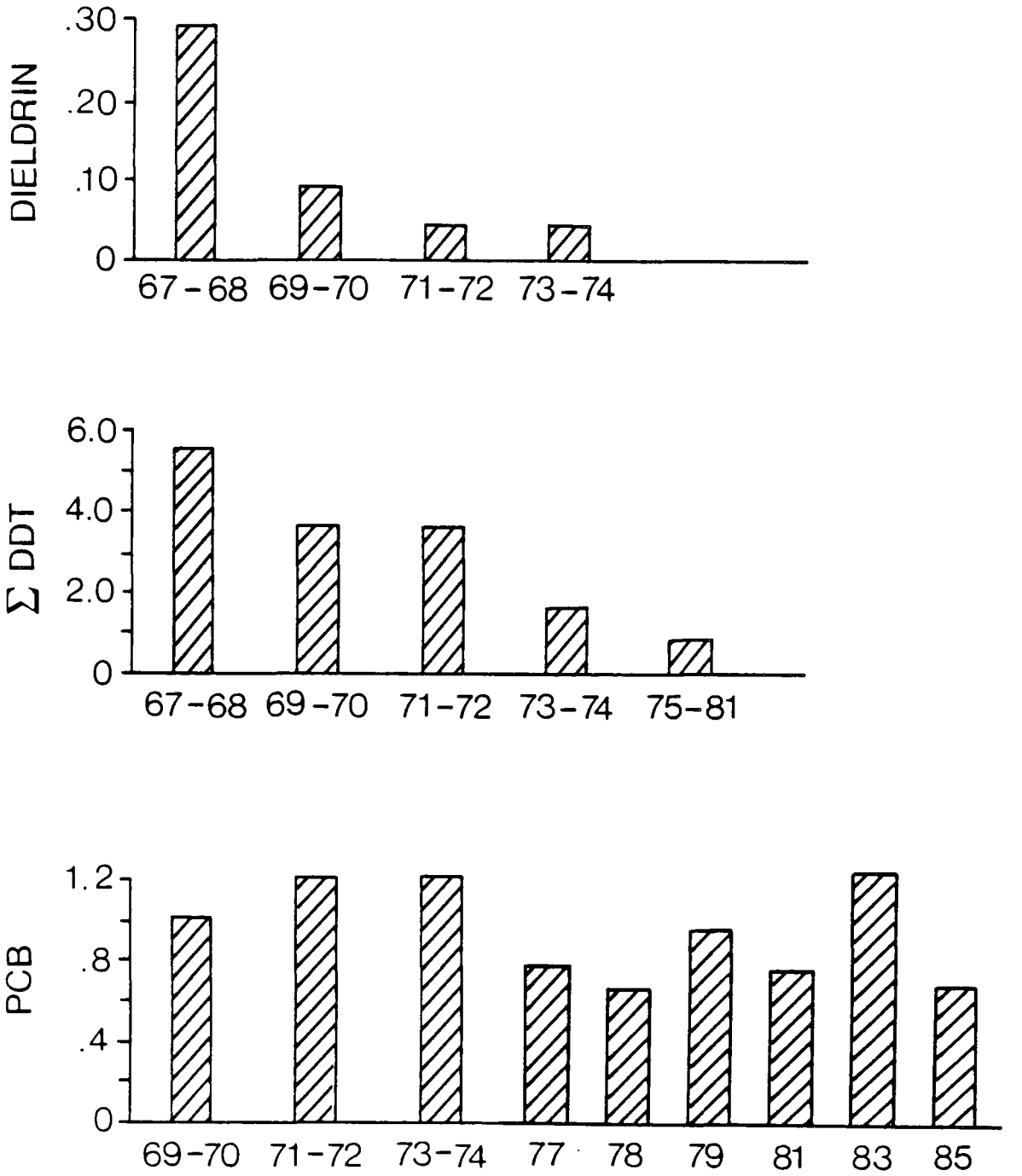


FIGURE 22 TRENDS IN CONTAMINANTS IN HUMAN MILK FROM ONTARIO RESIDENTS (µg/g fat basis)

Sources: see Table 3

Table 3 Trends in Contaminants in Human Milk

ug/g fat basis

		DIELDRIN		DDT		PCB's		
Year	Place	Mean+S.D.	Range	Mean+S.D.	Range	Mean+S.D.	Range	Source
1967-68	Ontario	0.284±0.291	0.05 - 1.53	5.399±3.340	1.85 -17.28			178
1969-70	Ontario	0.09	0.01 - 0.25	3.48	0.11 -11.4	1.0	0.7-1.2	210
1971-72	Ontario	0.04	0.01 - 0.17	3.48	0.33 -18.8	1.2	0.2-3.0	210
1973-74	Ontario	0.04	0.01 - 0.08	1.39	0.22 - 2.58	1.2	0.1-2.5	210
1975-81	Ontario			0.819	0.758- 0.881			164
1977	Ontario					0.80		164
1978	Ontario					0.66		164
1979	Ontario					0.96		164
1981	Ontario					0.79		164
1983	Ontario					1.24		164
1985	Ontario					0.67		164

Table 4
Organochlorine Residues (ng/g) in Adipose Tissue

Residue	Kingston				
	Male		Female		All
	Mean ± SD[a]	Range	Mean ± SD	Range	(Mean ± SD)
Heptachlor epoxide	36±21	10-110	33±18	10-90	35±20
Dieldrin	36±27	ND[b]-100	37±30	ND-120	36±28
p,p'-DDD	15±12	ND-80	13±10	ND-50	14±11
p,p'-DDT	146±136	ND-740	176±179	10-710	159±156
β-HCH	65±40	ND-210	228±707	10-3430	136±474
Oxychlordane	47±20	10-120	35±14	10-80	42±18
α-Chlordane	21±19	ND-80	14±9	ND-50	18±16
p,p'-DDE	3657±3410	10-17100	2744±1856	180-7590	3256±2856
Photomirex	11±14	ND-60	6±3	ND-20	9±11
Mirex	38±47	ND-190	12±13	ND-70	27±38
PCB	3708±4620	90-28300	1983±1123	600-7350	2950±3626
1,3,5-TriCBz	2±2	ND-14	2±4	ND-22	2±3
1,2,4-TriCBz	31±108	ND-653	8±21	ND-122	21±82
1,2,3-TriCBz	33±185	ND-1320	3±9	ND-54	20±139
1,2,3,4/1,2,4,5-TetraCBz[c]	1±2	ND-8	1±3	ND-16	1±2
PentaCBz	1±2	ND-8	1±3	ND-20	1±2
HCBz	101±67	10-402	113±74	32-458	106±70
2,3,4,6/2,3,5,6-Tetra CP	24±29	ND-133	20±22	ND-92	22±26
2,3,4,5-Tetra CP	6±4	ND-22	6±3	ND-22	6±3
PCP	35±44	ND-277	33±41	ND-247	34±43
2,3,7,8-TCDD					12.4×10^{-3}
	Ottawa				
Heptachlor epoxide	38±19	10-80	36±25	10-130	37±21
Dieldrin	43±29	ND-130	44±26	ND-90	43±28
p,p'-DDD	8±6	ND-30	11±13	ND-60	9±9
p,p'-DDT	113±70	ND-350	154±149	30-740	128±107
β-HCH	65±96	10-680	65±63	10-370	65±85
Oxychlordane	41±17	20-110	36±13	10-80	39±16
α-Chlordane	17±7	10-30	15±5	10-20	16±6
p,p'-DDE	2577±2046	280-10200	2523±1988	80-8190	2557±2013
Photomirex	6±5	ND-30	ND	ND	6±4
Mirex	12±8	ND-120	9±12	ND-70	11±16
PCB	2167±937	790-4760	1718±673	450-3570	2001±873
1,3,5-TriCBz	2±2	ND-13	8±15	ND-61	4±10
1,2,4-TriCBz	3±6	ND-39	14±32	ND-156	7±20
1,2,3-TriCBz	ND	ND	1±1	ND-8	1±0.8
1,2,3,4/1,2,4,5-TetraCBz[c]	ND	ND	0.6±0.4	ND-3	0.5±0.3
PentaCBz	1±6	ND-44	ND	ND	1±5
HCBz	71±48	17-315	91±55	21-280	78±52
2,3,4,6/2,3,5,6-Tetra CP	6±4	ND-31	8±10	ND-44	7±7
2,3,4,5-Tetra CP	7±4	ND-22	7±4	ND-17	7±4
PCP	17±12	ND-66	29±32	5-168	22±22
2,3,7,8-TCDD					8.6×10^{-3}

[a] Mean and standard deviation based on wet weight, not including NC values listed in Table 1.
[b] ND, not detected.
[c] Isomers had same GC retention time.
Source: 221

Some of these chemicals may accumulate with age, indicating continued exposure and rates of excretion less than uptake (80, 232, 142, 143). Significantly higher levels of DDD, mirex, hexachlorobenzene, 2, 3, 4, 6-tetrachlorophenol, and several others at low frequencies of occurrence, were found in the Kingston adipose tissue as compared to Ottawa tissues (221). Since it is possible, but not measured, it can only be speculated that this may reflect Kingston's physical location, both downstream and downwind from major source areas relative to Ottawa, however, the mechanisms involved in this difference need investigation. Significantly lower burdens of oxychlordane, mirex, and PCBs were found in Kingston females versus Kingston males (Ottawa differences were not significant at the 0.05% level) (221). As a further speculation, (since it is possible, but not measured) this may be partially due to placental transfer to the fetus during pregnancy, and to breast-feeding (170, 164, 210, 318).

Other Life Forms

In the St. Lawrence River, contaminants have been found in snapping turtles (185), eels (185), and Beluga whales (136,235). Contaminant levels in blubber in Beluga whales are very high for PCBs (up to 576 ppm) and total-DDT (up to 225 ppm). Organochlorine levels in the milk of a lactating female whale are even higher; 1725 ppm of PCBs, 2046 ppm of Total-DDT, and 1879 ppm of pp'DDE (136). It is extrapolated from other work on organochlorine transfer in marine mammals, but not certain, that the female Beluga whale loses a significant portion of its total organochlorine body burden through pregnancies and lactation (136). This load is transferred to the fetus through the placenta and to the suckling young through the milk (136).

In a number of places in Ontario, studies investigating acid and toxic rain have found metals, like cadmium, and mercury, at elevated levels in moose and deer (Ministry of Natural Resources warning to hunters); otters and wild mink (255); and Eastern Kingbird nestlings (256). Organochlorine and heavy metal contaminants are found throughout the arctic marine ecosystem (157, 265). Residues are found in polar bears, Arctic ringed seals, Baltic ringed seals, arctic cod, fish-eating marine seabirds, and harp seals (157, 243). While not Great Lakes focussed, this is relevant and important as it further shows that chemicals move into and through the atmosphere over long distances (265), and become generally incorporated in food chains.

3.0 STATES OF HEALTH IN THE ECOSYSTEM: NON-HUMAN

Birds

The severe embryonic abnormalities and mortality, congenital anomalies, and reproductive failure that occurred among fish-eating birds in the late 1960's and early 1970's, were the "early warning" anomalies observed in the field by wildlife biologists (73, 72, 259). Reproductive problems with fishing-eating birds in the Great Lakes were first reported in Lake Michigan in 1966 and in Lake Ontario in 1970. Analysis of Great Lakes fish-eating birds showed contaminant levels among the highest in the world (259).

A comprehensive program to assess the extent and toxicological significance of this contamination was implemented using the herring gull as indicator species (259, 262, 263, 264). Reproductive data collected by this program from colonies throughout the Canadian Great Lakes revealed that breeding problems were confined to Lake Ontario, and to a lesser extent, Eastern Lake Erie (Port Colborne) (259, 274). Congenital anomalies in Lake Ontario colonial fish-eating birds were substantially above background levels during the 1971-1975 period (259, 270, 271).

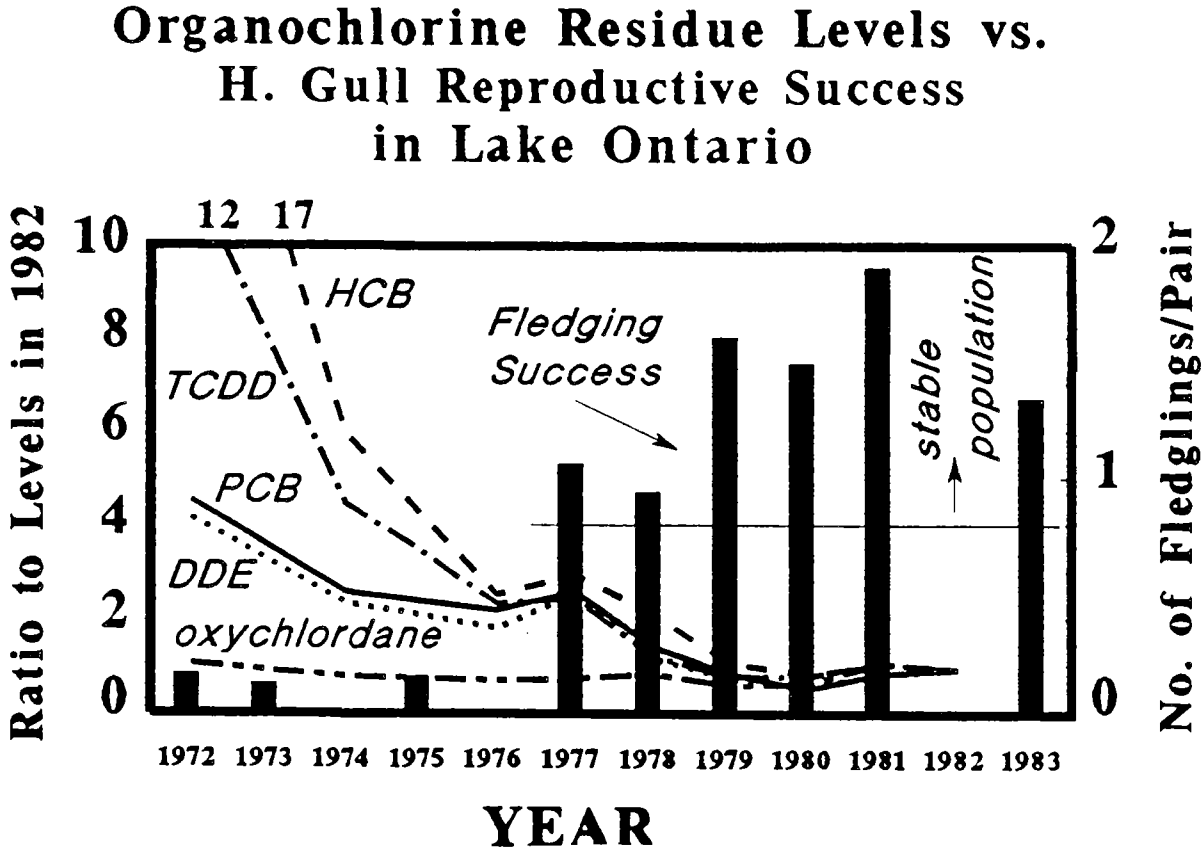
During the late 1970's, the overall reproductive success of Great Lakes fish-eating birds improved to "normal", with the exception of the Forster's Tern in Lake Michigan. The incidence of anomalies in Lake Ontario has returned to background levels, although an elevated incidence was reported for the double-crested cormorant from Lake Michigan (259, 270, 271, 274). The recovery of reproduction in the Lake Ontario herring gulls is shown in Table 5, together with an indicator of declining contaminant levels.

At the time of the first reports, there was scant, direct physical evidence to link these anomalies with the organochlorine loadings discharged into Lake Ontario, and other areas of the ecosystem, as documented above. Since then, however, the evidence concerning general pollutant-related effects found in fish-eating birds and other wildlife has grown considerably (73, 259, 262-265, 267-271). While it is rarely possible to statistically relate specific effects to specific chemicals, the geographic and temporal patterns of effects are reported to indicate that they are caused by xenobiotics (270, 271). This consensus is summarized in Table 6.

For the Bald Eagle, Osprey, and Double-Crested Cormorant, the causative agent in reproductive problems is thought to be specifically DDE. (259, 263, 270). For the Lake Ontario and Eastern Lake Erie herring gull colonies, organochlorine compounds are prime suspects (259, 262-265, 269-271). As noted, while specific-chemical, specific-effect, relationships cannot be statistically demonstrated, the evidence suggests that chick-edema active, teratogenic, embryotoxic and porphyrinogenic compounds, such as 2, 3, 7, 8-TCDD and its analogs are involved (259, 271, 275).

Other work showed that herring gull embryos in a late development stage (25 days) showed levels of the enzyme aryl hydrocarbon hydroxylase (AHH) (one part of the biotransformation-detoxication enzyme system that oxidatively metabolizes foreign compounds) induction that are positively correlated with levels of 2, 3, 7, 8-TCDD (259, 271, 272, 273). Also shown were significant depressions in the activity levels of the enzyme aniline hydroxylase (aniline is a derivative of benzene), and a correlation with mirex levels, particularly in the Lake Ontario colonies which showed the greatest depression (273). Egg injection experiments indicate that hexachlorobenzene may have contributed significantly to the high embryonic death rates noted in the 1970's in Lake Ontario gulls (273, 274).

TABLE 5



Source: R. Norstrom, Personal Communication

Table 6

INCIDENTS OF TOXIC CHEMICAL EFFECTS ON
WILDLIFE IN THE GREAT LAKES

EFFECT	PUTATIVE AGENT(S)
* 80-100% Loss of Double-Crested Cormorant, Bald Eagle and Osprey populations due to fragile egg shells.	p,p'-DDE
* Reduced populations of Common Terns Black-Crowned Night Herons due to fragile egg shells and other reproductive effects.	p,p'-DDE + ?
* Impaired reproduction in Forster's Terns in Green Bay due to TCDD-like toxicity.	2 PCB isomers and 2,3,7,8-TCDD
* Possible loss of Mink and Otter populations	PCBs
* Embryonic mortality in Herring Gulls in Lake Ontario (to 1976)	HCB, TCDD + ?

Source: R. Norstrom Personal Communication

Work on adult herring gulls from the Great Lakes has provided other biochemical effects or indicators that appear to be generally pollutant-related. Thyroid gland dysfunction in Great Lakes gulls was significantly greater than in Bay of Fundy controls. (276, 271, 275). The majority of Great Lakes gulls suffered from goiter (276). The evidence supported the hypothesis that polyhalogenated hydrocarbons were responsible for the observed goiter and thyrotoxic effects (276).

Elevated levels of highly carboxylated porphyrins (porphyria is thought to have been one of the causes of reproductive failure (271)) found in Great Lakes gulls compared to Bay of Fundy gulls were highly correlated with organochlorine residue levels (271, 270, 275). Significantly lower levels of hepatic retinoid levels (retinol, and retinyl palmitate) in Great Lakes gulls as compared to New Brunswick gulls, and significant differences between Great Lakes colonies, corresponded to gradients of pollutants (270, 271). Experimental studies with ring doves (dosing with a dioxin analog, 3, 4, 3', 4'-tetrachlorobiphenyl) showed an inverse relationship between retinol concentration and AHH activity.

Retinol is a form of vitamin A, whose molecular structures are readily attacked by oxidizing agents (277), such as electrophiles or free radicals. A precursor of vitamin A, B-carotene, exhibits good radical-trapping antioxidant behaviour under physiological conditions (2, 277, 278). Carotenoids are anticarcinogens in rats and mice and possibly humans, and are used medically to treat porphyria (2). This and other evidence suggests that the AHH driven metabolism of pollutants is creating reactive species (e.g. highly oxidized products of metabolism) which are involved in the biochemical effects (2, 272, 277, 278). It is noteworthy that similar metabolic mechanisms and reactive species are involved in fish carcinogenesis, and possibly other deleterious effects, as will be discussed in the next section.

More recently, in and around Green Bay, Wisconsin, reproductive impairment in colonies of Forster's terns and Common terns was observed. Crossed-bill syndrome was observed in cormorants, and herons were found dead or moribund (119, 197). From 1973 on, congenital anomalies are documented in 5 species of fish-eating birds, including the Forster's tern. Bill defects are reported to be the most prevalent, however, no data were given (119). Common to these events was the presence, in the birds, of various contaminants including 2, 3, 7, 8-TCDD, and other structurally related compounds or isostereomers, particularly certain co-planar PCB isomers (119, 76, 321). These related compounds share similar toxic properties (321).

Complementing and confirming these findings, recent field studies were carried out on the reproductive problems of the Forster's tern in the Green Bay area (119). The purpose of the overall study was to determine if the reproductive success of this bird on lower Green Bay,

downstream from, and on, major sources of the suspect contaminants, was different from an inland colony on Lake Poygan, upstream from these same sources. The results, synthesis of other work on contaminant mode of action, and companion follow-up studies indicate that the observed reproductive impairment in the Green Bay colony is probably related to organochlorine compounds and likely to be AHH inducing type compounds like 2, 3, 7, 8-TCDD and other related isomer specific dioxins, co-planar PCBs, or some other unspecified or unidentified compounds (119, 321).

