HEALTH OF OUR OCEANS

A Status Report on Canadian Marine Environmental Quality

Environment Canada Conservation and Protection
Environnement Canada Conservation et Protection

Canada

Health of Our Oceans

A Status Report on Canadian Marine Environmental Quality

Edited by
Peter G. Wells
and
Susan J. Rolston

A Project of the Marine Environmental Quality Advisory Group
Conservation and Protection, Environment Canada

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Senior Advisor
Marine Environmental Quality
Conservation and Protection
Environment Canada
Atlantic Region
15th Floor, Queen Square
45 Alderney Drive
Dartmouth, Nova Scotia
B2Y 2N6

or

Chief
Marine Environment Division
Federal Programs Branch
Environmental Protection
Conservation and Protection
Environment Canada
Ottawa, Ontario
K1A 0H3

"It is a curious situation that the sea, from which life first arose, should now be threatened by the activities of one form of that life. But the sea, though changed in a sinister way, will continue to exist; the threat is rather to life itself."

Rachel Carson

From *The Sea Around Us*
Oxford University Press, 3rd edition 1961

Dedication

This report is dedicated to the memory of Mr. Bill Brakel, Conservation and Protection, Edmonton, friend and colleague, and a member of the MEQ Advisory Group of Conservation and Protection. Bill was a keen supporter and worker on behalf of the marine environmental quality issue and the health of Arctic seas.

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Preface

This Status Report on Canadian Marine Environmental Quality is a project of the MEQ Advisory Group of Conservation and Protection, Environment Canada. It is the last of three projects assigned to the Group by the Assistant Deputy-Minister, Conservation and Protection, in 1985. The other projects were the first Canadian Conference on Marine Environmental Quality held in Halifax in 1988 (Proceedings published in 1988) and the Five-Year Conservation and Protection MEQ Action Plan approved in 1989. All three projects are intended to bring a new focus and direction to Environment Canada's marine environmental quality programs, and to achieve a higher government and public profile for marine environmental quality issues in Canada. This report was considered an essential step in comprehensively understanding the topic and in identifying priorities for action.

The report has evolved conceptually during preparation and has contributed to papers, talks and other reports on the state of Canada's seas. The report largely takes a contaminants and pollution approach. It in no way presupposes that Marine Environmental Quality can only or should only be evaluated in this manner. Quite the opposite, other assessments from biogeochemical, oceanographic, ecological and fisheries habitat viewpoints should be conducted. Ultimately, it would be invaluable to achieve a synthesis of the topic from the different disciplinary vantages. Perhaps this should be the aim of a future edition.

The MEQ Advisory Group welcomes comments from readers; indeed we would be disappointed not to receive your views and particularly new information on any aspect of the quality of our marine waters. Please let us know if the report has been useful, and how we collectively can "keep a hand on the pulse of the sea," and sustain it for the future.

P.G. Wells
Chairman
Marine Environmental Quality Advisory Group

Contributors

Chapter One

P.G. Wells, Environment Canada, Dartmouth, N.S.

Chapter Two

J. Karau, Environment Canada, Ottawa/Hull
C. Kriz, Environment Canada, Ottawa/Hull
S. Rolston, Seawinds Consulting Services, Hackett's Cove, N.S.

Chapter Three

L. Harding, Environment Canada, Vancouver

Chapter Four

E. Porter, Environment Canada, Yellowknife, N.W.T.
G. Packman, Department of Fisheries and Oceans, Ottawa
R. Shearer, Indian Affairs and Northern Development, Ottawa
T. Sackmann, formerly Environment Canada, Yellowknife, N.W.T.

Chapter Five

P.G. Wells, Environment Canada, Dartmouth, N.S.
W. Barchard, Environment Canada, Dartmouth, N.S.
M. Chevalier, Environment Canada, Montreal, P.Q.
L. Hildebrand, Environment Canada, Dartmouth, N.S.
T. McRae, Environment Canada, Ottawa
B. Moores, Environment Canada, St. John's, Nfld
M. Richardson, Health and Welfare Canada, Ottawa

Chapter Six

P.G. Wells, Environment Canada, Dartmouth, N.S.