It is of particular interest that the reproductive impairment is due not only to direct embryotoxic effects, (effects on the unhatched), but also to aberrent parental behaviour (119, 270, 271). Does this latter factor reflect contaminant effects at the adult stage of development? Or does it reflect less than lethal egg stage effects that nonetheless produced a lower quality, and less fit adult (and therefore, population)? These are interesting questions, with implications for all life in the ecosystem.

Fish

The effects of contaminants like pesticides, heavy metals, and other synthetic organics, on fish and other aquatic life are extensively documented. On the level of the individual organism, known and observed impacts come in various forms: metabolic depression (energy loss); reduced growth; reduced reproduction; reduced life span; reduced viability of eggs and juveniles; abnormal development; susceptibility to disease and parasitism; and the occurrence of tumors, skin lesions and neoplastic abnormalities (257, 258). At the population and community levels these effects can lead to reduced recruitment, changes in feeding and behavior, and community composition (140, 209, 257, 258).

It is known that the fish in the Great Lakes contain, or are exposed to, a large number of a wide variety of chemicals, including the three classes selected in this report. In one report 476 compounds were tentatively identified in Great Lakes fish, compared to only eight in hatchery fish of similar species and size (322). Again, like the fish-eating birds, the array of chemicals that are present in the environment, and the large number of variables and factors acting there, makes it rarely possible to derive exact or deterministic explanations of specific-cause and specific-effect links. This variability (the amplitude of the wave nature of matter) puts inherent limits on the precision or certainty with which cause-effect links can be measured. Reports that point to a lack of direct proof of a causal role for toxic contaminants in the development of tumors in indigenous fish may tacitly assume an absolute logical certainty that doesn't exist (105, 146). However, research concerning these basic, direct links provides consistent evidence of such a role.

There are difficulties linking laboratory results with field results. Laboratory experiments provide means of control allowing clear and detrimental effects to be defined (258). The field situation is by definition wild and complex, denying control and clear linkages. Detailed discussion of this problem cannot be done here. However, a concise description of the major obstacles is contained in a review of the effects of toxic chemicals on fish (258).

Experimental results show that a number of chemical agents, like PAHs, DDT, carbon tetrachloride, and dioxins induce tumors in fish (105, 144, 14). PCBs (Aroclor 1254) fed to brood female rainbow trout promoted an enhanced carcinogenic response (liver tumor frequency increased by approximately 30%) in progeny following embryo exposure to aflatoxin B1 (144, 14). Endrin induced preneoplastic changes in cutthroat trout livers (144). While such experimental work on fish is limited relative to mammals, at least 35 mammalian carcinogens experimentally induce cancer in one or more of some dozen species of fish (91).

Field work has revealed several types of tumors, including liver and skin cancer, in brown bullheads from the Buffalo River, New York, and the Black River, Ohio, as well as in other species in other waterways (Torch Lake, Michigan; Puget Sound, Washington, and the Hudson River). The sediments of both rivers are heavily contaminated with a variety of chemicals, including several dozen PAHs, and dye intermediates, some of which are known carcinogens (105, 14, 91, 118, 260, 266). It is noteworthy that while there are differences between fish and other species, fish also possess xenobiotic inducible enzymes, including AHH.

In the Buffalo River, about 17% of the adult bullheads exhibited grossly detectable cancers. The prevalence of similarly visible cancers in Black River bullheads was 30%. Furthermore, microscopic examination of liver tissue found that almost 80% of two-year and older bullheads had cancerous or pre-cancerous lesions (266, 91). No tumours were observed in the same species of fish from non-polluted water (266). Supporting this field work were experiments that fed bullheads extracts of sediments obtained from the industrialized portions (estuaries) of each these rivers. Both river sediment extracts induced liver cancer in the bullheads (58). Other work suggests that the parent and alkylated PAH with 4 and 5 aromatic rings are the primary genotoxic PAH contained in the fossil fuel effluents accumulated in the sediments of the Black River (Ohio) (266).

Research in similarly contaminated environments outside the Great Lakes yields some insights into factors and relationships that complement the laboratory and Great Lakes field research. A recent series of field studies of English sole from Puget Sound, Washington, are particularly useful (118, 260). In the sediments at one urban

location in Puget Sound, more than 900 individual organic compounds were detected, including over 500 aromatic hydrocarbons, and hundreds of chlorinated hydrocarbons. At another location, more than 200 nitrogen-containing aromatic compounds were also found. The presence of many other chemicals was indicated but limitations of analytical technique prevented their numbers and identities from being described (260). Previous work had shown that sediment concentrations of certain chemicals, such as aromatic hydrocarbons (AHs or PAHs) and metals, were correlated with prevalences of neoplasms and other liver diseases in fish inhabiting the sediments (118, 260). Thus the Great Lakes are not the only locations where these types of associations are found.

The general causal link is strengthened if this statistical relationship can be moved "inside" the fish, so to speak, thus demonstrating an observable physical link between chemicals "outside" and chemicals "inside". The findings show a significant positive correlation between the relative concentrations of metabolites of AHs in bile, and neoplasms and other liver diseases, in English sole from Puget Sound (118, 260). These metabolite concentrations also correlated significantly with the concentrations of aromatic free radicals in liver. Also found were significantly higher concentrations of aromatic free radicals in the livers of English sole with liver lesions compared to sole without liver lesions (260). It is noteworthy that the measured metabolites originate from parent AHs which have been identified as initiators/carcinogens, or promoters/cocarcinogens (118,260). Mammalian studies indicate that free radicals may play a crucial role in chemical carcinogenesis (260).

Other important fish health effects chemically induced in the lab include: damage to sperm and sperm processes; damage to oocytes (immature eggs), and decreased frequency of oocyte maturation; and damage to the cortex of the sex-hormone regulating adrenal gland (144). It was also found that benzo (a) pyrene metabolites bind in vivo to DNA and proteins in the gonads of English sole (212). All of these effects contribute to reproductive impairment, a field observation thought to be at least partially related to chemicals (258,322).

Other Aquatic Life

The hypothesis that environmental contaminants cause a wide range of deformities in chironomid larvae (insect larvae) first emerged in the late 60's and early 70's (22, 86). Recently, it received further substantiation. In an exhaustive study of the paleolimnology of the Bay of Quinte, Lake Ontario, (Prince Edward County, Ontario) a marked increase in the incidence of severely deformed chironomid larvae was observed in the most recent sediments. The incidence of deformities increased from 0.09% in the pre-European sediments, to 1.06% at the 1951 level, and 1.99% in the 1972 population of chironomids. This is an increase of more than 2200 percent. The coincident link to toxic industrial and agricultural pollutants was reported, however, no study of possible causal relations was done (215).

The incidence of deformities in Chironomus spp. larvae in Port Hope Harbour, Lake Ontario, (Northumberland County, Ontario) was higher in the more heavily polluted inner harbour area than in the outer harbour. Port Hope Harbour is contaminated by uranium and thorium decay chain radionuclides and several heavy metals. Radiation dose rates suggested that ionizing radiation could be a factor in the induction of deformities, however, heavy metals, and elevated water temperature may also be involved (261). Other reports linking increased frequencies of deformities in Great Lakes chironomids with agricultural and industrial toxicants are noted in (261).

Elsewhere, comparison of the incidence and severity of antennal deformations in Chironomus populations from contaminated and relatively uncontaminated ecosystems in south-central Saskatchewan show that both indices are higher in the contaminated one (216). The data suggest that the effects of contaminants occur at a very early stage of the larval cycle, and also that length of exposure is an important factor in the response (216). Evidence shows that a significant proportion (30-40%) of the burden of DDE (for example) in exposed females is transferred to the next generation via the egg mass. Researchers believe that the most deformed larvae probably reflect the longest exposure times, and the effects of contaminant bioaccumulation and transmission from generation to generation. Moreover, these larvae are thought to have a slim chance of surviving the larval stage, let alone the full life cycle (216).

Mammals

Beluga whales inhabiting the St. Lawrence river were reduced dramatically in numbers by heavy hunting in the early 1900's. Although hunting was stopped 25 years ago, the population has failed to recover and now numbers about 350. Studies in the Arctic have shown that exploited Beluga populations generally recovered when hunting ceased. Contamination by organochlorines is suspected to be an associated factor in the St. Lawrence Belugas' failure to recover (136, 235). Placental and mammary transfer of organochlorines is thought to be active in this population (136). Postmortem examination of strandings revealed perforated gastric ulcers, severe chronic active hepatitis, urinary bladder cancer, and ovarian cancer (136).

PCBs acted as the causal agent in the high incidence of reproductive failure and kit mortality experienced by commercial mink ranchers who fed their animals coho salmon from Lake Michigan. Laboratory studies clearly confirmed this causal link (177, 194). A variety of illnesses, including neurological dysfunction, and reproductive dysfunction, were induced in primates (rhesus monkeys) and mammals (mice) by lab controlled exposure to PCBs. Field observations indicate that wild populations of mink and otter close to Lake Ontario have declined (73). While habitat loss may be a factor, the possibility that chemicals are involved needs investigation.

The contamination of the Great Lakes ecosystem by organochlorine compounds is reported to be among the highest in the world, ranking with that in the Baltic (259, 262, 263, 264). Impairment of reproduction, ranging up to complete failure, has occurred in Baltic ring seals. This was associated with PCBs and Total-DDT in their blubber, however, it was concluded that PCBs or other substances co-varying with PCBs may be responsible. The impairment was possibly mediated through effects on steroid reproductive hormones which can cause failure of fertilized ova to implant or develop (243). Unusually high numbers of resorptions, or spontaneous abortions occurred.

4.0 STATES OF HEALTH IN THE ECOSYSTEM: HUMAN

Humans are larger, more complex, longer-lived, and slower to reproduce than most other animals in the ecosystem. They are also at the top of the food chain or web (mostly land-based, but with varying components from freshwater and marine food chains). These factors have a direct effect (dampen and delay) upon human health impacts of toxic substances. Greater complexity, (derived from a greater amount of genetic information) particularly in the nervous system and brain, entails a corresponding vulnerability and sensitivity that varies according to life stage (89, 232, 307, 308, 318). Longer lives and larger size, in any organism including humans, raise the possibility of chronic effects, even under low dose conditions (237, 309). Long-lived species should be particularly concerned about fat soluble, persistent, biomagnified compounds (258, 279). Slow reproduction requires more time to observe patterns of effects on the most sensitive life-stage, the unborn and future generations.

Cancer

The human cancer (all sites) mortality maps for Canada (Figures 23a and 23b), show age-adjusted mortality rates for the period 1966-1976 or as indicated (147). Figure 24 is a similar map for the U.S. covering the 1950-1969 period (97). These data are collected on the basis of usual place of residence of the deceased, and not place of death. In both cases, substantial spatial variation occurs. For example, high rates occur near the mouths of major watersheds and airsheds, and major urban centres, locations that have high relative densities of toxicants of all kinds. As a general observation for Canada, it can be stated that cancer rates are higher, in a higher proportion of census divisions, in the east than in the west. Despite the difference in data collection periods, similar trends can be observed in the U.S. data. In addition, there appear to be significantly higher rates in the U.S. side of the Great Lakes than seen in the Canadian data. However, the U.S. data describe a larger population, and cover almost twice as much time, and so are more powerful statistically. The examination of more extended and recent Canadian data was not generally possible in this review, however, data to 1981 for Niagara region is noted below.

Data measuring variations in smoking or socio-economic and behavioural factors, and their relationship to variations in cancer death rates (and other causes of death and/or disease) were not examined in this review. Although there is consensus that smoking is the single most important cause of lung cancer (as well as cancer at other sites), smoking is not the only cause, nor are all of the various types of lung cancer most likely to be caused by smoking as compared to carcinogens identified in occupational exposures (55, 313). There is evidence and argument that variations in smoking do not account for geographic excesses in lung cancer rates in U.S. males and females (55, 77, 280, 313). Also, 10 to 20% (or more) of lung cancer deaths in the U.S. occur in non-smokers, whose lung cancer death rates approximately doubled from 1958-1969 (55, 313). It also may be that less than lifetime studies underestimate the relative risks of lung cancer for non-smokers as against risks for smokers (55).

Moreover, recent analysis of excess age-, race-, and sex-adjusted mortality (79% due to either cancer or heart disease, and 3.5% due to accidents, suicide or violence) in residents of a U.S. federally designated poverty area, compared to residents of nonpoverty areas, in Oakland, California, examined these factors (280). The poverty area occupied a 10-mile-long strip divided by an interstate freeway, where residential areas exist side-by-side with warehouses, manufacturing industries, and railways.

The results of that analysis show that the increased risk of death essentially persisted when there was multivariate adjustment for baseline health status, ethnicity, income, employment status, education, access to medical care, health insurance coverage, smoking, alcohol consumption, physical activity, relative weight, sleep pattern, social isolation, marital status, depression and personal uncertainty. This study, and others cited in it, suggest that the social and physical environment of low socioeconomic position may be responsible for the persistent and pervasive link between socio-economic position and disease. This link is also observed in the United Kingdom (281), Ontario (282), and Canada (219, 284). Social factors such as higher crime rates, poorer housing and lack of transportation, and physical factors like higher levels of environmental contaminants, are the prime remaining candidates for assessment regarding their links to gradients of health and mortality (280).

From evidence presented in this report, it can be shown that the U.S. cancer mortality rates for humans (Figure 24) are high in the five locations where fish cancer is high (Black River, Ohio; Buffalo River, N.Y.; Hudson River, N.Y.; Puget Sound, Wash., and Torch Lake, Mich.). More generally, high rates are evident along the U.S. side of all the Great Lakes. Those areas adjacent to Lakes Huron, Erie, Ontario, and their connecting channels, the St. Clair, Detroit, and Niagara rivers also stand out, but surprisingly are not seen in the Canadian data.

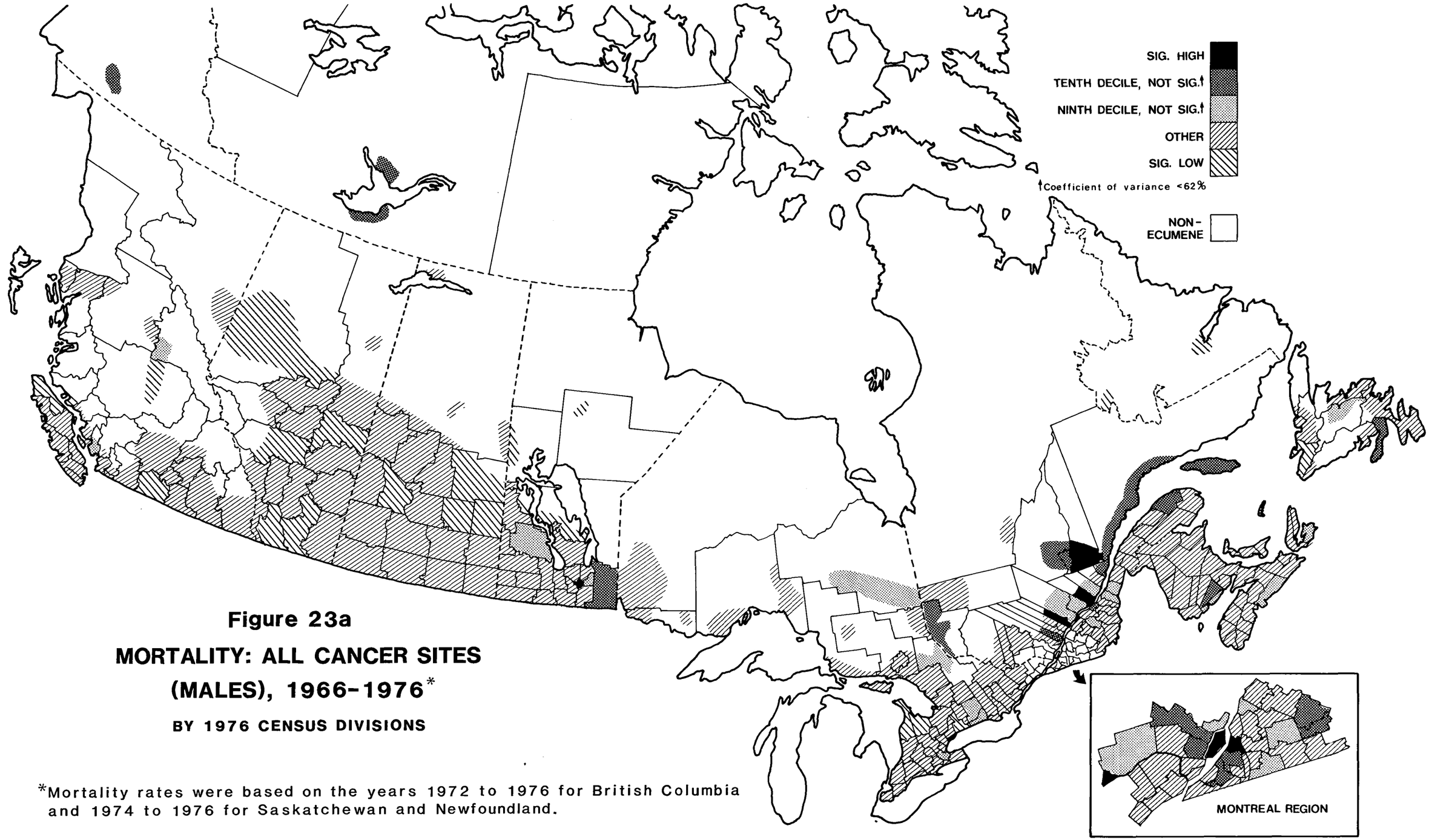


Figure 23a

MORTALITY: ALL CANCER SITES (MALES), 1966-1976*

BY 1976 CENSUS DIVISIONS

*Mortality rates were based on the years 1972 to 1976 for British Columbia and 1974 to 1976 for Saskatchewan and Newfoundland.

Source: Mortality Atlas of Canada, 1980. Health and Welfare Canada, and Statistics Canada, Ottawa.

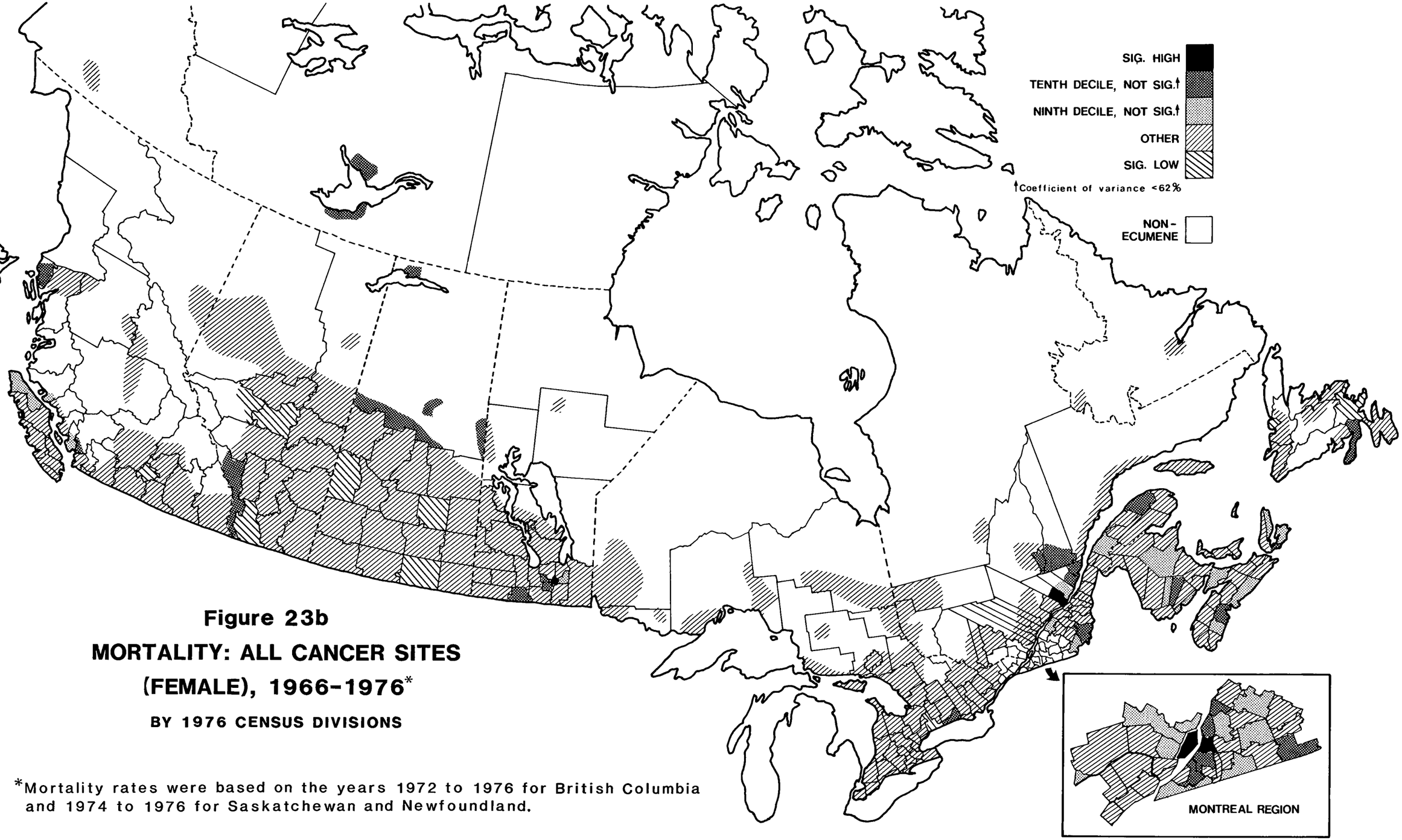


Figure 23b

MORTALITY: ALL CANCER SITES (FEMALE), 1966-1976*

BY 1976 CENSUS DIVISIONS

*Mortality rates were based on the years 1972 to 1976 for British Columbia and 1974 to 1976 for Saskatchewan and Newfoundland.