Glossary

S. Rolston, Seawinds Consulting Services, Hackett's Cove, N.S.

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W. Barchard (Environment Canada)
J.M. Bewers (Department of Fisheries and Oceans)
R. Bisson (Environment Canada)
R. O. Brinkhurst (Department of Fisheries and Oceans)
R.G.G. Brown (Environment Canada)
R. P. Côté (Dalhousie University)
P. Eaton (Environment Canada)
A. d'Entremont (Environment Canada)
C. Garrett (Environment Canada)
A. J. Gaston (Environment Canada)
D. Goyette (Environment Canada)
G.C. H. Harding (Department of Fisheries and Oceans)
J. Karau (Environment Canada)
B. Kay (Environment Canada)
C. Kriz (Environment Canada)
P. Laramée (Environment Canada)
A. Mc Iver (Environment Canada)
T. McRae (Environment Canada)
H. Nelson (Environment Canada)
M. Pomeroy (Environment Canada)
J.F. Uthe (Department of Fisheries and Oceans)
M. Waldichuk (Department of Fisheries and Oceans)
R.C.H. Wilson (Department of Fisheries and Oceans)
V. Zitko (Department of Fisheries and Oceans)

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Members of Marine Environmental Quality Advisory Group January 1991

Dr. Robert Bissón
Conservation and Protection
National Water Research Laboratory
Environment Canada
P.O. Box 5050
Burlington, Ontario L7R 4A6

Dr. Hugh Boyd
Wildlife Toxicology and Surveys Branch
National Wildlife Research Centre
Canadian Wildlife Service
100 Gamelin Blvd
Hull, P.Q. K1A 0H3

Mr. Bill Brakel
Economic Advisor, Conservation and Protection
Environment Canada
Twin Atria No. 2, 2nd Floor
4999 - 98 Avenue
Edmonton, Alberta T6B 2X3

Dr. R.G.B. Brown
Seabird Research Unit
Canadian Wildlife Service
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

Dr. A.R. Davis
Director, Water Quality Branch
Inland Waters Directorate
Conservation and Protection
Environment Canada
Ottawa, Ontario K1A 1C8

Mr. Alan McIver
EP, Conservation and Protection
Environment Canada
15th Floor, Queen Square
45 Alderney Drive
Dartmouth, N.S. B2Y 2N6

Mr. Merv Fingas
Environmental Protection Directorate
River Road Environmental Technology Centre
Environment Canada
Ottawa, Ontario K1A 0H3

Mr. John Gray
Communications, Conservation and Protection
Environment Canada
45 Alderney Drive
Dartmouth, Nova Scotia B2Y 2N6

Dr. Tony Gaston
Wildlife Toxicology and Surveys Branch
National Wildlife Research Centre
Canadian Wildlife Service
100 Gamelin Blvd
Hull, P.Q. K1A 0H3

Mr. Lee Harding
Manager, Marine and Estuarine Programs
Environmental Protection
Environment Canada
224 West Esplanade
North Vancouver, B.C. V7M 3H7

Mr. E. Hiscock
Seabird Research Unit
Canadian Wildlife Service
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

Mr. Geoff Howell
IW/L, Conservation and Protection
Environment Canada
15th Floor, Queen Square
45 Alderney Drive
Dartmouth, N.S. B2Y 2N6

Mr. John Karau
Vice-Chairman, MEQ Advisory Group
Marine Environment Division,
Federal Programs Branch
Conservation and Protection
Environment Canada
Ottawa, Ontario K1A 1C8

Mr. Paul Laramée
Conservation and Protection
Environment Canada
2nd Floor, 1179 Bleury Street
Montreal, P.Q. H3B 3H9

Ms. Karen Lloyd
Wildlife Toxicology and Surveys Branch
National Wildlife Research Centre
Canadian Wildlife Service
100 Gamelin Road
Hull, P.Q. K1A 0H3

Mr. L. Martel
Chief, Federal Programs Division
Conservation and Protection
Environment Canada
2nd Floor, 1179 Bleury Street
Montreal, P.Q. H3B 3H9

Mr. Dan McGirr
Water Quality Branch
Inland Waters Directorate
Conservation and Protection
Environment Canada
Ottawa, Ontario K1A 1C8

Mr. Terry McRae
SOE Branch
Environment Canada
10th Floor, Place Vincent Massey
Ottawa, Ontario K1A 1C8

Mr. Bruce Moores
Environmental Protection
Environment Canada
Newfoundland District Office
P.O. Box 5037
St. John's, Nfld 1C 5V3

Ms. J. Pagnan
Canadian Wildlife Service
Environment Canada
Ottawa, Ontario K1A 0H3

Mr. Ed Porter
Environmental Protection
Environment Canada
Northwest Territories District Office
9th Floor, Bellanca Bldg
P.O. Box 370
Yellowknife, NWT X1A 2N3

Mr. Peter Rodgers
Sustainable Development Branch
Canadian Wildlife Service
Environment Canada
Ottawa, Ontario K1A 1C8

Ms. Michele Taylor
Program Integration Division
Regulatory Affairs and Program Integration Branch
Environmental Protection
Environment Canada
Ottawa, Ontario K1A 1C8

Mr. Paul Wagner
Communications Directorate
Corporate Planning Group
Environment Canada
Ottawa, Ontario K1A 1C8

Dr. P.G. Wells
Chairman, MEQ Advisory Group
Conservation and Protection
Environmental Protection
15th Floor, Queen Square
45 Alderney Drive
Dartmouth, N.S. B2Y 2N6

Acronyms

AWPPA	Arctic Waters Pollution Prevention Act
BIOS	Baffin Island Oil Spill Project
CCEM	Canadian Council of Environment Ministers
CEPA	Canadian Environmental Protection Act
CIDA	Canadian International Development Agency
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
C & P	Conservation and Protection, Environment Canada
CWS	Canadian Wildlife Service
DEW	Distant Early Warning radar system
DFO	Department of Fisheries and Oceans
DIAND	Department of Indian Affairs and Northern Development
DOE	Environment Canada
EEZ	Exclusive Economic Zone
EPS	Environmental Protection Service, Environment Canada
FEARO	Federal Environmental Assessment Review Office
G-7	Group of Seven (OECD leaders)
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Pollution
ICOD	International Centre for Ocean Development
IMO	International Maritime Organization
IUCN	International Union for the Conservation of Nature and Natural Resources
IWD	Inland Waters Directorate, Environment Canada
LBSMP	Land-based Sources of Marine Pollution
MEQ	Marine Environmental Quality
NOGAP	Northern Oil and Gas Action Plan
NRC	National Research Council (U.S.)
NRCC	National Research Council of Canada
ODCA	Ocean Dumping Control Act
OECD	Organization for Economic Cooperation and Development
RODAC	Regional Ocean Dumping Advisory Committee
SOE	State of the Environment
SYSCO	Sydney Steel Corporation, Sydney, Nova Scotia
U.S. EPA	United States Environmental Protection Agency
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
VECs	Valued Ecosystem Components
WCS	World Conservation Strategy

Units of Measurement

CFU	Colony Forming Unit
CPU	Colony Producing Unit
cm	centimetre
d	day
g	gram
ha	hectare
kg	kilogram
km	kilometre
l or L	litre
LC50	Median Lethal Concentration
m	metre
mg	milligram
ml	millilitre
mmt/a	million metric tonnes per annum
ng	nanogram
ppt	parts per trillion
ppb	parts per billion
ppm	parts per million
μg	microgram

Scientific Abbreviations

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin (dioxin)
B[a]P	Benzo[a]pyrene
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CP	Chlorophenates
DDD	Dichlorodiphenyldichloroethane (pesticide residue)
DDE	Dichlorodiphenyldichloroethylene (pesticide residue)
DDT	Dichlorodiphenyltrichloroethane (pesticide)
DO	Dissolved Oxygen
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
MFO	Mixed Function Oxygenase (an enzyme system)
OCs	Organochlorines
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCP	Pentachlorophenol
TBTO	Tributyl Tin Oxide (organotin)
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TTCP	Tetrachlorophenol

Executive Summary

The report evaluates the national and international dimensions of the MEQ Issue (Chapter Two), and provides an assessment of MEQ from a national perspective (Chapter Six). Highlights are given below from the Pacific, Arctic and Atlantic chapters (Chapters Three to Five).