Source: Mortality Atlas of Canada, 1980. Health and Welfare Canada, and Statistics Canada, Ottawa.

Figure 24

CANCER MORTALITY 1950 - 1969, by county, all sites combined.

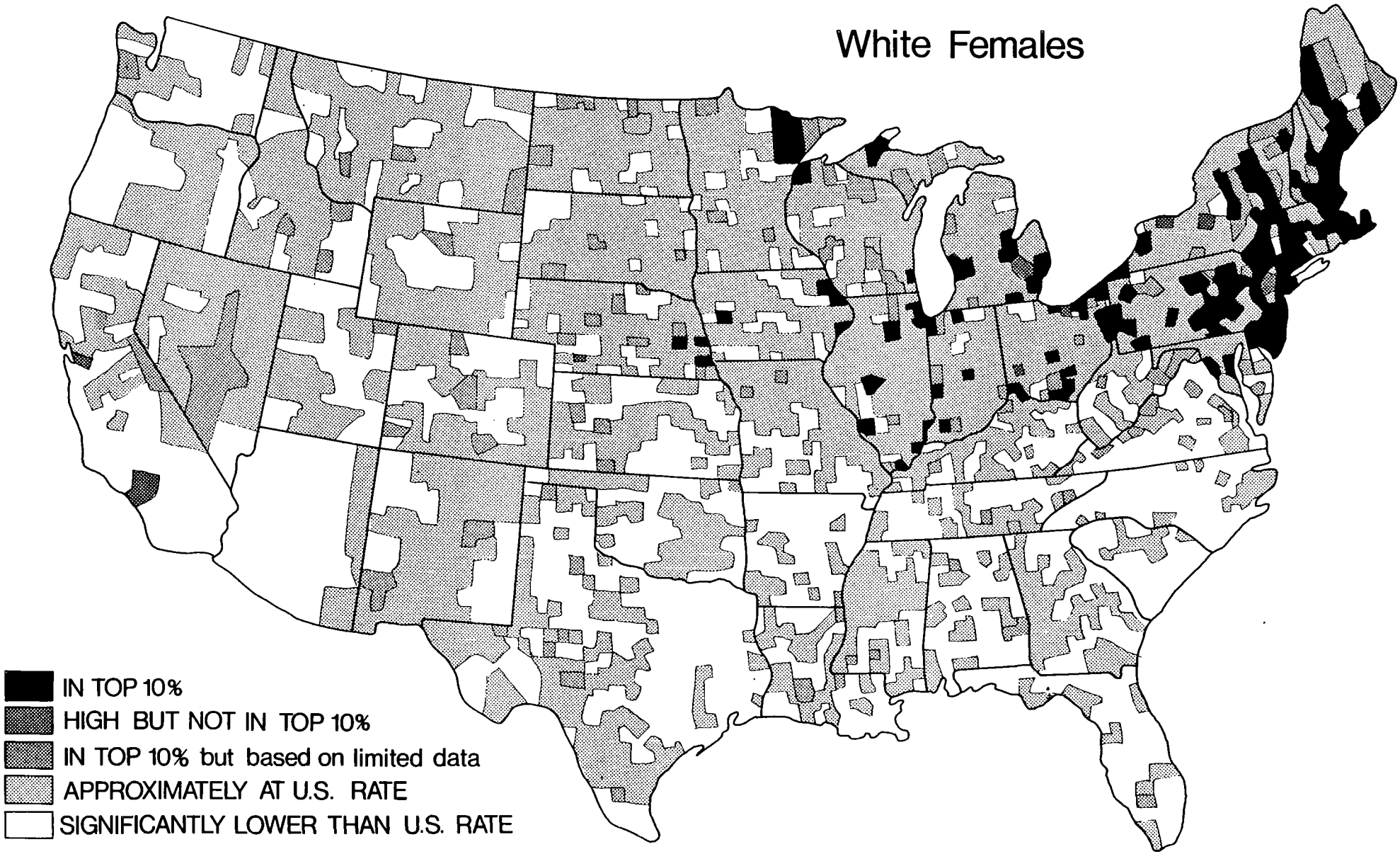
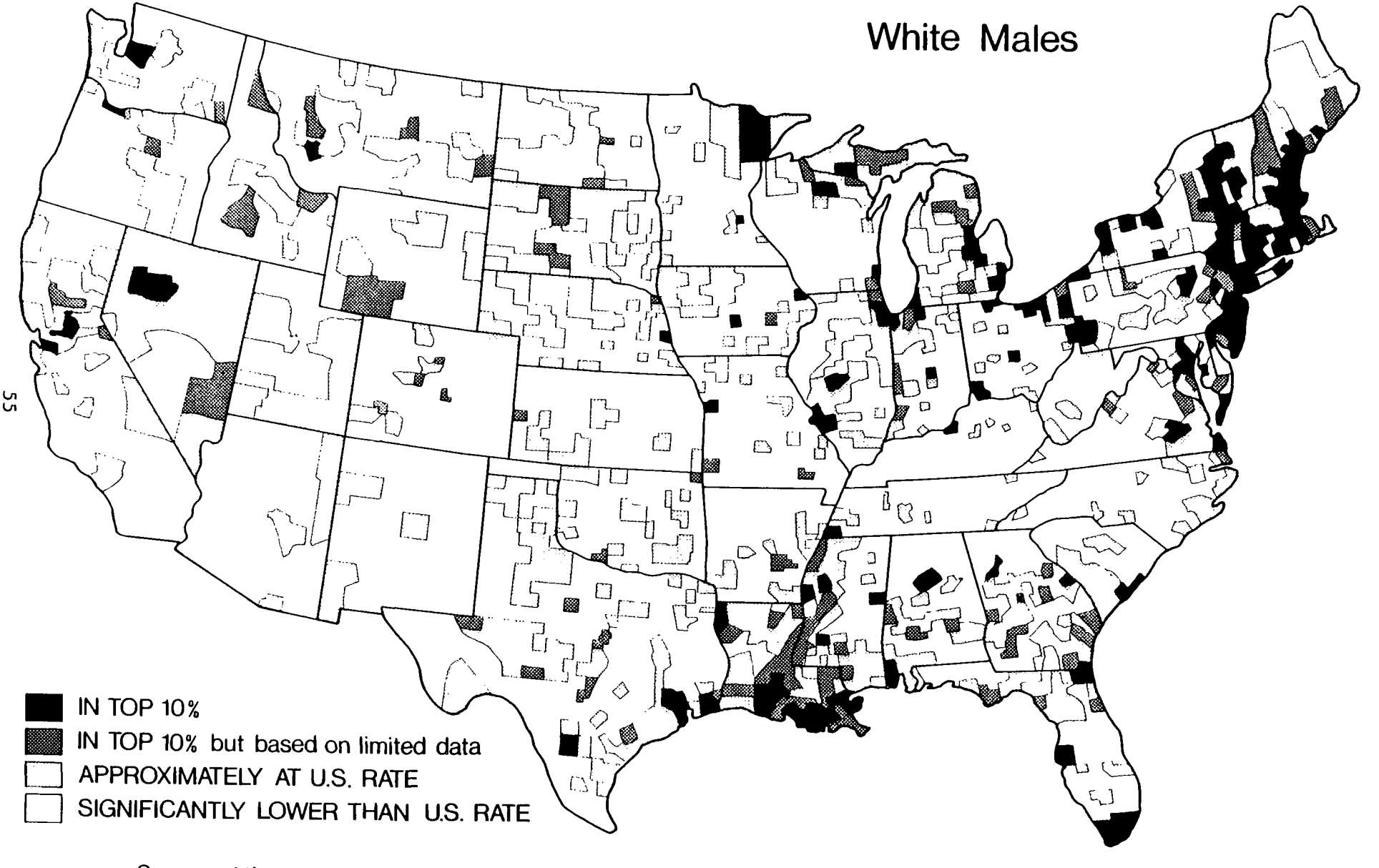


Figure 24

CANCER MORTALITY 1950 - 1969, by county, all sites combined,

White Males



Source: Atlas of Cancer Mortality for U.S. Counties: 1950-1969. 1975. National Cancer Institute.

This, again, may be due to the smaller populations and shorter time period in the Canadian data base. Lakes Superior and Michigan also have a number of high-rate counties. Although it may be coincidental, all of these areas are associated with major industries - automobiles, steel, chemicals and petrochemicals, and pulp, paper and wood products being among them - and collectively contain hundreds of known hazardous waste sites (e.g. Figure 25 (171)). All are sources of toxic chemicals to the Great Lakes ecosystem (154, 1, 34, 181, 52, 53, 171, 229). There are many indicators of this ecosystem contamination and cancer incidence association.

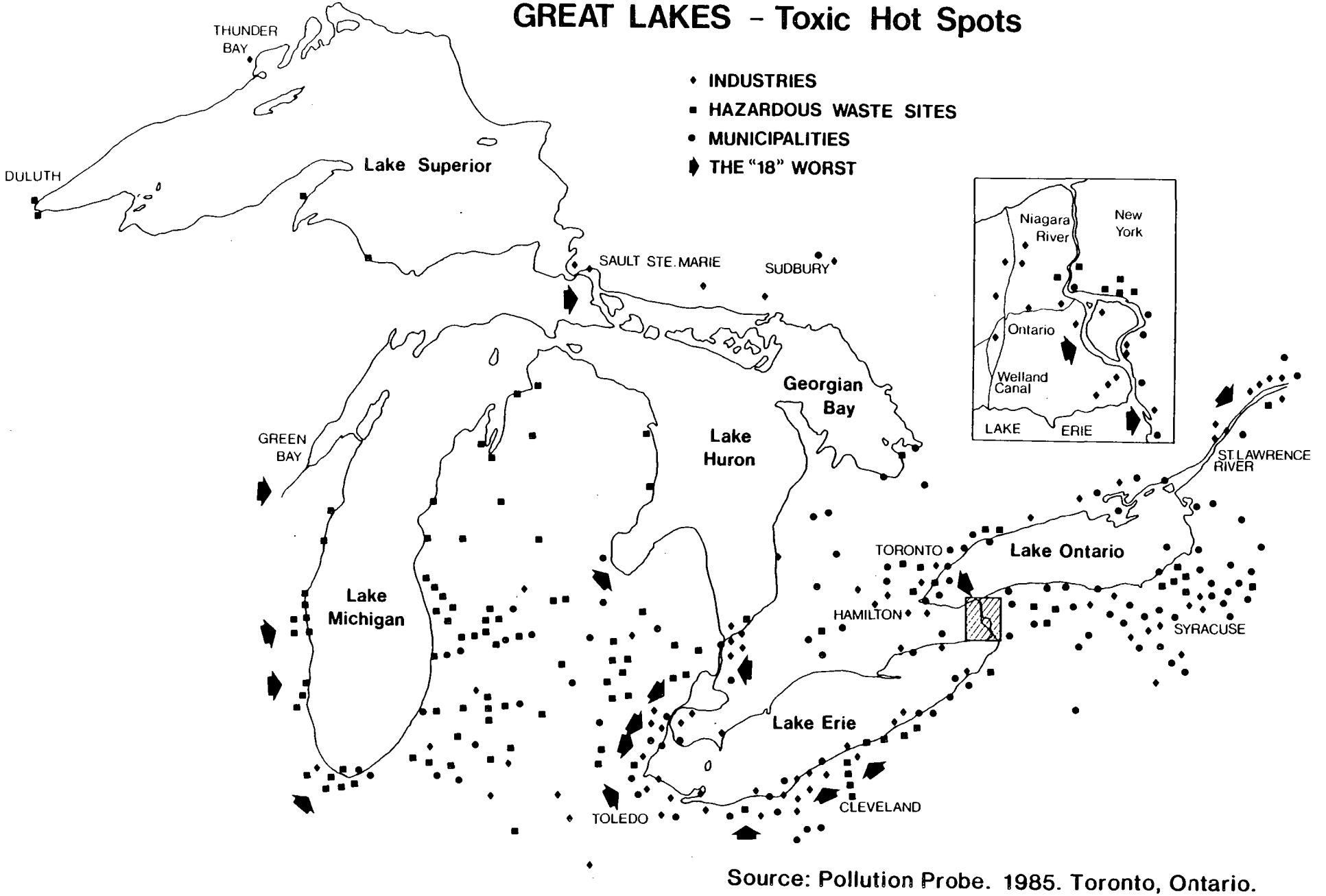
Of 215 hazardous waste disposal sites identified in Erie and Niagara counties (New York), one hundred and sixty-four are located within 3 miles of the Niagara River (154). In Niagara Falls N.Y., a chemical plant incinerator has been burning waste for about 25 years, a practice responsible in part for a major input of higher chlorinated dioxins and furans to the Great Lakes ecosystem, as discussed above (40, 41, 42). The St. Clair and Detroit Rivers are both classified as "Areas of Concern" (so severely polluted as to impair beneficial uses) by the International Joint Commission, as is the Niagara (154,1,34,104). As another indicator of ecosystem contamination, the levels of hexachlorobenzene and PCBs in herring gull eggs from Fighting Island in the Detroit River, although declining (as of 1982), are among the highest found in the Great Lakes since 1978 (283).

The Saginaw Bay and River system is also one of the most contaminated areas in the Great Lakes (105,171). In neighbouring Midland, Michigan, a chemical waste incinerator was reported to have been emitting particulates containing 260,000 ppb of octa-CDDs and 170,000 ppb of hepta-CDDs in 1980 (41). An evaluation of data pertinent to the toxicity and biologic activity of PCDDs and PCDFs supported the concept of a nongenetic (possible promoter) mechanism in the cancer process for 2, 3, 7, 8-TCDD (116). Fish from Saginaw Bay, the Tittabawassee River, (a tributary of the Saginaw River) and Lake Ontario, contained the highest levels of 2,3,7,8-TCDD contamination found in a survey of fish from the Great Lakes and selected Michigan rivers (58). Herring gull eggs from Saginaw Bay (and Lake Ontario) also contained the highest levels of 2, 3, 7, 8-TCDD found in the Great Lakes in 1980 (262). This area can also be clearly seen on the U.S. cancer map given in Figure 24.

In Canada, an increase in total cancer rates from west to east is evident for males (Figure 23a). The frequency of high rate census divisions increases in and around the Winnipeg urban area, again along Lake Ontario (Hamilton-Wentworth, Toronto, Northumberland and Peterborough census divisions), and continues to increase in the Montreal region, reaching a maximum there, and then along the St. Lawrence River. For females an increase is not generally evident, however, the frequency of high rate census divisions is again at a maximum in the Montreal region and downstream in the St. Lawrence River.

Figure 25

GREAT LAKES - Toxic Hot Spots



Source: Pollution Probe. 1985. Toronto, Ontario.

Those Lake Ontario areas in Canada showing the highest rates of all cancers are associated with steel-making, major urban cities (implying a larger and more statistically powerful sample), toxic hot-spots, and high levels of acid and toxic rain (Figures 7, 8, 9, and 25). Maps of the St. Lawrence River sections displaying the highest rates contain areas of contaminated sediments, and are lined with a wide variety of major pollution sources (Figure 12). This area also receives high levels of acid and toxic rain (Figure 8, 123). Among numerous point sources are petrochemical/chemical industries and refineries, including two major complexes (Cornwall area and east Montreal), a number of wood and paper related plants, mining related activity, several metallurgical works including aluminum refining, and major cities (Figure 12). As an example, aluminum smelting in Quebec has been associated with occupational bladder cancer, which has been ascribed to PAH (benzo(a)pyrene as indicator) (205). An excess of lung cancer among aluminum workers is also reported (205).

Again, these associations may be coincidental. The extent of connection between chemical pollution in these areas and higher cancer incidence in these same areas cannot be established in this review, and the occupational results are not to be taken as accounting for the overall cancer statistics. However, no matter that the evidence is mostly circumstantial, the consistent coincidence in space and time is strong, and suggests a causative linkage beyond mere chance.

Census divisions in the Ontario - Great Lakes - Upper St. Lawrence area with elevated rates (9th decile and higher) of organ-specific cancers which have known occupational causes (55, 311-316) (elevated exposures to toxic organic chemicals, metals, and radioactive substances), and where there was no sex-specific lung cancer excess (thus lessening the likelihood that smoking is involved), include: Lambton (bladder and prostate (males), leukemia (females)); Northumberland (pancreas and bladder (males)); Halton (lymphatic (females)); Grey (lymphatic (females)); Haldimand-Norfolk (pancreas (males)); Stormont (pancreas (males and females), bladder (males)); Leeds (bladder, and lymphatic tissues (males)); Perth (leukemia and lymphatic tissues (males)); Peel (bladder and lymphatic tissues (males)); Temiskaming (lymphatic tissues (males)); Peterborough (lymphatic tissues (males)); and Algoma, Elgin, Durham and Hastings, all of which have elevated male bladder cancer rates (147).

The census divisions of Essex, Niagara and Hamilton-Wentworth had elevated male bladder cancer rates, but showed higher male lung cancer rates as well, presenting a possible smoking confounder (147). Similarly, the Thunder Bay and Sudbury census divisions showed elevated pancreatic cancer rates and lung cancer rates, the latter in both males and females in the Sudbury division (147). Census divisions with elevated rates of endocrine-related cancers (such as breast, ovary and uterus), which are reported to depend considerably on promoting phenomena (309), include: Northumberland (breast, uterus, ovary); Waterloo, Grey, Brant and Huron (breast and ovary); and Algoma, Nipissing, Muskoka, Halton and York (breast). None of these divisions had elevated lung cancer rates to suggest a possible smoking confounder (147).

As noted previously, high total cancer rates appear neither on the map for the Canadian side of the Niagara River nor the St. Clair-Detroit River system for the 1966-1976 period covered. More recent statistics for the 1976-1981 period indicate that the Niagara region's over-all death rate from cancer was higher than the province of Ontario average by 5 percent for men and 3 percent for women (94). However, as of 1981 overall male cancer mortality in Niagara region had been higher than the Ontario average since 1953 (94). Excess mortality rates were particularly evident for liver (74%) and lung (17%) cancers in women. All of these differences were significant at a 0.05 one-sided test level, with the exception of the womens' over-all cancer rate. Liver cancer has been associated in other studies with such chemical exposures such as vinyl chloride and arsenic (94, 194). Note that these data indicate relative rates within Ontario only, and must be viewed as a frame of reference differing in sample size and variation from the Canada-wide data. It is, however, another point of view with its own information content in that it shows variation in cancer rates that can be associated with known sources of toxic chemicals.

While there is substantial variation and argument with respect to sex, organ site, time period, place, and cause, the fact remains that overall age-adjusted cancer incidence and mortality rates (chosen as the best overall indicators of the pace of the cancer process) as of 1981-1982 are accelerating in Ontario, Canada, and the United States (94, 55, 163, 5). In the U.S., the overall probability, at 1980 death rates, of a person (born in 1980) getting cancer by the age of 85 was 27% for both men and women (55). This rate has increased relative to the rates of 19% for men and 22% for women born in 1950 (55).

Taking sex into account, the Ontario male overall cancer mortality rate trend line from 1951-1981 is increasing (94). For Ontario females, the overall cancer mortality rate trend line from 1951 to 1981 is down, however, from 1970 to 1981 the trend line is flat to slightly increasing (94). In the U.S., cancer-related mortality rates from 1950-1982 rose steadily for white males, and rapidly and steadily, for non-white males (55). For white females rates fell slightly and recently began to rise again, and for non-white females declined slightly and recently levelled off (5).

Taking site into account, it is seen that changes in death rates from lung cancer have substantially affected mortality rates from all cancers combined, and in fact are mostly responsible for the increase in the overall incidence and mortality rates in both Canada and the U.S. (5, 94). In fact, if lung cancer was ignored, the age-adjusted mortality rates actually show a decreasing trend (5, 94). Moreover, further excluding cervical and stomach cancer from the U.S. data leaves an almost flat rate trend (5). However, lung cancer incidence and mortality rates are not the only sites showing rate increases (5, 94, 55, 312). Reliance on any one overall or dominant measure alone is simplistic, as such rates can mask steep increases in relatively rare organ-specific cancers in high-risk population subgroups (55, 94, 312).