Marine Environmental Quality on the Pacific Coast

Sources of pollutants in the West Coast marine environment are ocean dumping of dredged materials, municipal effluents, mine tailings, pulp and paper mill discharges, and spills and related environmental accidents. Contaminants of concern include heavy metals, PCBs, chlorophenates, PAHs, organotins, dioxins and furans, and other organics. Geographic areas of concern are the Fraser River Estuary, False Creek, Vancouver Harbour, the Victoria area, Howe Sound, Kitimat Arm, Rupert Inlet, Alice Arm, Neroutsos Inlet, Alberni Inlet, Prince Rupert Harbour, Porpoise Harbour, Muchalat Inlet, Cowichan Bay, Stuart Channel, Northumberland Channel, Malaspina Strait, and Discovery Passage.

Signs of widespread ecosystem stress have been detected and degradation is pronounced in many inshore waters along the coast.

Adverse effects include loss of fish habitat, toxicity, bioaccumulation of toxic chemicals in fish, and shellfish harvesting closures. More widespread, but very low levels of chlorinated organic chemicals also occur in migratory seabirds and marine mammals.

Two kinds of areas are closed to fisheries due to contamination. Shellfish growing areas are closed due to bacteria, and waters near pulp mills are closed for harvest of certain species due to dioxins.

On the positive side, installation of a deep outfall off Sturgeon Bank for effluent from the Iona Island sewage treatment plant has reduced bacterial contamination of beaches. Victoria is consolidating its numerous shoreline sewage outfalls into one, and is planning for treatment. Installation of clarifiers and in-plant controls at coastal pulp mills has resulted in major reductions in severe water quality degradation. Installation of diffusers and long outfalls at most pulp mills has allowed recovery of shoreline biological communities. Most mills are installing secondary treatment facilities and removing dioxins in advance of new federal and provincial regulations.

The shortage of long-term, trend monitoring programs precludes establishing many trends in marine environmental quality. Indices of MEQ are scarce. Overall, the quality of the Pacific coastal marine environment has been assessed descriptively in this report. Nevertheless, many threats and their effects are clearly shown.

Marine Environmental Quality on the Arctic Coast

Site-specific industrial effluent discharges have resulted in elevated concentrations of metals, PAHs and other hydrocarbons in Arctic sediments and biota. Sewage effluents from coastal communities may be linked to bacterial contamination of native foods and increased incidences of enteric disease. The long-term effect of abandoned base metal mines on local Arctic marine ecosystems requires further study. Finally, studies now are linking long-range transport of air- and water-borne pollutants to the elevated levels of organochlorines being found widely in marine mammal tissues and their food chains.

Concerns remain focused on the continuing input of hydrocarbons and related petroleum-industry chemicals to offshore and nearshore areas, particularly those subject to chronic spills. Future concerns include the effects of oil-based drilling mud discharges and the risk of major spills during hydrocarbon exploration or production in the Beaufort Sea, the Arctic Islands, and Lancaster Sound. Alternative waste disposal practices must be explored in anticipation of the need to manage large quantities of inert wastes.

To date, Arctic marine environmental quality guidelines and objectives for selected geographic areas and substances have not been formulated, nor has a formal comprehensive and coordinated monitoring system been established. Consequently, existing baseline data have generally been restricted to site-specific information on individual marine components. Existing monitoring programs need to be expanded to provide time-series data on metal, organochlorine and hydrocarbon levels near sources of contamination, and at distant stations. As well, continuous, area-wide information on changes in critical MEQ parameters are needed.

Marine Environmental Quality on the Atlantic Coast

There has been much effort over several decades to ameliorate use conflicts, especially impacts of industrialization and coastal development. There have been successes in water pollution control, toxic chemicals management, habitat protection and wildlife conservation. These have collectively slowed marine environmental decline and losses. However, water, sediments and biota are contaminated in many areas; natural habitats and wildlife are diminishing; fish stocks are seriously depleted; and threats to human health sometimes occur. The quality of the coast is clearly threatened by a number of stresses.