In 1976, cancer was the chief cause of death from disease among U.S. children under 15 years of age, accounting for 11.3% of all childhood deaths (232). More recent estimates put the overall U.S. incidence rate at about 30% (2), and one in three (27). In Ontario, estimates suggest that one in four persons will develop the disease (163) and the measured rate is still rising (94,163).

Estimates of relative cancer risks (derived from animal models) of 15 to 20 chemical contaminants in the Great Lakes indicate that sport fish consumption poses cancer risks that are several orders of magnitude higher than the risks posed by drinking Niagara River water (301). Preliminary comparisons indicate that drinking urban groundwater and breathing urban air may be as hazardous as frequent consumption of sport fish from the Great Lakes (301). These estimates are subject to substantial uncertainty, and do not take into account the risks posed by non-fish food chain contamination, or any of a number of other routes of human exposure. With these exclusions in mind, compared to an average U.S. lifetime risk of cancer of all types, which is 25,000 out of 100,000, the so-called proxy measures of relative risk ranged from 751 to 9601 per 100,000 (301). It should be noted that the actual lifetime cancer risks, and the relative "proxy" risks cannot be compared directly without appropriate caveats, as one is absolute, based on epidemiological data, and one is an extrapolation (301, 320).

In the assessment of risk factors in cancer, relative to the contamination of the natural environment of the Great Lakes, relevant comparative epidemiologic data from environments similarly contaminated can be helpful. Studies using aggregate (county) data have demonstrated positive associations between the percentage of population employed in petroleum, chemical, petrochemical, transportation (equipment manufacture), and paper industries, and overall cancer and lung cancer mortality (77, 78, 79, 68, 55, 244). In U.S. counties with heavy involvement in the chemical industry, the mortality rate due to nasal cavity and sinus cancer was exceptionally high (244). There are also data sets which demonstrate associations between mortality rates due to lung cancer and levels of atmospheric carcinogens (e.g. PAH, and nitrated PAH or nitroarenes) (55, 244, 285).

Epidemiological studies of small areas in Louisiana have shown that lung cancer rates (risk) increase with: (a) close proximity (within 1 mile), and length of exposure, in that order, to a large (more than 100 employees) petrochemical plant; (b) length of exposure and proximity to petroleum industry plants; (c) the number of high risk industries within 0.8 miles of residence; (d) residential and high risk occupational exposure together; and (e) for male workers in the fishing industry (Louisiana has a large fishing industry in the Mississippi delta) (77).

Other studies using small area data from the New Orleans region and the Chesapeake Bay area have shown an association between increased white male cancer deaths, the amount of toxic waste generated and the number of toxic waste sites (78, 79). Recent reports indicate that the southern Louisiana and New Orleans area studies have been confirmed by two other independent studies (cited in 54). A number of review articles and studies (mostly U.S., but one Canadian) report statistically significant relationships between drinking water quality and cancer incidence and mortality, frequently in the gastrointestinal and urinary organs. (38, 77, 94, 219, 291). The Canadian study showed an association between total organic carbon and cancer of the large intestine in males (219). Other studies are inconclusive, however, these are fewer than the unequivocal reports in the literature reviewed here (38, 77, 219).

In particular, a U.S. cross-sectional study showed that the total organic contaminant burden (measured as the sum of carbon chloroform extract and carbon alcohol extract (38)) in drinking water has highly significant relationships with mortality from cancers of the gastrointestinal and urinary tract (38, see also 219). This may be particularly important when it is considered that these are the organs of absorption and excretion. This contaminant burden more or less reflects the use of chlorine disinfectant and the subsequent increase in the concentration of certain halogenated organics (e.g. chloroform). However, there can be numerous other organic compounds in drinking water and it is the link between organics and cancer that is important and is discussed more fully in (38, 77).

Reproduction

Toxic Chemicals and Reproductive Health

The importance of toxic chemicals as factors contributing to reproductive impairment in the human population was extensively surveyed and summarized in a report commissioned by the U.S. President's Council on Environmental Quality (CEQ), in cooperation with a number of other agencies with related interests (155). Other published reports describe the diverse aspects, effects and possible scale of the problem (30, 45, 192, 120, 172, 173, 155, 232). The evidence (155) suggests that environmental factors, broadly defined but including chemicals like pesticides and industrial pollutants, are contributors to certain types of reproductive impairment (e.g. difficulty conceiving, miscarriages and spontaneous abortions, sperm toxicity, and numerous fetal/infant related problems).

A sample of chemicals that are known or suspected causes of reproductive impairment in humans is shown in Table 7 (30, 45, 192, 120, 172, 173, 155, 25). It is noteworthy that most of these chemicals show up in toxic waste and some have been identified in human tissues and mothers' milk (Table 4). Other studies and reviews indicate that 2, 3, 7, 8 - TCDD is a potent teratogen in animals, including mammals and primates (119, 197, 151, 269, 292, 150, 286). One review report indicates that developing mammalian fetuses are especially sensitive to 2, 3, 7, 8 - TCDD, with maternal exposure resulting in increased frequencies of stillbirths, and among live births exposure results in teratogenic effects, such as cleft palate and spinal column deformities (286). A number of 2, 3, 7, 8 - substituted dioxins, the structurally related dibenzofurans, PCBs, and chlorinated napthalenes, can also be potent teratogens (as much as 1/20th to 1/50th of TCDD, but usually less) (119, 197).

Experiments have shown that certain chemical agents, especially PAHs, accelerate the process of degeneration that many primary oocytes (immature eggs) undergo before the host animal reaches puberty (155, 232). Particularly persistent toxic agents like certain PCBs, dioxins, furans, and their isosteres, can continually induce enzyme systems known to affect steroid hormone levels in some mammals (232, 243). This can cause the failure of the fertilized ova to implant, or failure to develop after implantation (miscarriage or spontaneous abortion), or affect a number of different reproductive functions, such as, the endocrine control of reproduction and spermatogenesis. (157, 119, 155, 232).

The male reproductive organs are also sensitive to various environmental stress factors and to chemicals (155, 47, 50, 111, 152, 26, 232). In a U.S. study examining sperm density and toxic chemical body burdens (47), a number of polychlorinated substances were found in virtually every one of the sperm samples. Included were PCB's, hexachlorobenzene, polychlorophenols, DDT metabolites, polychloronaphthalenes, and variety of unidentified compounds. Sperm density is known to be sensitive to the presence of a number of toxic substances (47, 50, 26, 232). Some of these compounds can decrease the cell division rate by causing DNA damage. If damage occurs, cell division is delayed until repairs can be made. This delay is amplified into even higher decreases in sperm density (47). Faulty repairs can lead to mutation or cancer (47).

While there are a number of factors, such as changes in smoking and sexual activity, that can contribute to decreases in sperm density, statistical analysis indicated that about 27% of the population variance in sperm density in this study (47) could be explained by the presence of toxic chemicals. Those chemicals identified as PCBs all had negative slopes against sperm density, and contributed significantly to the overall correlation (47).

Table 7

Chemicals That Are Considered to be Proven or Potential Reproductive Hazards in Humans

Chemical	Source (s)
Acrylonitrile	172
Alcohol	120,155
Aldrin	25
Aminopterin and Methylaminopterin	192,155
Anesthetic gases such as: Nitrous Oxide, Halothane	
Methoxyflurane	30,155
Aniline	120
Arsenic	30,120,155,25
Benzene	30,155,120,172,25
Benzo (a) Pyrene	45
Beryllium	30,155
Busulfan	45,192,155
Cadmium	30,155
Caprolactam	155
Captan	120
Carbaryl	30
Carbon Disulfide	30,155,120
Carbon Monoxide	30,155,120
Carbon Tetrachloride	30,172
Chlordane	30
Chloroform	30,172
Chloroprene	30
Chromium	172
Clomid	45
Coumarin	192
Cyanoketone	45
Cyclophosphamide	45,192
Dibromochloropropane	30,155
Diethylstilbestrol (DES)	45,192,155
Dihydrotestosterone	45
Dimethylacetamide	172
Dimethylbenzanthracene	45
Dimethylformamide	30,173
Dimethylsulfoxide	25
Dioxin	25
Diphenylhydantoin	155
Epichlorohydrin	25
Estradiol	45
Ethylene Dibromide	155
Ethylene Thiourea	173
Formaldehyde	155,120
Formamide	173
Hexachlorobenzene	155
Hexachlorophene	25
Hexafluoroacetone	173
Hexachlorobutadiene	120
Hexachlorophene	25
Hexafluoroacetone	173
Hormones including Estrogens Progestogens, Androgens, Testosterone and other synthetic hormones	30,45,192
Hydrazine Hydrate	172
Hydrazine Sulfate	172
Hydrogen Sulfide	120
Kepone	30,155,25
Laboratory Solvents	155
Lead	30,155,120,172,173,25
Lithium	30
Malathion	30,25
Manganese	25
Mercury	30,155,192,120,172,155,25
Methadone	3
Methotrexate	172,155
Methoxychlor	3
Methyl Ethyl Ketone	172
Methyl Methanesulfonate	3
Monosodium Glutamate	3
Nickel	30
Nicotine	120,155
Nitrates, Nitrites	120
Nitrobenzene	120
Paraquat	30
Parathion	30
PCB's	30,45,192,120,155,25
Perchloroethylene	25
Phenobarbitol	45
Phenol	120
Phenytoin&Trimethadione	192
Phosphorus	120
Phthalate Esters	155
Procarbazine	45
Propylene Glycol	25
Radiation	120
Selenium	155,120
Styrene	155
Thalidomide	192,155
Thiotepa	172
Tobacco Smoke	155
Toluene	30,155,120
Turpentine	120
Vinyl Chloride	30,120,172,155,25
Warfarin	155
Xylene	30,155,120
2, 4, 5-T	30,25

There is some debate whether a low sperm count alone is sufficient reason for infertility, and that it may be meaningless unless the parameter of sperm motility (swimming ability) is included (50, 132, 26, 56, 18). A very recent study (in Albany, N.Y.) examined statistical relationships between these biological measurements (sperm density and motility) and the concentration of individual PCB congeners contained in semen samples (26). A highly significant (0.995) relationship between sperm count and motility was found. Also found was a highly significant (greater than 0.99) inverse relationship between motility in the so-called infertile group (sperm count less than 20 million/ml) and the concentrations of three PCB congeners - 2, 4, 5, 3', 4'-pentachlorobiphenyl, 2, 4, 5, 2', 4', 5'- and 2, 4, 5, 2', 3', 4'-hexachlorobiphenyl. The model predicts that the maximum observed concentration of any of these congeners would produce complete lack of motility in this group. These PCB congeners are among the most refractory or resistant to metabolic breakdown, and have among the highest bioaccumulation factors in animals (76, 95, 265)

This evidence is significant in that it shows a discernible and statistically powerful association between biological measurements of infertility, and toxic chemicals that are found throughout the human populations of industrialized countries. It may also be significant that these human levels are similar to those concentrations currently measured in other components of the Great Lakes ecosystem. Despite the clear statistical relationship identified between PCB congeners and sperm motility and density, no detailed investigation has been carried out on the effects of PCBs upon sperm function. It is noteworthy that in vitro exposure of primate semen to 2 ppm methylmercury resulted in a reduction of sperm swim speed of 69% of control (287). Investigation of this problem is needed.

Case Studies

Case studies of human populations in the Great Lakes ecosystem likely to be exposed to the highest levels of toxics are few, but consistent in their findings. A significant association between low birth weight and residence near the Love Canal swales during the period of chemical waste dumping was shown (211). Figure 30 shows this association graphically. Figure 31 shows that mothers who ate PCB contaminated fish from Lake Michigan gave birth to infants who were 160 to 190 grams lighter, and had smaller head circumferences, than the infants of a control group of mothers who did not eat such fish (59). The infants of the fish-eaters also showed significant behavioural and motor development anomalies (108)

Given the large number of chemicals identified in Lake Michigan fish (fish-eating birds in the Great Lakes can contain more than 200 halogenated hydrocarbons (91, 320)), no specific toxic mechanism for PCBs is elucidated - they may be acting as an indicator for the total toxic burden, a more potent contaminant or metabolite, or some combination. More detailed study is being carried out as the children

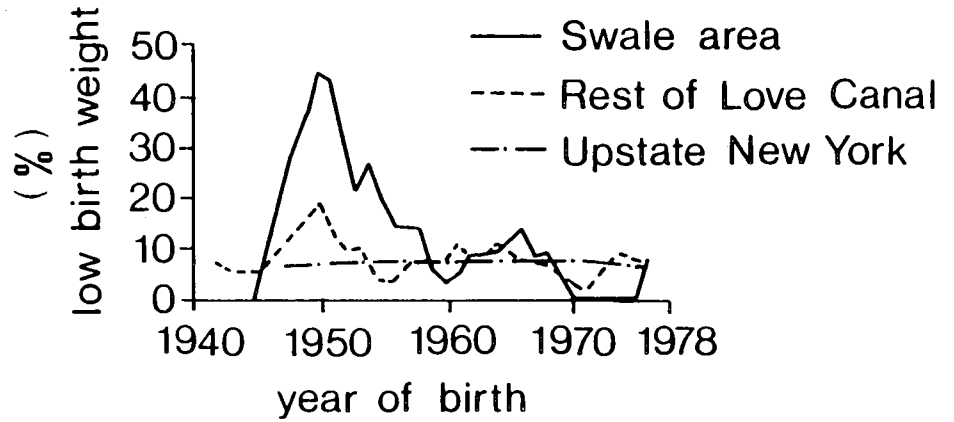


Figure 30 **Low Birth Weight and Residence Near Love Canal Swales**

Source: Vianna, N J and Polan, A K. 1984. Incidence of low birth weight among Love Canal residents. Science 226: 1217-1219.

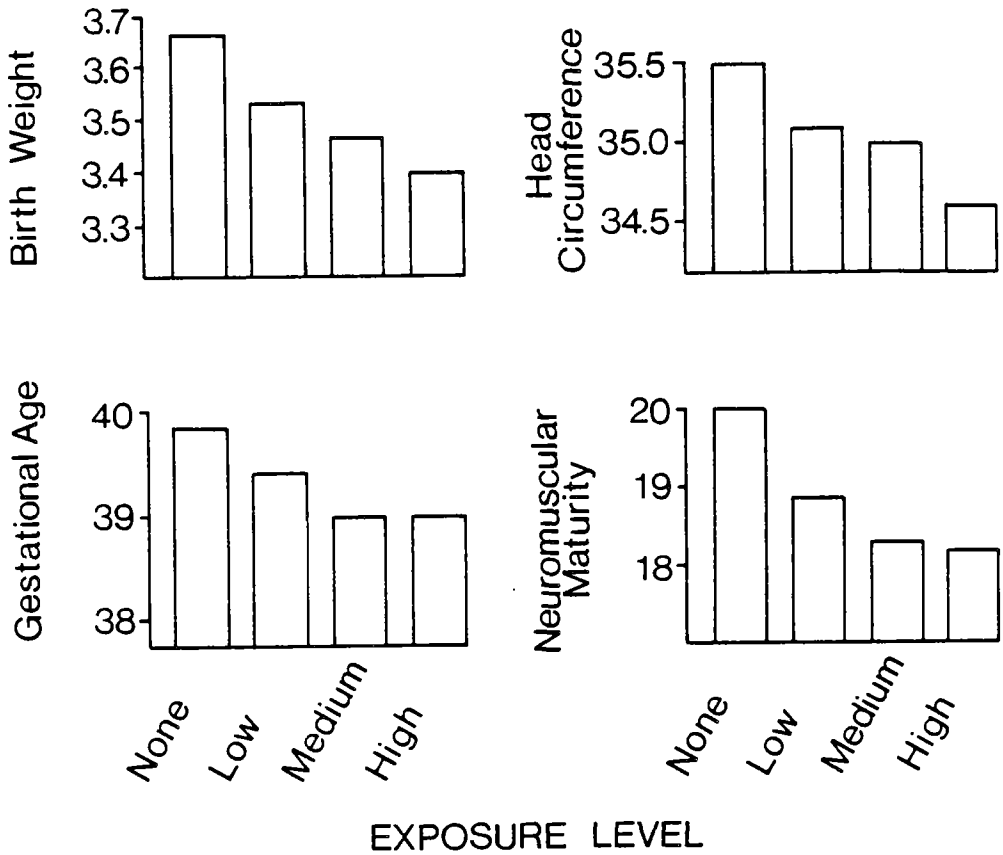


Figure 31 Dose-response relationships for birth weight, gestational age (Ballard examination), head circumference, and neuromuscular maturity by overall contaminated fish consumption. Groups means were derived from analyses of covariance, in which they were adjusted for the effects of maternal prepregnancy weight, type of delivery, and consumption of alcohol and caffeine prior to and during pregnancy and cold remedies during pregnancy. Exposed infants were divided into three approximately equal groups: low exposure 2.0 to 3.4 kg/yr, medium 3.5 to 6.5 kg/yr, high 6.6 to 41.7 kg/yr. Source: Fein, G. G., Jacobson, J. L., Jacobson, S. W., Schwartz, P. M., and Dowler, J. K. 1984. Prenatal exposure to PCBs: effects on birth size and gestational age. J. of Pedriatics, 105:315.

continue to be monitored (234). The need for continued follow-up in such identified case studies is demonstrated by the so called Yusho incident. Japanese adults were acutely exposed to PCBs and PCDFs through the use of contaminated rice oil. Infants exposed in utero were small for gestational age and tended to be born premature. Follow-up studies noted disturbances in responsiveness and neuromuscular functioning, including an average IQ of 70, and numerous other problems (194).

Therefore the vulnerability of the unborn, and the new-born, to the effects of chemical contaminants at a number of life cycle stages must receive special attention. During the first month or so of gestation, the developing female fetus already contains the immature eggs or her own children (232). Each egg contains a single copy of the genetic contribution of the mother, the DNA of which weighs only 3 trillionths of a gram (89). Combined with a similar mass of DNA from the father, the fertilized egg contains the original coded information that will be used to create an adult human being (89). The vulnerability of future generations, and of the species, to damage is clear. However, it is noteworthy that damage to the DNA in the immature eggs of the developing fetus cannot be expressed, or passed on to future generations until that female reaches childbearing age. Thus, any associated reproductive problems are inherently unobservable until 20 years or more after their effects have been induced. For instance, any such damage that may have been done to those born during the peak contamination periods of the 1960's and early 1970's will not begin to be discernible until the 1980's and 1990's. Moreover, they may not appear for many generations (64,126).

A mutation or chromosome change in the original code can affect every cell in the body of the descendent individual, with results that may be disastrous (126). Since every part of the body and every metabolic process is influenced by genes, the range of effects includes every kind of structure and process (126). In this vein, it has only recently been realized that postnatal results of damage might be expressed as functional rather than structural aberrations (232, 126, 107). The central nervous system and brain, particularly in the fetus, are notably sensitive. Behavioural toxicology and teratology have become growth disciplines (107,232).

Future generations are also exposed via the transplacental transfer of contaminants during the pre-natal stage of fetal development, and through maternal excretion in the milk during breast feeding (186, 170, 73, 204, 220, 234, 318). Being so small, and experiencing unprecedented growth, development, and maturation of tissues, the new-borns (and the fetus) can be more susceptible to damage than adults (232, 204, 220). Depending on development period, there is a broad spectrum of possible effects, such as; structural anomalies, growth retardation, functional disorders, or transplacental

carcinogenesis (childhood cancer) (232). In particular, the central nervous system and the myelin sheathes that surround it, are composed largely of lipid materials, making their structures and properties directly vulnerable to subtle changes caused by the inclusion of lipophilic (lipid or fat soluble) compounds like PCBs (204), and indirectly to possible metabolic or immune system mediated responses to such xenobiotics (foreign molecules) (232). In Ontario, a breast-fed newborn weighing 3.5 kg, and drinking 600 ml/day of 3% fat mother's milk containing the 1985 average concentration of 0.67 mg/kg (ppm) of PCBs (See Table 3), would consume 3.43 ug PCB/kg bodyweight/day which is 3.43 times the U.S. FDA so-called "allowable" daily dose for adults (95,204).

Measurements of Reproductive Health

Infertility

Specific information and data on human reproductive health are not generally collected with toxic chemical concerns in mind, nor are they generally available specific to the Great Lakes. A number of studies (155,232) show that reproductive impairments of one kind or another are both frequent and widespread in the U.S. population. It was estimated that 30 to 80 percent of all conceptions result in spontaneous abortion, stillbirth, or infant death, the higher number representing the summation of all three (155, 232). In Canada, it was estimated that 50 to 70 percent of fertilized embryos do not survive to birth, mostly because of defects (107). Early spontaneous abortions may go entirely unnoticed, as they rarely are recognized as such. Notably, there is no uncontaminated baseline population or sample that can be used as evidence to judge whether such loss rates were ever much closer to zero, or what a natural rate or the natural ground in an unperturbed environment would be.

From 7,000,000 to 11,000,000 married couples in the U.S. were infertile as of the early 1980's, 3,000,000 of whom have at least one partner who is noncontraceptively sterile (155,232,247). The number of North American couples that have difficulty conceiving or are involuntarily sterile is estimated at 15% or more (232,247,249), and 20% (319). Since the real infertility rate is masked by contraceptive practices, it is necessary to consider gross measures such as birthrate.

Fertility as Measured by Birthrate

In the U.S., between 1960 and 1976, the average annual birth rate (or age-specific fertility rate (24, 198, 81)) per 1000 women, 15 to 44 years old, fell by 45 percent, and per 1000 women in the prime age group, 20-24 years, fell by 57 percent (81). These rates remained fairly stable through the last decade. In Canada, average annual birth rates or age-specific fertility rates per 1000 young women in the age groups 15 to 19, and 20 to 24, fell by 31% and 35%, respectively,

between 1966 and 1976, and by 45% and 43% respectively by 1981 (24, 198). Women between 40 and 44 experienced the sharpest decline: 77% by 1976 and 83% by 1981. The annual crude birth rate (per 1000 total population) in Canada declined steadily from 29.3 in 1921 to a then historical low of 20.1 in 1937, turned around in the late 1930's, and rose through World War II to 24.3 in 1945. Following the war it rose to 28.9 in 1947, remained almost stable between 1948 and 1959, but then declined steeply to a record low of 15.4 in only 15 years to 1974. After increasing slightly for a few years, the rate declined again to a new low of 15.3 in 1981. Emerging trends appear to continue downward (24). The U.S. experienced a similar decline in total fertility, and both Canada and the U.S. now have rates below replacement levels. Among the provinces, Ontario and Quebec had the lowest gross reproduction rates in 1981 (24).

All this information is indicative of the substantial decrease in childbearing that has occurred in Canada, the U.S., and in other heavily industrialized countries. It is postulated (249) that low fertility in the U.S. is due to widespread use of contraception (including heavy reliance on surgical sterilization and increased use of oral and intrauterine methods), and by a postponement of marriage and increasing age at first pregnancy or attempted pregnancy (249). However, there is no convincing evidence or analysis indicating that changes in these and other demographic and social factors are of sufficient size and timing to so completely explain the large drop in fertility that occurred over the 10 to 15 years prior to 1976 (247, 248, 249).

For instance, the only available data on changes in contraceptive use is for the U.S., and shows that the percent of couples using contraception increased from 63% in 1965 to 68% in 1976 (248). Changes in contraceptive effectiveness due to switching to the pill and sterilization may be estimated to have reduced the percentage of births that were unwanted by about 10 percentage points over that same period (249,247). Abortion was not legalized in the U.S. until 1973, so that large enough documented increases in that factor are too late. Unless there were very large absolute increases (not switching methods) in contraception in the early 1960's, it appears that the above data can be associated with less than half of the decline in fertility in American women over the period of most rapid decline. Other social factors are largely untestable hypotheses (249). This suggests that other factors are at work here. While there is no direct evidence connecting toxic chemicals to this decline, it is possible that they are one of these factors.

It is noteworthy that widespread, increased and earlier use of contraception makes it less likely that couples would discover fertility problems. Moreover, couples sterilized for contraceptive reasons at a relatively young age cannot discover fertility problems that would have appeared later in life (248). Thus, the detection of trends in fertility problems is masked by trends in contraceptive use. Overall, the life-style or behavioural changes postulated to account for the entire decline in fertility experienced in the U.S. and Canada, and by the Western, industrialized countries as a whole, are untested and unproven hypotheses or theories. Similarily, the possible connection with toxic chemicals is also untested and unproven.

Sperm Counts

A collation of published data on sperm counts from "unselected" fertile (or presumably fertile) men appears in Table 8, in order of publication date (47, 111, 202). Where possible, the country of origin is noted, however, most of these data are from the U.S.. Figure 29 shows measured sperm density distributions of samples of American males, taken in studies done in 1929, 1974, and 1979 (47).

Taken together, these figures suggest that sperm densities in U.S. males, and other nationals, have significantly declined over the last 30 to 50 years. Where measured, median densities declined by 30% to 50%. Also, three U.S. studies (1974, 1977 and 1981) indicate substantial increases in the proportion of men with counts less than 20 million cell/ml - from 0.5% in 1938, to 20% and 23% in the noted years. Sperm counts of less than 20 million/ml are frequently used to classify samples as infertile or functionally sterile, however, this practice has limitations and is the subject of debate (47, 207, 50, 152, 202, 132, 26, 56).

Interpretation caveats, such as counting methods, different sample populations, counting errors, psychological factors, social class and ethnicity, age, improving medical conditions, and time since last ejaculation were reviewed (111) and seen as not invalidating the conclusion that a real secular decline has occurred (111). The only data set available from a single clinic (Reproductive Biostatistics Laboratory) are on infertile populations, and show no appreciable trend from 1951 to 1976 - the median count falling slightly from 74 to 66 million/ml over that period (132).

On specific causative factors related to toxic industrial chemicals, whether in the Great Lakes ecosystem, or other areas subject to heavy industrial development, one cannot make precise toxicological conclusions per se because the studies designed to test for and measure such specific toxic effects have not been done. While various toxic chemicals have been linked to male infertility in a variety of circumstances (232, 25, 50, 26), there are thousands of industrial chemicals freely circulating in the environment. A number of other factors may also be involved - for example, chronic effects of long-term use of oral contraceptives, and changes in cigarette smoking (232). Regarding the possible connection with toxic chemicals, these data parallel the pattern of production and release of many toxic chemicals to the ecosystem, however, the connection simply cannot yet be demonstrated. All that can be noted is an association that indicates untested and unproven hypotheses.

Table 8 - Reported Sperm Counts of Unselected Men

YEAR	PLACE	MEAN (10^6 cells/ml)	MEDIAN (10^6 cells/ml)	% LESS THAN $20X10^6$ /ml	N	SOURCE
1929	U.S.	100	90		271	133
1934	U.S.	119			15	11
1938	U.S.	120	120	0.5	200	101
1948	-	103			29	124
1949	-	143			15	44
1949	U.S.	145			49	57
1950	U.S.	101	85		100	56
1951	U.S.	107	90	5	1,000	131
1956	U.S.	135			21	122
1962	Sweden	139			116	71
1962	U.S.	83			12	69
1963	U.S.	110			100	182
1964	U.S.	97			50	227
1969	U.S.	48			13	70
1971	Sweden	86			29	49
1974	U.S.	48	38	20	390	152
1975	U.S.	79	65	7	1,300	174
1976	U.S.	83			13	75
1977	U.S.	63	50	23	4,122	228
1977	U.S.	53			7	169
1977	U.S.	93			11	218
1978	-	97			12	23
1978	U.S.	86			13	195
1978	-	100			33	175
1978	-	56			4	135
1979	U.S.	61			50	193
1979	France	98	86	7	190	43
1979	U.S.	62			22	74
1979	U.S.	61			52	180
1981	U.S.	83	60	23	132	47
1983	Libya	65		14	1,500	202

This is measured, for example, by Lake Ontario sediment concentration peaks at about 1960 for chlorinated benzenes, octachlorostyrene, hexachlorobutadiene, mirex, and PCBs, as well as substantial sediment accumulations throughout the ecosystem, by 1960 and beyond, for metals, PAH, PCDD, and PCDF (e.g. Figures 1 to 6, 10, and 11). Also, the U.S. production of DDT peaked just after 1960 as did the fallout of radionuclides from atmospheric testing (302). The data are also consistent with the known and perceived hazards to humans of chemicals and heavy metals (319, Table 7). While not included in Table 7, DDT, and the overall (some are in Table 7) cyclodiene group of chlorinated insecticides are reported to be linked to male infertility (including decreased spermatogenesis) (25). DDT affects reproductive organs and litter size in juvenile rats (232); is known to be estrogenic in rats, causing persistent estrous and reproductive tract anomalies when administered during the neonatal period (232); and is associated (DDE) with premature births in humans in one study (155). Moreover, based on recent reports, DDT would be considered a human reproductive hazard (319).

Congenital Anomalies and Adverse Reproductive Outcomes

The Canadian mortality rates due to congenital anomalies (Figure 26) indicate that the region with the greatest frequency of high rate census divisions begins just downstream of Lake Ontario, and continues along an upward gradient all the way down the St. Lawrence river. This pattern is similar to that seen for cancer rates in Canada (Figures 23a, 23b)

Trend data on human birth defects in the Great Lakes ecosystem was not collected by the surveillance system, which was organized in 1966 by Health and Welfare Canada, until Ontario joined the system in 1973. The few data available (Figure 28) indicate declines in the measured rates of most anomalies from the outset of the registry in 1973, followed by relative stability with some evidence of increases in certain cases (166). This pattern is consistent and parallel to the decline of the Lake Ontario herring gull egg contamination (Figure 15); the contaminant residues in beef and pork (Figures 19 and 20); and the PCB residue patterns in human adipose tissue and human milk in Ontario (Figures 21 and 22, and Tables 2 and 3). It is also synchronous with what is known of the contamination history of the St. Clair River-Lake St. Clair system (52, 53).

Congenital anomaly occurrences (with identifiable toxic chemical associations) have been reported in Wallaceburg (Kent County), Ontario, Prince Edward County, Ontario, and New Brunswick. The New Brunswick study looked at the incidence of birth defects from 1971 to 1981. It found that the higher rates were concentrated along the Saint John River Valley - the centre of agricultural activity in the province- and in northern New Brunswick counties. The abnormalities corresponded with agricultural seasons and patterns of land use. While the exact causal agent was not pinned down, an association between neural tube defects (e.g. anencephaly, spina bifida, hydrocephalus) and potential agricultural chemical exposure was demonstrated. An approximate annual cycle of stillbirths, and an association with chemical exposure was also found (93).

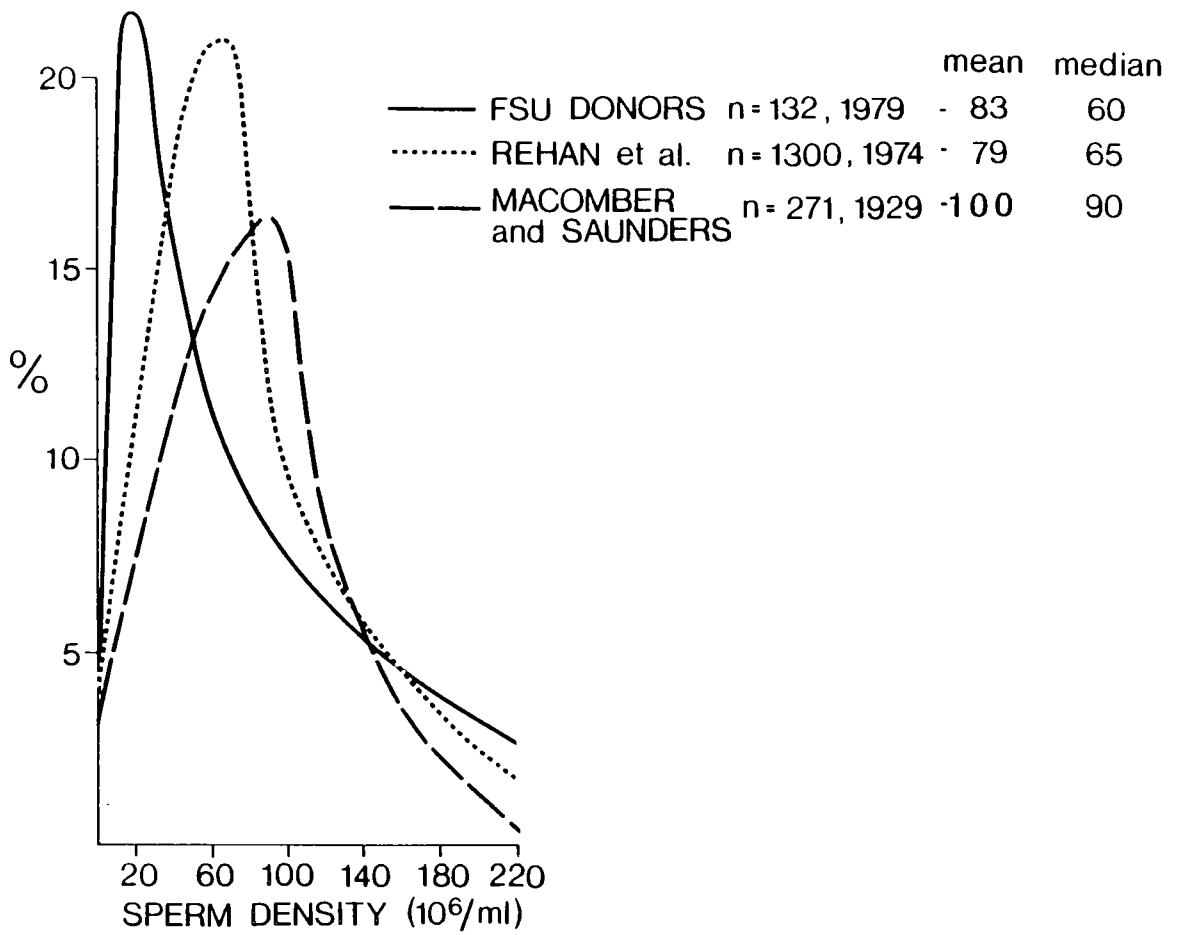


Figure 29 Sperm density distributions (smoothed over 40 million-cell/ml increments) for Florida State University donors as compared to the prevasectomy population of Rehan et al. in 1974 and the prenatal clinic population of Macomber and Sanders [273] in 1929.

Source: Dougherty, R C et.al. 1981. Sperm density and toxic substances: a potential key to environmental health hazards. In McKinney, ed Environmental Health Chemistry. Ann Arbor Science Publishers Inc. Ann Arbor, Mich.

During the 1969-71 period (3 years), Prince Edward County (PEC) was one of a number of counties, at the eastern end of Lake Ontario and along the St. Lawrence River, that had specific or total congenital anomaly rates above the provincial averages (165). In addition, compared to Ontario, a significant (0.01) excess in the number of stillbirths (at least 28 weeks/gestation) occurred in PEC during the period 1970 to 1973, and a seemingly anomalous increase in the rate of stillbirths of at least 20 weeks duration occurred from 1967 to 1974 (from 13.9 per 1000 total births to almost 40 per 1000 in 1974) (A. Gilman, personal communication, who contends that this was matched by a significant deficit in neonatal deaths in this period and led to an overall significant decline in peri-natal mortality during the entire study period ending in 1976).

While a possible connection is unmeasured, it may be that toxic chemicals were a factor in these events. This particular county contains a century-old community of commercial fisherman on the Isle of Quinte. In view of this stability, and the likelihood of fish consumption, these people were probably exposed to the contamination in Lake Ontario, which peaked in the early 1970s, as indicated in the herring gull egg measurements for the Scotch Bonnet Island Colony located just offshore; a colony with severe reproductive failure (73,72, Figure 15, Table 5). It was also during this period that deformities in chironomid larvae populations in the Bay of Quinte had accelerated to the peak recorded level noted above (215). The Bay of Quinte is also reported to be contaminated with pentachlorophenol (263).

A time limited cluster of spina bifida livebirths occurred in the Wallaceburg area of Kent County from October 1973 to July 1974. Although a small number of cases (8), the incidence was about 20 times the Kent County 1969-1971 rate, and about 8 times the Ontario 1973 rate (G. Sherman, personal communication). Thus, while the reasons for the cluster are unknown, and the cluster may appear small, it is nonetheless an order of magnitude above the background noise. Exposure to toxic chemicals may also have been a factor in these birth defects, as Wallaceburg is downstream from the St. Clair River.

Recent reports have documented current and some presently known historical events in the contamination of this River (53, 52, 229). These reports indicate that for a number of compounds (the historical record is short) direct discharges from industry, and general downstream and ecosystem contamination (as measured in Lake St. Clair fish; e.g. mercury, PCBs, DDT, chlordane, and lindane (53)), were substantially worse (up to an order of magnitude) 10 or more years ago.

Evidence showed that some chemicals, both routinely discharged (53, 52) and associated with spills (52) were present in the drinking water supplies of Wallaceburg (229). It is possible that known higher discharges, and or known and unknown spills contaminated Wallaceburg's

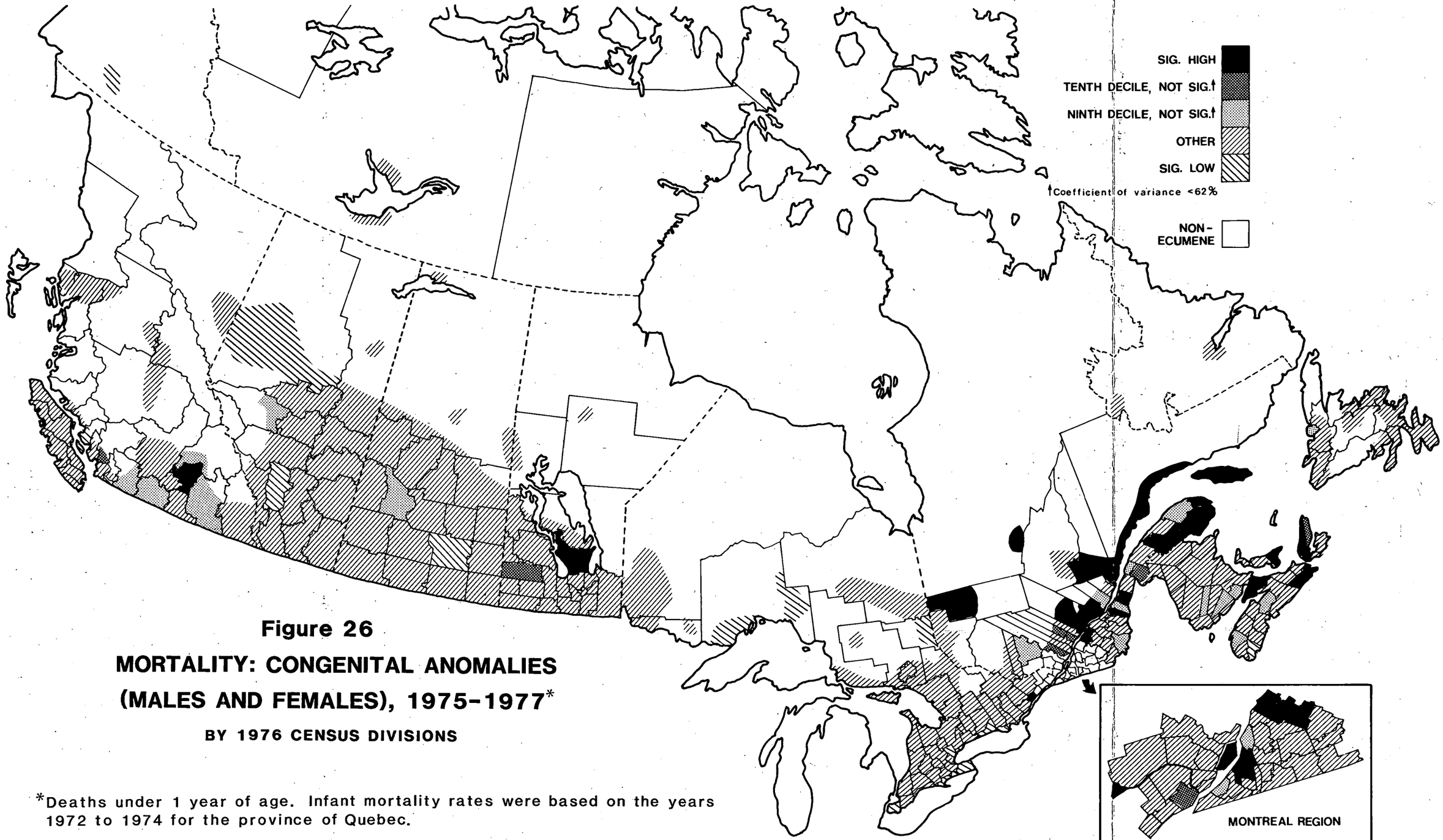


Figure 26

MORTALITY: CONGENITAL ANOMALIES (MALES AND FEMALES), 1975-1977*

BY 1976 CENSUS DIVISIONS

*Deaths under 1 year of age. Infant mortality rates were based on the years 1972 to 1974 for the province of Quebec.

Source: Mortality Atlas of Canada, 1980. Health and Welfare Canada, and Statistics Canada, Ottawa.