There is a wide range of contamination and pollution sources. Many municipal effluents are not treated. Pulp and paper effluents, although often improved in quality since the early 1970s, still disrupt fish habitat and contaminate biota, and are a focus of much attention. Refineries are generally in compliance for regulated substances, and chlor-alkali plants have controlled their mercury discharges. The Sydney "tar pond" led to massive harbour contamination, and is now being cleaned up. Ocean dumping, primarily of harbour sediments, is regulated but local problems sometimes occur from contaminants and fish offal. Mining and associated industries cause loss of intertidal habitat. Coal production industries have caused contamination, and the closure of fisheries. The smelter at Belledune, N.B., has improved effluent quality, but mining industries upstream in other areas have contaminated estuarine sediments.

Riverine inputs of contaminants can be substantial but the impacts are often poorly understood. Spills of oil and hazardous chemicals occur periodically. There are many non-point sources of pollution; agricultural run-off affects some shellfish growing areas. Atmospheric transport may contribute significantly to contaminant input into the Atlantic offshore, and locally into some estuaries. Effects of urban runoff are largely unassessed.

Many anthropogenic substances have been detected in waters, sediments and biota and some trends are apparent. Mercury has decreased in some industrial emissions (pulp and paper mills, chlor-alkali plants) but is in substantial amounts in sewage and is found in many harbour sediments. A range of heavy metals are found in sediments and biota.

Organochlorines are widespread along the Atlantic coast. PCBs are commonly found in harbour sediments, and often in fish and mammals. Levels of dissolved hydrocarbons and floating tar in surface waters are generally low or undetectable. However, frequent coastal oiling on the south coast of Newfoundland is a major wildlife concern. PAHs from industry, wharves, urban runoff and oil spills are found in sediments and biota in a number of locations, and have led to fisheries closures. Creosoted materials contaminate most harbours. Benzo[a]pyrene is present throughout the Saguenay Fjord and its metabolites and other chemicals contaminate the belugas. Some organotins (butyltins and methytins) are frequently found in harbour sediments throughout the Atlantic Provinces.

Persistent plastics, litter, and lost fishing gear are growing problems, fouling shorelines and killing fish and wildlife at sea. Natural toxins are also prominent contaminants in local coastal waters.

Coastal development and physical changes are widespread, and increasing in extent and number. Dams, wharves, dikes, causeways and tidal power projects individually or collectively have influenced the quality of many estuaries and nearshore waters. Physical impacts of commercial fishing on bottom habitats and organisms are now being investigated.

Knowledge of the fate and effects of contaminants in biota provides a sensitive measure of MEQ along the Atlantic coast. Commercially valuable shellfish, crustaceans and fish contain a wide range of contaminants, but evidence of trends in levels in limited. PAHs are bioaccumulated in mussels in the St. Lawrence Estuary, and in lobsters in Sydney Harbour, reflecting industrial activity. Many organochlorines are found in fish, and may be causing effects in some species. No formal systematic monitoring program is yet in place for these biota.

However, contaminant effects on seabirds are a proven sensitive indicator of MEQ. Seabirds provide some of the best available trend information to date. The St. Lawrence Estuary and Gulf rank most contaminated at all sites along the Atlantic coast. Gannets in the north-western Gulf have shown declines in several chemicals, and populations have recovered from DDT effects. Oil pollution continues as a major threat to seabirds, especially in offshore waters and at spills.

Contaminant levels in mammals are well documented for seals, porpoise and whales, but with the exception of seals, rarely permit trend analysis. Contaminant levels in harbour porpoises in the Bay of Fundy are high, as are levels in the St. Lawrence belugas. Such contamination may be a major signal of declining environmental quality.

Geographic concerns along the Atlantic coast include harbours, bays, gulfs and estuaries, whole coastlines and the offshore. Many of these areas continue to be under cumulative chemical and physical pressures. The opportunity exists now for an Atlantic network of estuarine, coastal and offshore programs to reverse some of the disturbing trends in marine environmental quality and to ensure the long-term sustainability of Canada's Atlantic coast.

Chapter One

Introduction

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Canada's Seas

Canada, bounded by three oceans, has one of the longest coastlines in the world (243,797 km, Marsh, 1988). It also has one of the largest exclusive fishing zones, extending up to 320 km from the coast, and encompassing approximately 4.7 million km^2 of ocean. The seas include estuaries, nearshore (coastal), and offshore (open ocean) waters, a wide range of shorelines, and adjacent lands and overlying atmosphere (Figure 1.1).