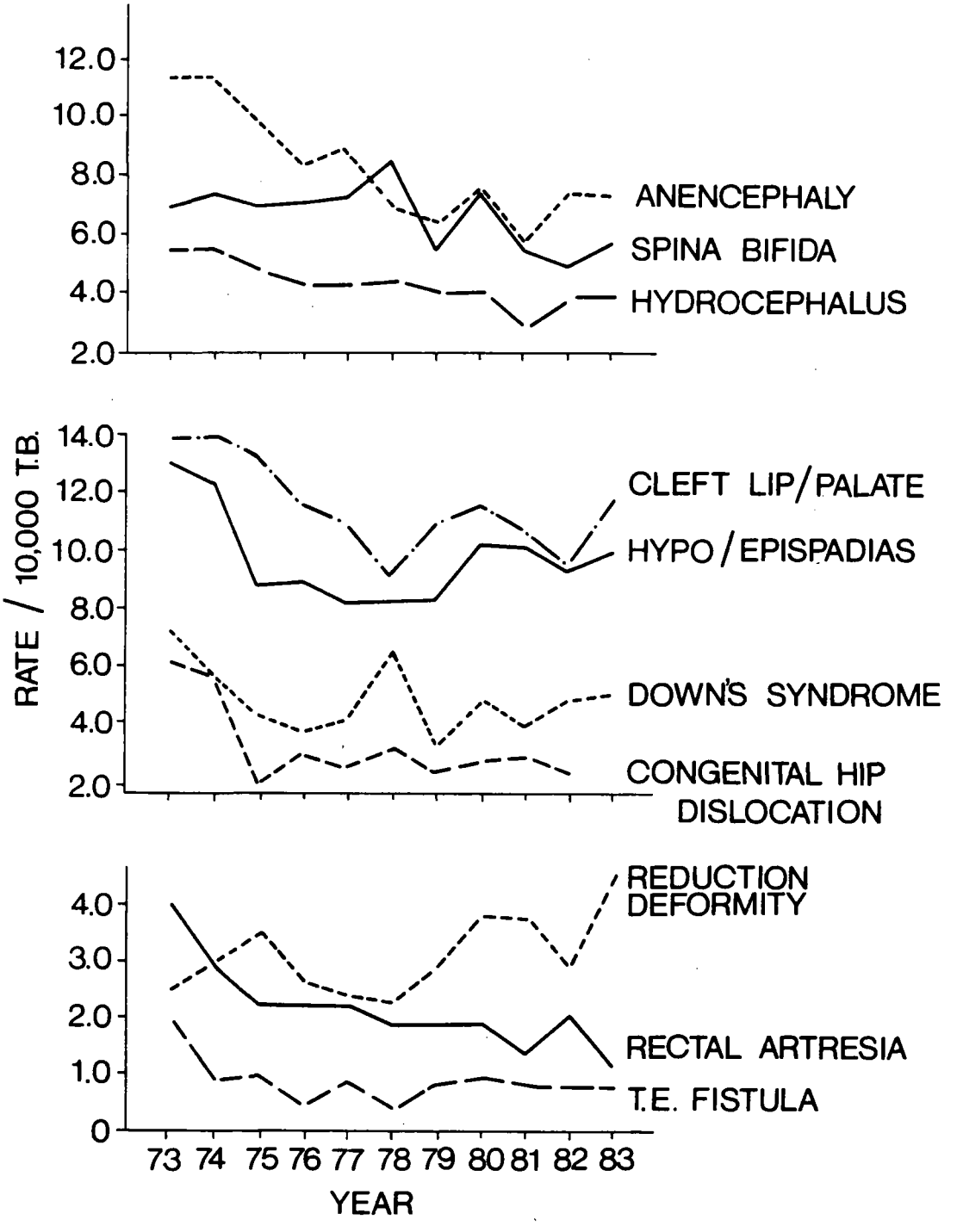


Figure 28. CONGENITAL ANOMALIES RATE 1973-83

Source: Ontario Ministry of Health. 1985. Congenital anomalies in Ontario: a review 1973-1983. Ontario Disease Surveillance Report 6: 33.

drinking water at correspondingly higher levels during the period leading up to the 1973-74 outbreak. Other pathways of exposure to known or suspected mutagens/ teratogens are also possible causes. These include: expected higher levels of volatiles moving from water to air; the eating of contaminated fish from Lake St. Clair, or the river (52,53); and industrial atmospheric emissions (52). Contaminant levels in fish were recorded as being up to ten times higher than present levels (53). It was stated that atmospheric emissions were also significantly higher then, but no data were presented (52). Some industry self-monitoring data exists on trends in sulphur dioxide levels and aerosol (fine particulates) loadings back to 1973, and more recent dated trends on other indicators are available for Sarnia (258).

Over the last decade, a variety of sophisticated techniques (e.g. amniocentesis, and chorionic cell sampling) have evolved to detect defects in the unborn, and the potential in prospective parents for defects in their children (289). Systematic use of these tests, and therapeutic termination of those deemed to be "defective", are increasing. Anomalies that are identified and terminated by screening programs are not registered. Furthermore, the true dimension of spontaneous abortions or miscarriages is unknown, as only those cases involving hospitalization are reported and available to a central registry. Failure to register such events deprives society of an important warning signal. Continual accurate monitoring of the frequency of these events is an important and required strategy in assessing the contribution of environmental agents to genetic disease in the human population (289). Consideration of the present deficiencies is required.

Other evidence suggests that official vital statistic records of birth defects in the U.S. (and probably Canada) include only about 1/10 to 1/20 of the defects that are ultimately detected upon careful follow-up (155, 232). The March of Dimes estimated that 8% of newborns have major defects recognized in the first year of life. When both major and minor defects are ascertained from infancy through to early childhood, the proportion increases to about 16%. Other estimates confirm these general ranges (155,126,36,65,232). Low birth weight children (less than 2500 gm) had a much higher incidence of severe anomalies diagnosed through age five years (36, 232). These reports indicate that better statistics are needed (289).

Allergies and Asthma

Increasing numbers of people are reportedly coming down with environmental hypersensitivities, allergies, asthma (increasing rates of illness and death among children and young adults in recent years in Canada (323)), or in the extreme, a disease called "total allergy syndrome" or "Twentieth Century Disease". These latter people are

allergic to almost everything, especially synthetic chemicals, to the extent that they can't tolerate most food, water, ordinary buildings or cities. This disease is very debilitating and can even be fatal. Victims have great difficulty avoiding exposure to the chemicals to which they are allergic.

A number of chemicals and metals that are produced, used, and/or exist as trace pollutants throughout the Great Lakes ecosystem and elsewhere, are identified as skin and asthma allergens (e.g. formaldehyde and food additives) (25, 128). Again, this situation may be further complicated by more familiar allergens (e.g. pollen, animal hair, and cigarette smoke).

As a postulate, it is also possible that some chemicals and/or their metabolites can bind to proteins, creating "foreign" structures or particles which may induce an immune response or allergic reaction (232). The mechanism of antigen formation in the induction of a contact hypersensitivity reaction in the epidermis of guinea pigs, by quaternary ammonium compounds (widely used in preservatives, disinfectants, cosmetics, and medications), has been demonstrated (290). Published studies designed to test for and measure such a toxicological role in humans were not found in this review. The possible role of such binding, or other toxic effects of xenobiotics, in the development and frequency of allergy, asthma, total allergy syndrome, environmental hypersensitivity, and general auto-immune diseases should be investigated (232).

Degenerative Conditions

Although average quantitative life expectancy is increasing, due largely to declining infant mortality and improved medical technology which keeps people alive longer, (it may still be substantially below the real potential (107)) so is the apparent prevalence of chronic sickness and disability in the population. In Canada from 1951 to 1978, 70 percent of the gain in life expectancy for men, and 80 percent of that for women, involved some form of disability. In the United States from 1966 to 1976, essentially all of the gains in life expectancy for both sexes are reported to have come with some form of disability (233,107).

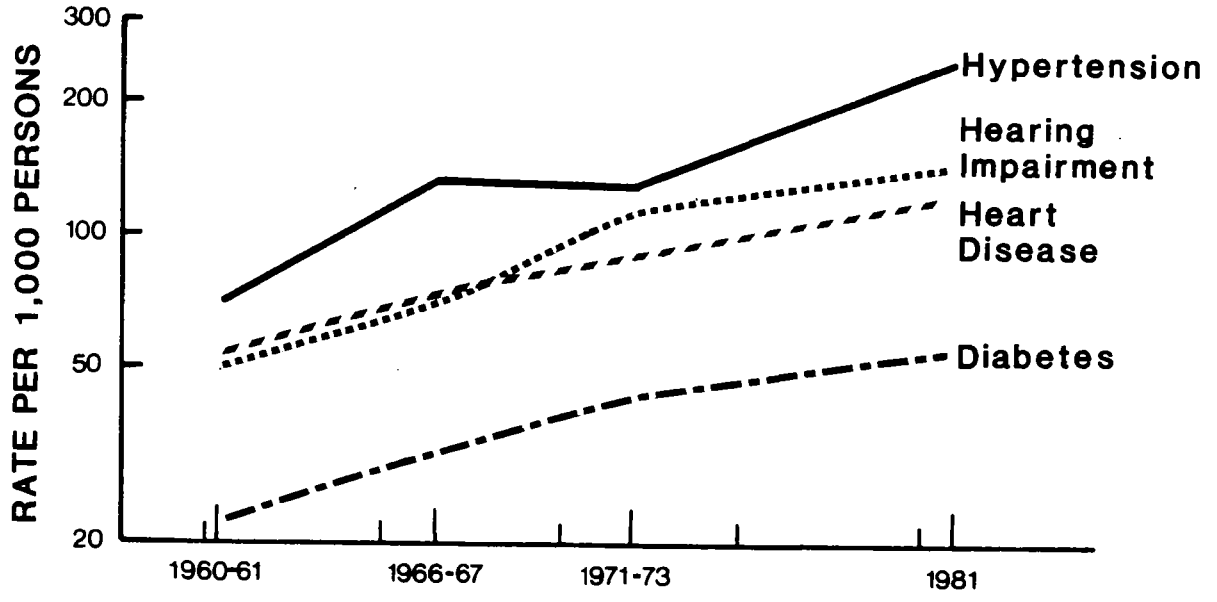
The trends in the prevalence of certain chronic conditions, and disability or activity limitation due to chronic conditions in selected age groups of the U.S. population are shown in Figure 32 (60). There is: (a) a marked increase in the prevalence of these chronic conditions; and, (b) for males aged 45-64 there is a more than doubling in the percentage who are disabled in some way. For the children under age 17, there has been a doubling in the rate of chronic health problems leading to some form of activity limitation (60). From the health statistics available, it appears the situation in Canada is not much different (107). It is noteworthy that age-linked increases in blood pressure, serum cholesterol levels, and body weight, usually interpreted as age-intrinsic risk factors in cardiovascular disease, are turning out to be usual in prosperous industrial countries, but not in pastoral and traditional agricultural societies (293).

Numerous persistent toxic industrial chemicals and metals are reported to be associated with, or risk factors in, the development of these and other chronic, degenerative conditions (25, 95, 60, 3, 9, 7). Note that some of the studies include populations living near hazardous waste sites (25). Significant positive associations were found between serum PCB and blood pressure, hypertension, circulating triglycerides and cholesterol, and between DDT and cholesterol (95, 25). Lead, cadmium and arsenic are significant factors in lipid and protein metabolism, as well as in the development of hypertension, ischemia, and arteriosclerosis, and consequently, of the premature ageing syndrome (25, 60). Recent studies carried out on Wistar rats have elucidated the complex biochemical and metabolic changes involved in the development of cadmium induced pathology of the cardiovascular system (3).

As noted earlier, the use of relevant comparative epidemiological data from other locations can be helpful in the assessment of risk factors in disease, relative to environmental contamination. A Czechoslovakian study of a population of 1600 people exposed to emissions of arsenic, lead, cadmium, sulphur dioxide, and some 20 other substances from a thermal power station, revealed an increase in certain metabolic risk factors of atherogenesis measured as significantly increased levels of blood cholesterol and beta-lipoproteins (low density), and decreased alpha-lipoproteins (high density) compared to controls. The exposed population also had a higher prevalence of ischemic heart disease (9).

Two Czechoslovakian studies examined factors relevant to chronic conditions in children, and to possible subsequent chronic disease in adults (7, 8). One examined the fatty acid composition of the lipid fraction of human milk samples obtained from women living in an area exposed to thermal power station emissions, compared to a control group. Human milk from the exposed group had a fatty acid composition significantly different from the controls. This shift in fatty acid composition increased some of the metabolic risk factors involved in atherogenesis (7). The other study found significantly lower levels of four immunologically relevant (non-specific immunity) blood proteins in adolescents (12-16 years) of both sexes chronically exposed to power station emissions, as compared to a group of matched controls. Trace pollutants found in the fallout from the power station were implicated in the induction of the observed declines (8)

The age-adjusted mortality rates in Canada due to diseases of the circulatory system, of which ischemic heart disease (heart attack), and cerebrovascular disease (stroke), are the major subdivisions, appear in map form in Figures 33 and 34. The steep gradient from west to east is readily apparent for both males and females. Moving past the cluster of high rate divisions in Manitoba, the Great Lakes-St. Lawrence region has the greatest frequency of high rate census divisions. High rates occurring in areas known to be major sources and/or receptor sites of many toxic chemicals include: the Thunder Bay, Sault Ste. Marie, and



Prevalence of selected chronic conditions as reported in health interviews with U.S. residents, ages 45–64.

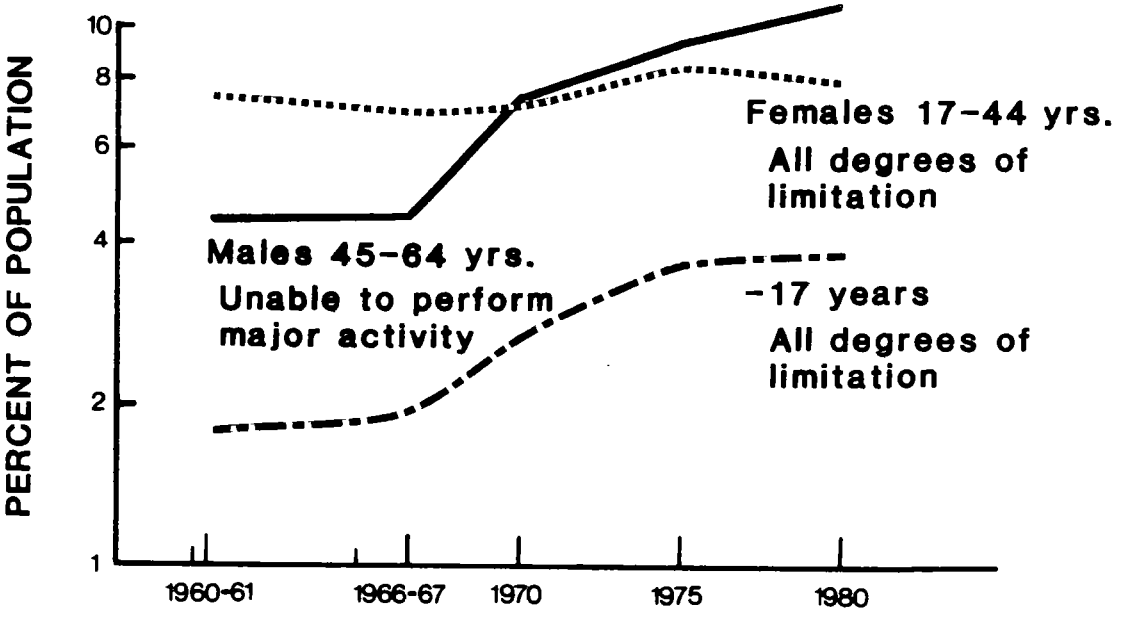


Figure 32 Limitation of activity in U.S. residents due to chronic conditions.

Source: 60

Sudbury regions; along the St. Clair River, Lake St. Clair, and Detroit River systems; the Niagara and Hamilton- Wentworth regions; and along the St Lawrence river to the Montreal region and beyond.

Areas with high mortality from diseases of the circulatory system are associated with major sources of many toxic chemicals in patterns consistent with, and more frequently than those for the cancer, and congenital anomaly maps discussed above. Relative to cancer, it is possible that progression toward a condition where a heart attack or stroke occur, may outstrip malignant progression (92).

Psycho-social Conditions

There are a number of instances (such as Love Canal, N.Y. and Three Mile Island, Penn.) in which people were exposed to relatively high levels of hazardous substances. Most of the social and psychological effects of exposure to toxic substances stem from fears and anxieties about future health impacts (134). This causes long term stress because the worries about these health effects and effects on children and grandchildren remain even after the people have left the area or the source is removed. People suffer depression, become pessimistic and generally suspicious of others. The stress often causes marriages to break up and imposes severe trauma on children (134).

These impacts are exacerbated by the people's feelings that they have no control over the situation (134). Homeowners find it difficult to escape because their homes became financial traps which they cannot sell (134). While the physical aftermath of toxic exposure can be severe, the social and psychological impact could prove more critical (134). For example, a high level of distress was shown to be associated with significantly poorer DNA repair in lymphocytes, as compared to low distress subjects. This and related studies provide some evidence of the mechanisms by which psycho-social factors may be directly associated with an increased incidence of cancer and infectious disease, and more general immune response effects (114).

5.0 UNIFYING FACTORS AND MECHANISMS OF ACTION

Unifying Factors

The above data and studies reflect synchronous and analogous events in the history of the contamination of the ecosystem. For the fish, birds, and other non-human lifeforms, there are a number of studies documenting the experimental, statistical, and physiological links between toxic chemicals and states of health. For humans, the toxicological evidence is relatively limited, but growing significantly in key areas. Until recently, this evidence was either non-existent, or based on occupational studies for a few chemicals. Now, a few new studies provide insights into some of the biochemical and metabolic changes involved in the mechanisms of human cardiovascular and immune system toxicity induced by complex mixtures of metals and other pollutants present in power plant emissions (60, 9, 7, 8, 3).

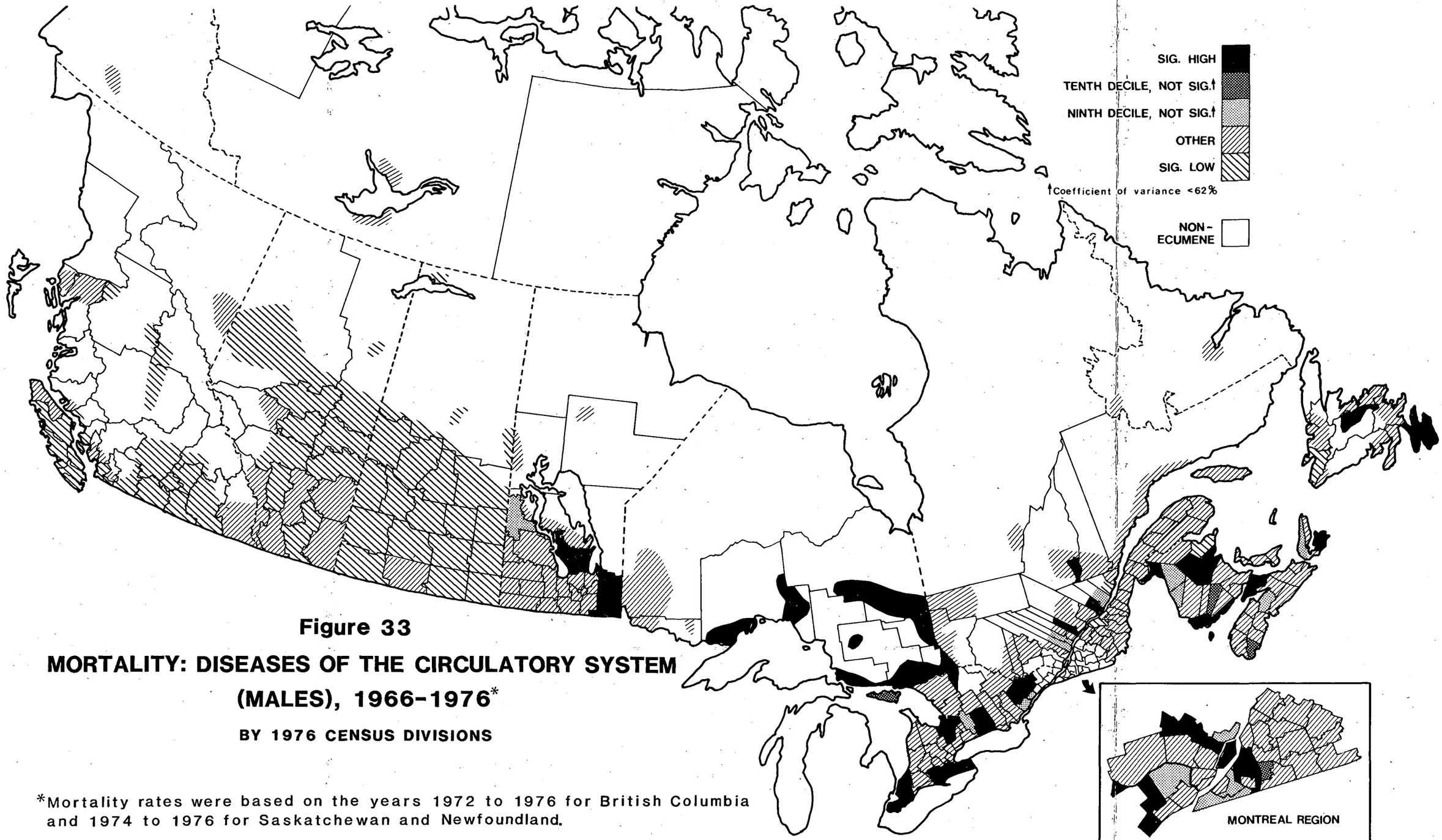


Figure 33

MORTALITY: DISEASES OF THE CIRCULATORY SYSTEM (MALES), 1966-1976*

BY 1976 CENSUS DIVISIONS

*Mortality rates were based on the years 1972 to 1976 for British Columbia and 1974 to 1976 for Saskatchewan and Newfoundland.

Source: Mortality Atlas of Canada, 1980. Health and Welfare Canada, and Statistics Canada, Ottawa.

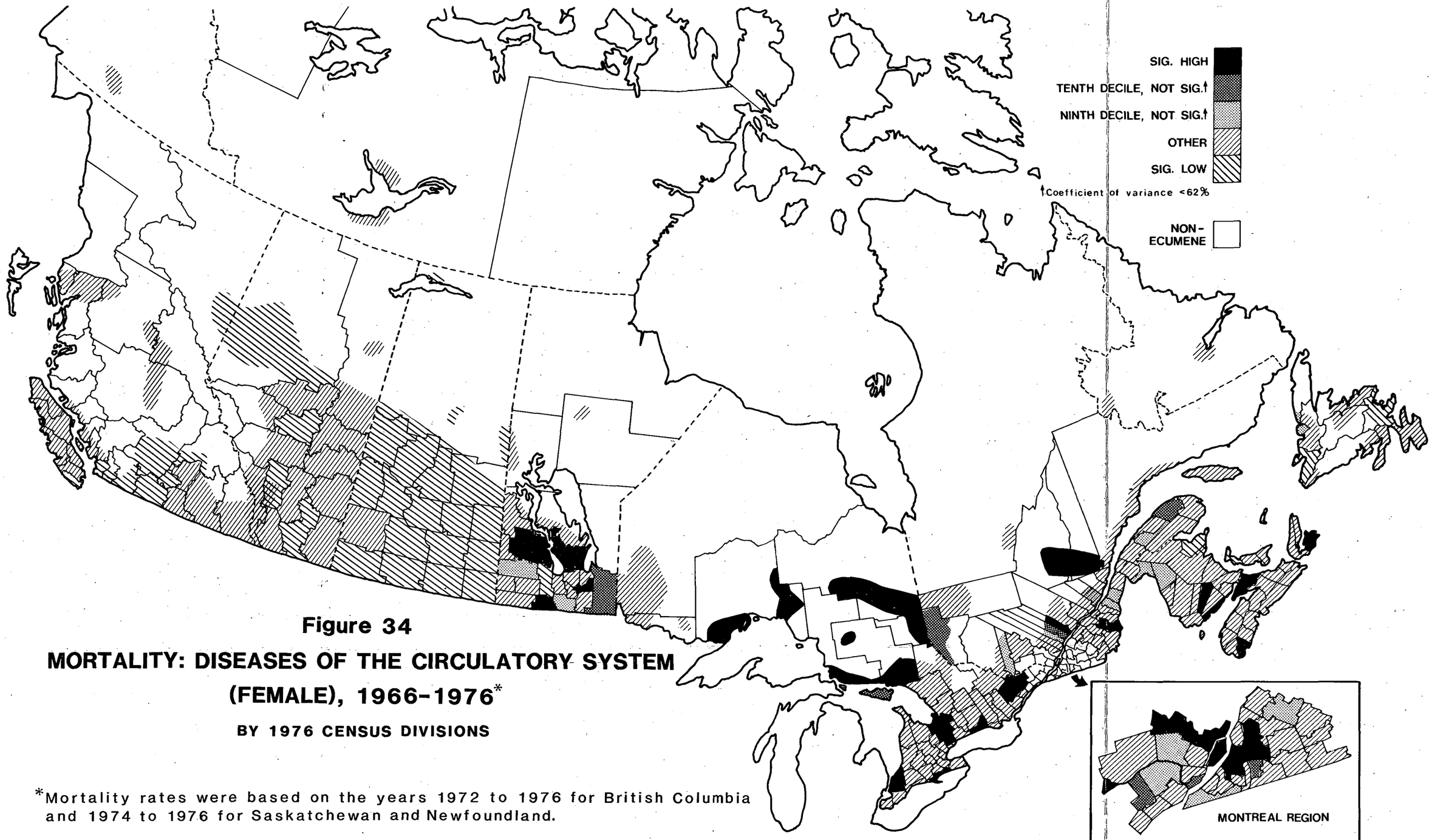


Figure 34

MORTALITY: DISEASES OF THE CIRCULATORY SYSTEM (FEMALE), 1966-1976*

BY 1976 CENSUS DIVISIONS

*Mortality rates were based on the years 1972 to 1976 for British Columbia and 1974 to 1976 for Saskatchewan and Newfoundland.

Source: Mortality Atlas of Canada, 1980. Health and Welfare Canada, and Statistics Canada, Ottawa.

However, these measurements of blood proteins in humans exposed to xenobiotics only scratch the surface of the inherent information potential, because such analysis provides a minimally-invasive, biologically relevant monitoring approach to human xenobiochemistry and toxicology. Other specific examples of possible monitoring for the effects of toxic chemicals on humans include the suggestion that measurements of in vivo human exposure to chemicals capable of causing genetic damage, and measurements of in vivo genetic damage occurring in humans, are of strategic importance in assessing the contribution of environmental agents to genetic disease in humans (289). Such strategies are a complement to and improvement over "safety", "guideline" or "standard" assessment approaches based on animal experiments, short-term genetic assays of chemicals and complex mixtures, and/or concentrations in water, food and air, particularly for those individuals with enhanced sensitivity, such as infants and adolescents (8).

Classical epidemiological methods, or statistical studies, often suffer from a lack of sensitivity or power (253, 281). This is due mainly to the adoption of premises that: (1) imply acceptance of a background or "usual" rate of disease as "expected" or "normal"; (2) that generally reduce the risk detectable (e.g. by failing or being unable to adjust for population mobility (284)); and (3) fail to account for chemical exposure histories (166, 94, 253). Epidemiology requires a diversity of exposure; and an environmental hazard that is widespread or universally present may be impossible to find by traditional methods, even when it entails an order of risk important for the population (281). In fact, there are no unexposed humans to act as scientifically "clean" controls, and no background of disease rates free of the effects of this exposure.

The epidemiological evidence presented above, particularly the small area studies, provides some statistical evidence of links between human health (cancer, circulatory and immune system disease) and toxic chemicals. Other studies of critical subpopulations (59, 108, 211, 26) show similar results related to reproduction, and still others should be done. For example, the synthesis of epidemiological data from a number of studies looking at the health of long-term consumers of PCB contaminated fish from Lake Michigan, and their newborn infants, reveals strong correlative evidence of deleterious effects (234).

However, the design of most single studies, especially of the population at large, faces serious problems in trying to detect and evaluate health effects due to extended, widespread and low-level exposures to hundreds or thousands of chemicals - many of which bioaccumulate. Indeed, for part of the population, exposure begins before conception. Such exposure, antenatally or in childhood, could have a lasting and non-specific effect on health, which could influence susceptibility to a variety of conditions (281), including cancer (297), and possibly asthma (232). The fact that exposures and effects are cumulative, and stochastic or statistical rather than unique, are further problems (126,289,309). Additionally, interpretation of such studies is complicated by the multifactorial nature of most disease. In any observed disease situation, a web of multiple and often related variables exists.

Nonetheless, there is a need to develop and sustain large-scale epidemiological efforts. These are fundamental to the continual, accurate study of the health and frequency of disease in the overall population; and they are necessary to help determine the extent to which environmental exposure, genetic damage, and other forms of toxic effects can be linked to genetic and other disease (281, 289). Moreover, there is a significant genetic disease burden in humans, and present knowledge suggests that environmental agents contribute substantially to this burden. However, current knowledge based on in vivo measurements of exposure and damage, as well as epidemiological findings, indicates that the link between toxic exposure and genetic damage remains largely untested in humans (2, 64, 65, 92, 126, 257, 278, 280, 281, 289, 293, See Appendix).

These problems with methodological premises, and the number of confounding factors, underly the often stated dictum that statistical association alone can never establish causality. According to this dictum, all of the above associations and synchronicities could be the result of chance. But, the cancer in fish, congenital anomalies and reproductive problems in birds, the 25% and rising human cancer rate, the 16% human birth defects rate, and declining human fertility present a convincing degree of circumstantial evidence that toxic chemicals do affect ecosystem health. However, since statistical connections alone are not sufficient to prove this theory, it is necessary to consider physical factors and relationships between the actions of toxic chemicals, disease processes, and observed states of ecosystem health.

Despite their obvious differences, all life forms - fish, gulls, cormorants, bears, whales, voles, and humans - are similar chemically. The universality of the genetic code, and of metabolic systems, means that the basic biochemical mechanisms and processes supporting the very different forms of life on earth have fundamental similarities (126, 253, 264, 294-296). While there are substantial natural variations between individuals, strains, and species, humans, like other mammals, fish, birds, and all other species examined to date, possess analogous enzyme system capabilities of metabolizing a wide variety of chemical pollutants, and drugs (46, 85, 82, 117, 115, 113, 2, 258, 271-273). Thus, to the extent that life forms share enzyme systems, they share, at least qualitatively, the same sensitivity and vulnerability to the insults or toxic stress that may arise from the way in which toxic compounds interact with these enzymes within the cell (258, 271, 272, 276, 295). Other direct-acting toxins (e.g. metals, nitrogen dioxide, ozone) do not require bioactivation, as they are sufficiently reactive to initiate a toxic effect or process (278, 309).

Mechanisms of Action

The mechanisms whereby toxic chemicals interact with living systems to induce damage that may cause genetic error and disease, cancer, and other degenerative health problems, have been investigated in many experimental and field systems, including mammals, aquatic and wildlife species, human cells,

and rodent germ cells. Some of this work has been discussed in previous sections above, and some only noted (208, 257, 278, 285, 289, 294, 295). These mechanisms are extremely complicated in all their details, and many steps remain to be elucidated. A detailed review of the vast literature on this subject exceeds the scope of this report. However, other reviews of important aspects of this literature exist.

It is within the scope of this report to discuss certain basic concepts which provide a framework for considering how various types of toxicity reflect interactions between xenobiotics (or their metabolites) and biologically important structures, as shown in Figure 35 (295). Because this discussion contains many unfamiliar technical terms, jargon, and abstract concepts, it requires careful reading and study, and may disconcert the average reader. Therefore, a summary review, in general terms, of some major mechanisms of action, relevant to Figure 35 and the subject matter of this report, follows in an Appendix.

6.0 DISCUSSION AND PRINCIPLES OF CAUSALITY

There are between 60,000 and 100,000 (151) chemicals and metals produced, used and/or dissipated in substantial quantities around the world, and about 30,000 (159) in and around the Great Lakes ecosystem. Estimates of new chemicals added each year vary from thousands worldwide, to 300 in Canada (159). Based on chemical structure parameters, quantities in use or produced as byproducts, and degradation and daughter products, there may easily be thousands of chemicals with structures suggestive of mutagenic or carcinogenic potential in the environment in large amounts. The three groups of chemicals specifically considered in this report contain a substantial number of these kind of toxins. Many of these chemicals are man-made and have never before existed in nature, thus presenting novel challenges to biological defenses, some of which are designed to deal only with oxygen-based reactive species (278).

From existing evidence, some of which was presented in previous sections, it is apparent that the human environment has become increasingly rich in toxic, xenobiotic chemicals, each present in trace amounts. Human exposure routes to these contaminants are many and varied, including ingesting, inhaling, or dermal contact through water, soil, plants, animals, fish, indoor and outdoor air, as well as direct exposure to an extensive variety of manufactured products that are themselves toxic. Moreover, the body has to cope with every chemical, no matter how infinitesimal the amount. Thus, perceptions derived from the human scale of experience - chemical concentrations that appear vanishingly small in the space of this scale - are of limited value in judging the significance of such concentrations. Biological systems are enlivened by metabolic and biochemical processes in which trace, even ultra-trace, amounts are the norm (84). This perceptual problem is especially important to recall in viewing compounds that bioconcentrate and bioaccumulate.

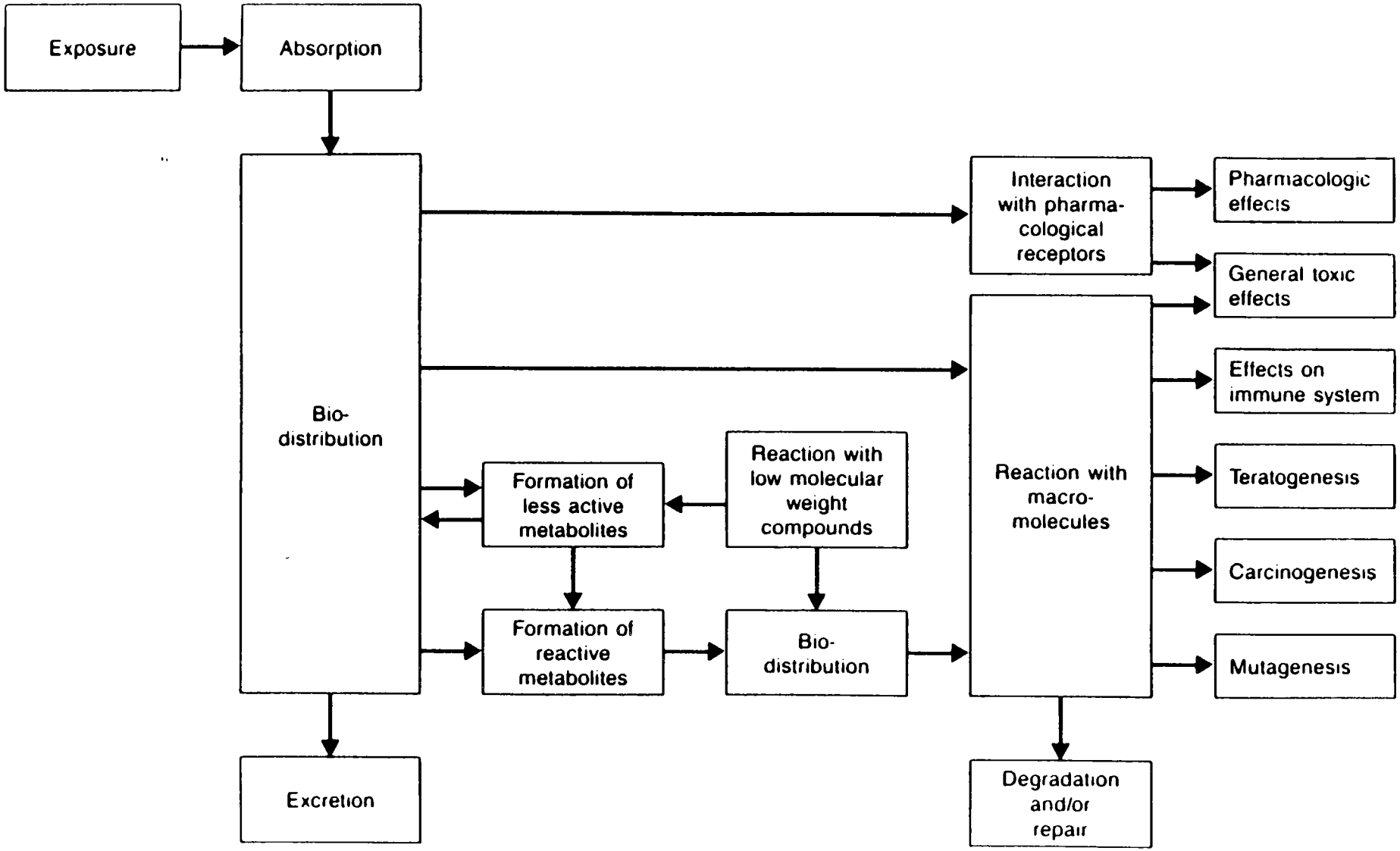


FIGURE 35 Overview of absorption fate and disposition of xenobiotics in mammals and fish.

Source: Guarino, Anthony, M. 1987. Aquatic versus Mammolion Toxicology: Applications of the Comparetive Approach. Environmental Health Perspectives, Vol. 71, pp. 17-24

Biochemical processes can consist of complex, multiple-step, multiple-chemical chain reactions, or cascades. The mechanism of action of 2, 3, 7, 8-TCDD, and its isosteres, is of this form (151). Such a process can be initiated by the release of only a few hundred molecules of one substance. This release triggers other substances amplified into the millions or billions of molecules through several steps to an endpoint involving profound changes at the whole-body level, for example, in preparation for stress. Thus each molecule must be considered to exert its influence in interaction with the biosystem.

Evidence presented in previous sections on ecosystem health and the mechanisms of action Appendix describes the nature of some of these molecular interactions, their influence on certain metabolic and biochemical processes, and suggests a number of deleterious effects that are mediated by these influences through several possible causal relationships. Also identified were 20-40 year long (can be shorter or longer) and multi-generational latency periods for several of the more serious effects. These lines of evidence, when looked at in total, indicate that the Great Lakes ecosystem, and the environment in general, are contaminated by a large number of man-made chemicals that can act directly, or interact, to increase the human disease burden. However, the cause-and-effect links are usually obscured for individual contaminants, and even for individual diseases.

Therefore, the concept of the total toxic load, or lifetime burden, representing the summation of a wide variety of environmental toxicants of varying potencies at low dose levels, is of great practical relevance (96, 38, 281). Low levels of exposure over long periods of time can produce effects in animals similar to higher doses over shorter periods (237, 309). Metals, and chemicals resistant to metabolism may persist in tissues indefinitely, and can accumulate to ever higher levels with time and continued exposure.

It is of great importance that single toxic chemicals do not occur in isolation. This "total burden" concept cannot be separated from the idea of thresholds and hypotheses about low-level exposures (or low-doses) because both ignore the need to deal with total environmental exposure, rather than exposures to single chemicals (257 - pp 595-604, 208). Both also ignore, for example, that 25% cancer mortality rates strongly indicate a broad exposure to carcinogens within the environment. Assuming simple additivity (208, 301) implies that the current operational part of the dose-response curve is from 25% incidence on up. If this is true, then the lower left, undefined section of the dose-response curve is irrelevant to real-world exposures, and small additional amounts of chemical carcinogens added to the human environment are going to cause small additional increases in cancer (257, pp 595-604, 208). As a corollary, it would seem to follow that small amounts of chemical carcinogens removed from the human environment will cause small additional decreases in cancer.

This point was raised for carcinogens almost 20 years ago (96), ten years ago (257) and again more recently (38, 208), but it seems to have made little headway. Regulatory processes still focus on single chemical, single exposure pathway calculations. While such calculations may provide useful information on toxicity (probably based on experiments in mice or rats), regulation itself is based on the substance causing an identifiable illness. This approach assumes that the given substance is the only health hazard a person is exposed to. Since the biological reality consists of the integrated effect of multiple toxicants, how may any one chemical be declared safe in isolation? Valid scientific proof of safety is far more difficult to provide than corresponding proof of hazard, requiring about 30 times more data, and far exceeding what is ordinarily feasible in valid studies (298). Declarations of safety that ignore this point may constitute substantial risks to exposed populations (253).

Principles of Causality

As a conceptual aid in evaluating the weight of the evidence presented in this report, it is useful to keep in mind some basic causal principles. The ability to describe the space-time relations of both the material-dependent interactions, and the statistical properties (e.g. frequencies or rates, variations, and links) provides the basis for strong claims about cause-effect connections. The physical or material-dependent interactions cause the motion or forces involved in a particular process. These interactions (and therefore the influence) are necessary for causal relationships (100, 299). But these causal connections exist on the basis of complexes of relations, made up of multiple factors (both natural and man-made), multiple steps, and large natural variations, all of which acting together lead to contingencies and chance (100). The interactions of these contingent relations makes the process and its results contingent as well. Therefore, the casual necessity of a particular set of relations is never absolute (16).

This means that for an individual life form in a particular place and time, no definite general prediction can be made concerning the effects of specific toxic chemicals (aside from outright poisoning). For individuals living in a homogeneous or "mass" society, like those in industrialized countries, things like cancer appear as random events (96). However, for a large aggregate of individuals, and/or over time, there are statistical properties or laws indicating that variations in a particular cause, or class of causes, produce regular and predictable trends in the effect(s) (100,16).