There are many unique features of the Pacific, Arctic, and Atlantic coastlines and their ecosystems. As described by Environment Canada (1986a),

> the Pacific coast has a narrow continental shelf, less than 50 kilometres wide, and a complex shoreline of rugged mountains, inlets, fjords and islands. The Arctic coast has a lower species diversity than found in warmer waters, but Arctic waters contain many unique features, including the highly productive polynyas. The Atlantic coast has a much wider continental shelf, and includes the Grand Banks. Major current systems and upwellings are found on the shelf and in large estuaries, such as that of the St. Lawrence.

Canada's shorelines encompass both high and low energy zones, and range from marshes and mudflats, long, sandy beaches, to rugged, exposed rocky shores.

Canada's seas are used for fisheries, transportation, energy, recreation, industry, extraction of non-renewable mineral resources, and disposal of wastes. Uses also include the traditional life styles of maritime communities and native peoples, and the continuance of natural ecosystems including diverse and often unique biota and habitats. Uses often conflict, and in combination may lead to unexpected changes in a water body's condition, threatening its long-term use and value to mankind and other organisms. Exploitation of the fisheries resources in Canada's seas is currently worth three to four billion dollars annually to the economy, and coastal transportation routes support our international trade.

Other intrinsic values of our seas, social, cultural, and ecological are inestimable. An unique feature is that the economic and social values of the sea varies from region to region. It supports the traditional way of life and survival of many indigenous peoples across the Arctic and on the West Coast. The social fabric and economies of many communities in Atlantic Canada and southwestern British Columbia are forged with the coasts and their resources.

Canada's Obligations

Canada's obligations for protecting and conserving its seas, and contributing to the global stewardship of the oceans, are reflected by the many agreements, conventions, treaties and guidelines that the country is signatory to, and its long history of marine research, pollution control, and wildlife conservation. Our international responsibilities and national mandate commit us to maintaining the quality of marine waters, sediments, and their biota and ecosystems – in short, to protect, conserve, and sustain the marine commons (Borgese, 1986; WCED, 1987; Wells, 1988; see Chapter Two).

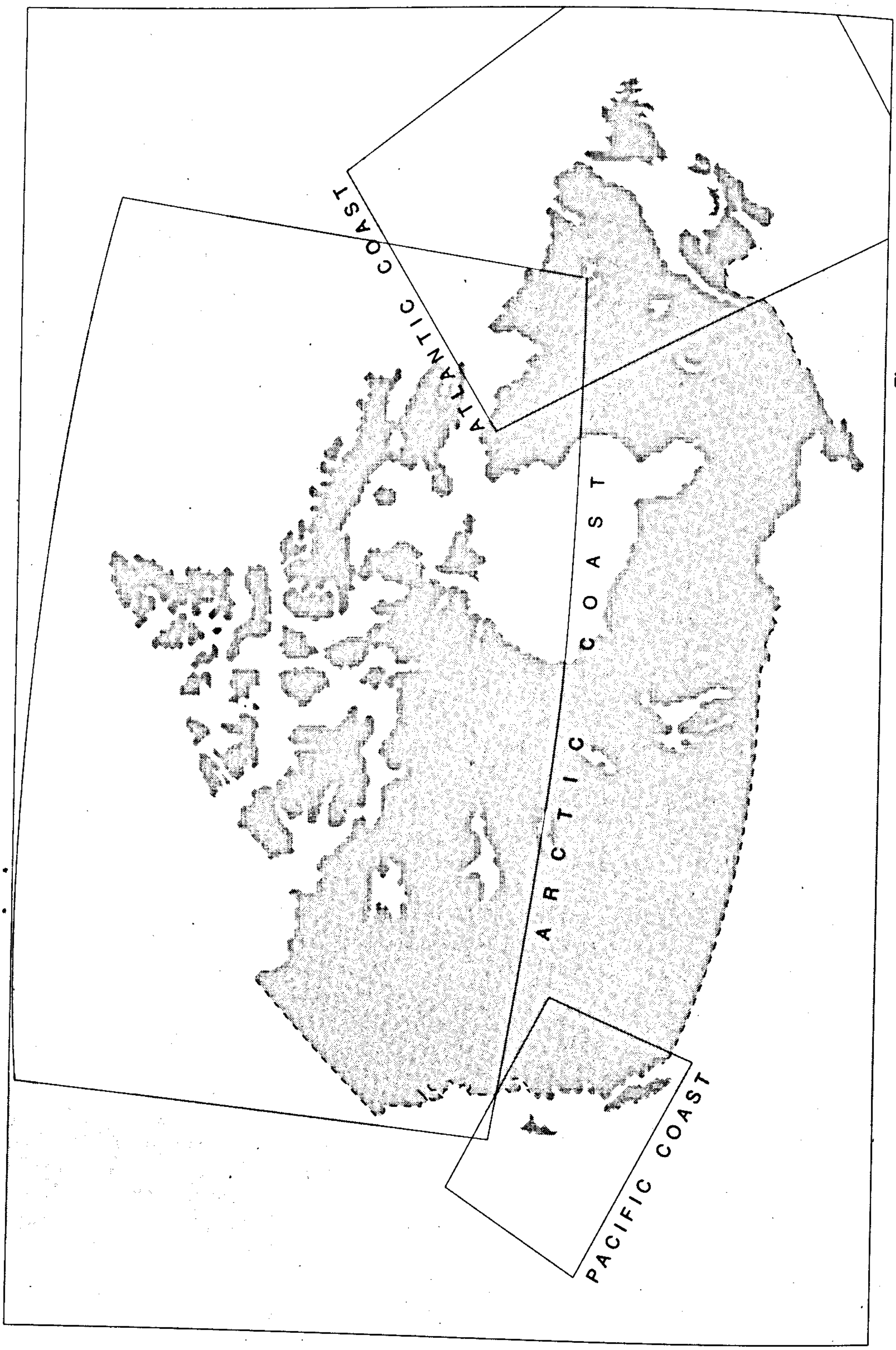


Figure 1.1 Features of the Canadian Coast

Threats and Concerns

The many uses of our seas and their coastlines are threatened or diminished by contaminants, wastes, and disturbance from human activities, particularly pollutants from land-based sources. Over the years, there have been many examples of human illnesses from paralytic shellfish poisoning or other shellfish toxins; of the reduced marketability of fisheries products due to known or suspected contamination; of reduced natural populations of plants, invertebrates, fish and wildlife; and of limitations to other uses such as recreation.

Concerns about marine environmental quality have been voiced for many years in scientific, public, and political fora. Recent concern has been due to the frequent visible and measured effects of pollutants, e.g., the recent *Nestucca* oil spill in British Columbia, fishery closures due to dioxins in fish, high levels of PCBs in whales, and visible sewage in harbours. In addition, there is growing concern about the long-term impacts of cumulative, low-level, continuous discharges toxic chemicals (Howells et al., 1990). Chapters Three to Five describe some of these concerns in detail for the three coasts.

Definitions

It is worthwhile clarifying the terms marine pollution, contamination, and marine environmental quality (also called MEQ), as they are the main topics of this report.

Marine Pollution, as per the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP, 1987), is "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which result in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality of use of sea water and reduction of amenities." The United Nations Convention on the Law of the Sea definition for marine pollution refers to that "... which results in or is likely to result in deleterious effects," hence covering both known and potential impacts of the inputs of substances or energy. In both definitions, pollution involves the occurrence of harmful effects to natural species and communities. This contrasts with **contamination**, which refers to the presence or bioaccumulation of contaminants or toxic chemicals. Marine contamination and pollution are primary threats to marine environmental quality.

Marine Environmental Quality is the condition of a particular marine environment (shoreline, estuary, bay, harbour, nearshore and offshore waters, open ocean) measured in relation to each of its intended uses and functions (Wells et al., 1986; Wells and Côté, 1988). It is usually assessed quantitatively for each environmental compartment, on temporal and spatial scales. It is measured using sensitive indicators of natural condition and change. Such measures are interpreted using objectives and limits set by environmental, health, and resource agencies.

As an environmental issue, MEQ has local, regional, national, and international dimensions. The issue involves a wide range of protection, conservation, habitat, and resource activities. Many agencies and organizations, nationally and internationally, work on MEQ (see Chapter Two).