For these reasons, the effects of toxic chemicals may be viewed as interactive, cumulative and stochastic processes, rather than singular and unique events (126, 289). In ecosystem terms, the density of an effect or disease in the ecosystem is related to, or driven by, the density (e.g. concentration times potency) of its causes. This holistic and statistical view entails certain necessary and essential connections between two events

that characterize any process - the beginning and the end. These connections determine law-like relationships between the initial and final states of a process, and do so without involving consideration of the specific and direct mediations in between (100).

This means that while the complex of causal relations and contingencies that lie between the initial and final states of any disease process (e.g. cancer, atherosclerosis, reproductive anomalies, and "aging") are too complicated to follow, it is known that the relationship between these two states must always be characterized by a gradient of potential, or a force, that connects them. The energy (or magnitude) of this force is proportional to, and transmitted by, the toxic agent or material-dependent interactions that initiate and drive the process. As a possible example of the quanta of this force, the creation of electrophiles and their interaction with nucleophiles involves the existence and motion of atomic charges, or an electromagnet field or force.

The resultant (e.g. the net effect of forces acting, or of the "action") of this force is a function of the resistance (e.g. defence and repair mechanisms (278, 289) of the medium or life form. The observable (how it is measured) of this force is relative accelerations (e.g. gradients, waves) in disease rates, from place to place in space (e.g. geographically), and/or from point to point in time (100, 16, 17, 217). Force being a field concept, the strength of its signal in any neighborhood is proportional to the strength (e.g. density, mass or energy) of the neighboring sources. The ecosystem health related data, maps, tables, and discussion can be viewed from this perspective.

In this sense, the toxic agents are like seeds; the greater their number the greater the force, and the higher the aggregate probability of disease. This is analagous to a form of free lottery, in which the more tickets (toxic agent risks) distributed, the larger the pool from which the aggregate number of prizes is drawn, and the more likely that an individual will "win".

7.0 CONCLUSION AND RECOMMENDATIONS

There is strong evidence and some consensus, that chemical pollution is toxic to humans and other species in the Great Lakes ecosystem and causes a variety of health effects.

Despite the need for additional information on environmental contamination and human health, there appears to be a connection between levels of overall environmental contamination and numerous health problems, including cancer, reproductive problems, and degenerative disease, in the industrial-chemical society of the Great Lakes ecosystem. The strong associative or circumstantial evidence of effects is further strengthened by the collateral evidence on some basic mechanisms whereby environmental contaminants may induce and/or accelerate degenerative and other diseases.

To stop a process it is necessary to eliminate its causes. By corollary, the best immediate strategy is to use existing technology and encourage new technologies to stop pollution at source and to detoxify existing sources of hazardous chemicals already in the environment. In addition, the use and production of toxic chemicals could be curtailed and safer substitutes found.

Efforts could also be concentrated on minimizing human exposure to all potentially hazardous chemicals. These measures may be of great benefit in reducing human disease even as society awaits further evidence on the ecosystem health implications of toxic chemicals.

8.0 APPENDIX - MECHANISMS OF ACTION

One mechanism of toxic action consists of metabolic interactions giving rise to reactive metabolites or electrophiles (electron deficient reactants), free radicals, or both. These in turn give rise to further interactions that can result in broken chemical bonds, oxidative deterioration of cell membranes (lipid peroxidation), reduction-oxidation cycling, irreversible binding with, depletion of, inhibition of, or other changes in macromolecules, such as antioxidants, enzymes, proteins and nucleic acids (208, 260, 277, 278, 285, 295, 304, 289, 309). The metabolism of PAHs, aromatic amines, PCBs, and other compounds involves pathways that create reactive metabolites (199, 10, 208, 95, 186, 245, 246). Interactions involving free radicals are known to be associated with ionizing radiation (206), cigarette smoke (37) aromatic amines (19), halogenated alkanes (e.g. carbon tetrachloride, chloroform) (21,35), PAHs (32), PCBs, and polybrominated biphenyls (PBBs) (155), sulfur dioxide (153), and other toxic chemicals (137). In fact, almost all synthetic aromatic compounds and many inorganic compounds are metabolized to a reactive free radical by at least one enzyme (137). Nitrogen dioxide is a reactive free radical in itself, and ozone is a powerful oxidizing agent (277, 278).

These reactive metabolites, free radicals, and metal complexes can react with the cell membrane and with many cell macromolecules such as proteins (e.g. enzymes), RNA, and DNA, causing cell injury (309, 278, 285, 289). Of these, perhaps the most critical is DNA because of the limited redundancy of the genetic information encoded in it (206). The interaction of these agents with DNA can lead to chromosomal aberrations, strand breaks, covalently bound adducts, and/or numerous other forms of damage that may alter genetic information (206, 208, 285, 289, 309).

There is strong evidence supporting a causal link between the carcinogenic potency of PAH (e.g. benzo(a)pyrene) and the amount of reactive metabolite bound to DNA in the form of covalent adducts as a result of cellular metabolism (245, 246, 289, 309). The mutagenic and carcinogenic activity of PAH and a number of other compounds was found to be significantly correlated with electronic structure calculations of reactivity, (measured as the energy of the lowest unoccupied molecular orbital) (130, 145, 62). The stability (calculated enthalpy or total energy of reaction) of adducts formed with nucleophilic (electron rich) macromolecules such as DNA, was found to be indicative of the relative mutagenic potency of a series of nitroaromatic compounds (130).

There are numerous repair enzyme systems which continually repair DNA lesions (289), although it is reported that no DNA repair system reduces DNA damage to zero (208). Moreover, the major cellular processes of DNA replication and DNA repair are extremely complex. Many biochemical mechanisms are involved and numerous factors, including individual health, age, sex, species, immune system integrity, and a variety of toxic agents, can diminish the amount of damage removed, as well as the fidelity of DNA synthesis and replication (199, 10, 208, 289). For example, formaldehyde (a widespread air pollutant, particularly indoors) is reported to inhibit the DNA repair of the

putative premutagenic (289) alkylated base O6-methylguanine in normal human fibroblasts, in addition to causing mutations in human cells and potentiating the action of another mutagen (198). DNA replication fidelity may be diminished by the actions of various chemicals, agents or conditions on nucleotide pool sizes and content, either directly by altering nucleotides in the pools available, or by altering the cellular mechanisms responsible for regulating the pools (208, 121). In addition, some metal complexes (e.g. organic tin compounds) can alter or inhibit RNA polymerase, the enzyme that transcribes DNA, and without which the genetic information would have no means of expression (208, 225).

It seems as though any damage that persists depends on the balance of numerous (and possibly saturable) interacting systems and processes (e.g. activation, deactivation, damage, replication and repair) that are multi-level and internal to the organism, as well as extending outside to the environment (90, 114, 137, 199, 206, 208, 213, 232, 278, 285, 289). This complex of relationships is important, since the integration or averaging of a large number of varied kinds of fluctuating factors inherently involves an element of probability in the outcomes observed at the individual and population levels (16, 126). This element of chance may be part of the reason why individual cases of genetic related diseases, such as cancer, appear as random events (96).

Unrepaired or misrepaired lesions, even single, simple ones, in a single molecule of DNA may be amplified many times as the DNA is transcribed and translated. Ultimately, even the simplest error can be transmitted to countless numbers of daughter cells. The mutational origin of cancer, the necessary, and critical first step in the multistage process leading to tumour formation, is all but proven (91, 118, 85, 82, 117, 97, 151, 47, 138, 139, 115, 113, 2, 126, 137, 208, 232, 245, 246, 250, 285, 289). It is reported that even a single error can start the process (13, 208). Somatic mutations are also likely involved in other stages of cancer induction, progression and metastases (208, 92, 232, 245, 246).

Various agents and processes appear to induce tumor formation without causing DNA damage or mutations directly. Organochlorine pesticides (e.g. DDT) are highly lipid (fat) soluble, and the accumulation of these compounds in the lipid layer of cell membranes could inhibit intercellular communications, thus providing a cancer promoting mechanism (222, 245): lessened contact-mediated communication is one general characteristic of tumor cell populations (92). Significant correlations between indices of lipid solubility, and carcinogenicity in rats were found for a series of PAH and benzidine compounds (145, 62).

There is substantial evidence linking dietary fat and cancer (e.g. breast and large intestine), probably acting mainly at the promotional stage (99). Dietary fat is correlated with bile acids in the gut, which are in turn correlated with colon tumors (99, 318), however, bile acid is reported not to be a carcinogen (318). The liver excretes chemicals and/or metabolites in

bile, and some organic chemicals induce bile production by the liver (318, 260). Depending on lipid solubility some excreted chemicals may cycle from gut to liver (318). Some chemicals are also accumulated and secreted in breast milk (318). Dietary fat (plant and animal lipids) is a main pathway by which chemical contaminants are concentrated and passed up the food chain. This review found no studies that considered the role of fat soluble and other exogenous carcinogens in the diet, in relationship to cancer (55).

PCBs and 2,3,7,8-TCDD are highly fat soluble, and considered to be cancer promoters, possibly acting in multiple ways: (1) by inhibiting cell to cell communications; (2) by enhancing the production and buildup of reactive metabolites through their enzyme induction properties; and (3) by supressing the immune system (95, 98). Michigan farmers with silos coated on the interior with a sealant containing PCB reported cancer frequency rates that were four times higher than those reported by a sample of Iowa farmers, and eleven times higher than the rate predicted by the national Surveillance, Epidemiology, and End Results Program (SEER) cancer morbidity rates (102). Exposure to phenoxy herbicides, especially 2,4-D, was found to be associated with higher risks (as much as 6 to 8 times) of non-Hodgkin's lymphoma in Kansas farmers (233). Chlorinated phenol compounds can contain ppm levels of dioxins and furans as microcontaminants (184), and if 2,4-D is made by the same company using the same equipment that was used for the production of 2,4,5-T, then it can also be contaminated with 2,3,7,8-TCDD (251).

The detailed mechanisms by which initiated cells with altered genetic information result in cancer appear to be the least understood aspect of carcinogenesis. While chemicals, other toxic agents, and their further mutational, chromosomal, cytotoxic, and immune system effects, can be involved in the promotion and progression of initiated cells to cancer, it must be noted that other agents and processes besides chemicals can be involved (e.g. hormone-induced tumors) (208,232,309).

Mutational forces that do not initiate and drive the cancer process nonetheless introduce a random error generating process (which may or may not be expressed) into the very blueprint of the organism and species. Accurate reproduction of cells, whole organisms, or species necessarily requires accurate reproduction of the coded information under which they operate. While the human species has endured through thousands of generations with the presence of numerous natural sources of mutagenic potential, industrial, chemical, and technological expansion has markedly increased the mobility and scale of man-made chemicals freely circulating in the environment - many with potent mutagenic activity (126,64). Defense and repair mechanisms exist, however, it is reasonable to assume their balance and stability properties coevolved with the spectrum, frequency, and biophysical origin of mutagen exposures that existed over their period of development. Since all mechanisms have operational limits, it is possible that new types of exposure accompanying the growth in chemical use have increased the amount of damage in the human population of the industrial-chemical age, and that it has also increased the load of genetic disease transmitted from generation to generation (64, 126, 232).

It is necessary to consider the hypothesis that 'natural' toxins in the human diet far outweigh in impact the combined carcinogenic (mutagenic) effects of all man-made chemicals (303). It is reported that many organic chemicals found in plants or vegetables and coffee, are natural mutagens and carcinogens, and the human dietary intake of these chemicals is postulated to be at least 10,000 times higher than the dietary intake of man-made pesticides (2,301,303). The use of this number alone ignores that this very same diet also contains many natural antimutagens and anticarcinogens to balance the toxic chemicals. It is important to note that reference to the amount of carcinogen alone also ignores potency, which can vary by more than 50 millionfold (301,116,2). There are also substantial variations (more than a billionfold (2)) in the levels of particular carcinogens to which humans are exposed (208), unknown variations in individual sensitivity (208), and unexplained variations in human body burdens of certain chemicals (Table 4). Placed in the context of this amount of variation and compensation, the 10,000 times is less significant. It is also worth noting that human exposure to man-made chemicals is probably continuous throughout all life-stages.

Of utmost importance is the oxygen radical mechanism of toxicity suggested for the 'natural' toxics (2). It is reported (278) that mammallian cells have a number of mechanisms to defend against oxygen radical attack, a fact not unexpected given the need over evolutionary time for life to cope with leaving the water to live on land. That oxidative deterioration of cell membranes (lipid peroxidation) does not occur to any significant extent in normal circumstances, attests to the effectiveness of these defenses (278).

On the other hand, xenobiotic chemicals could enhance oxygen radical attacks in the cell by either increasing free radical generation (e.g. redox cyclers) or decreasing the capacity of the cell to defend itself (278). Furthermore, some xenobiotic-derived radicals cannot be inactivated as efficiently as the oxygen-based radicals, and may escape removal because some of the defenses are designed to deal only with oxygen species (278). Others may escape because of their site of generation (278). The possibility exists that in certain circumstances, such as the presence of certain xenobiotics, the cell defenses may be decreased or even completely overwhelmed, allowing a general mechanism of toxicity with a number of possible effects (278).

There are some 2000 to 3000 genetic diseases, divided into three main categories. The best defined category in terms of incidence consists of chromosomal mutations, such as Down's syndrome or mongolism, Klinefelter's syndrome, and Turner's syndrome, and virtually all of which are constituted by new mutations which have arisen in the germ cells of either the father or the mother. There are also about 1000 dominant gene mutations, including hereditary cancers, and over 1000 known genetic disorders which have the heritable properties of recessive gene mutations, including cystic fibrosis, and sickle cell anemia. Of these latter two categories, no estimates are available concerning what proportion is due to new mutations as opposed to mutations which occurred in past generations (64, 207, 126, 65).

There is evidence indicating that environmental mutagens can have multiple deleterious effects on human health, through induction of somatic mutations (289, 92). Among these numerous disorders, the most important in terms of incidence in industrial countries is atherosclerosis (causing almost one half of all deaths). Circumstantial evidence suggests that the fibrous plaques that are the critical lesions in the disease are small "benign" tumors of smooth muscle cells induced by localized mutagenesis (92). That is, the deposits or plaques may be caused by the same kind of genetic mutations that cause cancer tumors. Direct evidence supporting this theory is provided by the finding that genetic material extracted from plaques can produce cancer-like changes in cultured mouse cells, and tumors in mice (167).

The thrombogenic plaques that cause death are rich in cholesterol and other associated lipids, and can contain complex mixtures of trace chemical substances including lipid soluble, toxic man-made compounds. The accumulation of such pollutants in the plaques of two heart attack victims was shown to include at least eight chemical classes, including PAH, organochlorine pesticides, and halogenated organics. Specific toxic industrial compounds characterized include; napthalene, methylated napthalenes, biphenyl, acenaphthene, fluorine, anthracene, phenanthrene, pyrene, phthalate plasticizers, p,p'-DDE, p,p'-DDT, trichlorobenzene, and hexachlorobenzene (61). The toxic properties, including mutagenic potential, of some of these compounds are well understood.

The cumulative burden of tissue lesions clonally derived from mutated somatic cells could contribute substantially to that collection of degenerative conditions usually associated with "aging" (2, 92, 126, 64, 304). The accumulation of metaplasias (transformation of tissue from one differentiated type to another) of the gastrointestinal tract as life progresses can be readily accounted for by somatic mutation (92). Metaplasias are linked as predisposing lesions to gallstones, duedonal ulcers, and adenocarcinoma. These processes, together with a number of other common disorders believed to have a genetic component, (e.g. diabetes, epilepsy, schizophrenia, senile cataracts, essential hypertension, heart disease, mental retardation, and early senility) may be caused in part by chemical mutagenesis and metals toxicity (64, 207, 115, 113, 2, 107, 126, 65, 92, 304). It seems, in conclusion, that while chronological age, and physical processes associated with "aging" are related, they are not necessarily the same thing (2,293,304).

Other interactions by toxic chemicals that inhibit or induce enzyme systems, possibly continously and indefinitely (272), can lead to possible disease processes, and/or accelerations of disease processes, and other undesirable results (200,201). Certain heavy-metal toxins, such as lead, cadmium, and mercury, inhibit the most vital defense systems of enzyme activities that have anticarcinogenic properties. (2,208,278). Other examples of toxic effects include: disturbance of anticoagulant control and osteomalacia (200); chemical porphyria (liver disease) (200,201,276); effects on lipid metabolism (76), and hormone metabolism with possible immune function alteration (76,213,20); estrogenic effects (76), and alterations in the carcinogenic and other potencies of other compounds, possibly involving an acceleration in the production of reactive metabolites and their buildup (76,278).

A number of the contaminants of concern in the Great Lakes ecosystem entail enzyme induction activities - e.g. 2, 3, 7, 8,-TCDD, and structurally related dioxins, furans, co-planar PCBs, other compounds and/or their degradation products (201, 76, 186, 321). PCBs and PAH have been shown to cause supression of the immune system (95,213,250). In the Lake Michigan fish-eating mothers studies, the highly exposed group showed increased susceptibility to infectious disease, particularly those of bacterial origin (235,236). Long-term (median, 2 years) human exposure to 2,3,7,8-TCDD is associated with depressed cell-mediated immunity in one study (98). In one other study, the insecticide aldicarb (trade name, Temik) is associated with altered immune function in humans (63). In mice, aldicarb suppressed the immune system at levels as low as 1 ppb (ug/kg), a level that occurs in human drinking water in certain locations (305).

Environmental agents that alter (e.g. suppress or enhance) the immune system can impede the body's ability to fight infection, maintain homeostasis, detect cancer cells (which promotes cancer), and protect against other stresses (232, 305). Such effects may also be involved in the induction of numerous forms of auto-immune disorders, such as allergies, arthritis, diabetes, and varied forms of hypersensitivity reactions (e.g. cell mediated attacks on myelin that may lead to multiple sclerosis) (232).

A substantial number of synthetic industrial and pesticide compounds are highly lipid soluble and therefore accumulate in lipophilic tissues. The nervous system is a lipophilic reservoir and an accumulation of these chemicals could result in neurotoxicity (39,25,102,232). The reversible (and possibly irreversible for some PCBs (235)) binding of such compounds to lipophilic sites in the cells of lipid-rich structures (e.g. the myelin sheath that protects the nerve fibres of the brain and spinal cord) can interfere with several cellular processes. Reactive metabolites covalently bound to cellular structures can slightly change the molecular structure (e.g. making the membrane less selectively permeable), causing long-term damage (61).

These toxic mechanisms are analogs to both the viral and molecular mimicry or "synthetic molecule" theories of multiple sclerosis. There are a number of mechanisms (in addition to the hypersensitivity reaction noted above) and toxic chemicals (e.g. hexachlorophene, triethyltin, and lead) that can involve pathological changes in myelin or myelin producing cells (232,308)

Other, more subtle effects on the central nervous system; for example the gradual deterioration of intelligence, memory, and other complex functions, may be results of cumulative genetic damage, and/or other forms of chemical neurotoxicity (126, 39, 102, 232). Methylated compounds of mercury, lead, or arsenic, readily enter brain tissue and produce irreversible degeneration of neurons (232). The salts of aluminum, lead, and arsenic, among other inorganic compounds, can produce permanent neurobehavioural deficits (232). Aluminum binds to DNA and proteins, thus initiating a possible pathway for brain cell protein changes (129, 252). It is coincidental that brain cell protein changes appear to be implicated in a

number of human disorders, like presenile and senile dementia of the Alzheimer's type, however, while aluminum is neurotoxic, it is not known whether aluminum is causally related to Alzheimer's Disease (129, 252). Aluminum containing compounds are added to drinking water at the treatment facility, and to foods such as processed cheese, pickling salts and pickled vegetables, cake mixes, self-rising flour, frozen dough and baking powders, as well as a variety of non-prescription drugs (306). It is estimated that Alzheimer's disease presently attacks about 7% of the U.S. population older than 65 (31).

A very high correlation (0.967) between pesticide use and the incidence of Parkinson's disease was found in Quebec (127). This highest rural incidence occurred in the high pesticide use "breadbasket" areas, southwest of Montreal. In Montreal itself, there were higher rates in the industrialized east end. Further supporting the link, 67 percent of the study's patients have a deficiency in the enzymes (P-450 monooxygenases) responsible for detoxifying the suspect chemicals, compared to 18 percent in the study's normal population (127).

Reportedly, the disease was unknown before the industrial era, however, no reliable estimate of overall incidence was found. Pesticides are just one class of potential chemical or environmental neurotoxins whose structures and properties resemble compounds known to be involved in the etiology of the disease. More generally, there are more than 850 chemicals identified as known neurotoxins in humans and animals. Most pesticides (e.g. DDT, other organochlorines, chlordecone, synthetic pyrethroids) exhibit some neurotoxic effects, and are largely responsible for about 375,000 such human poisonings each year worldwide (232). The mechanisms of action of the neurotoxins pyrethroids and DDT are elucidated as modifications (prolonged opening) of the nerve membrane sodium ion channels (307). The toxicological amplification from channel to animal is substantial as pyrethroid modification of less than 1% of the flux through the channel is sufficient for symptomatic poisoning (307).

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