An acceptable standard of marine environmental quality contributes significantly to the economy, the multiples uses of marine waters, and to the continued existence and functioning of natural habitats, species, populations, and communities. Degraded marine environments may result in limited uses, the reduction in value of fisheries species, and threats to human health and fish habitat and unacceptable aesthetic change.

Crucial to our ability to measure MEQ reliably and detect trends, or other changes, is an understanding of the oceanography of the natural environment, the functioning of specific ecosystems, and of marine toxicology. The combined use of chemical, geochemical, physical, biological, oceanographic, and toxicological criteria, as well as general observations of habitat condition, must be measured systematically over time and space. Figure 1.2 illustrates the sequence, key measures and comparisons essential for an assessment of MEQ.

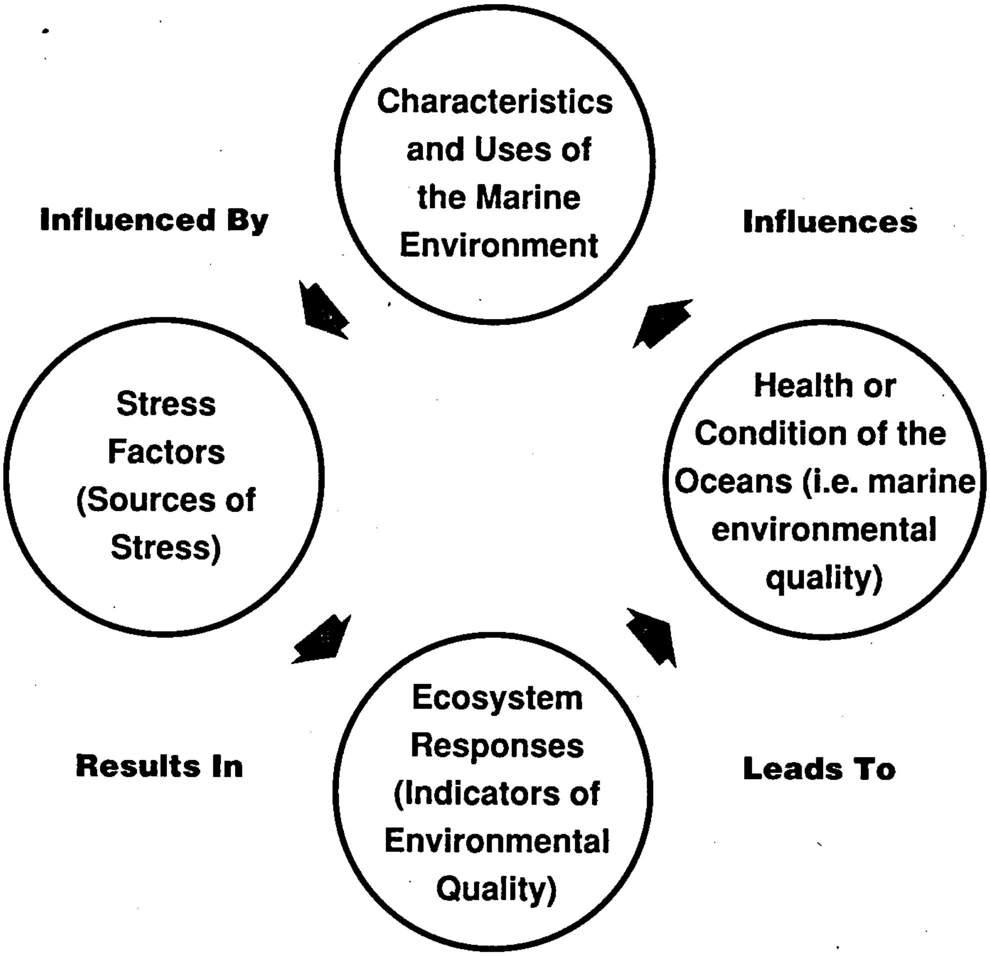
Scope of the Report

Environment Canada's responsibilities for marine environmental quality include evaluating the adequacy of marine environmental research pertaining to Canada, assessing and disseminating information on the states and trends of marine environmental quality, and identifying priorities to ensure effective action on marine environmental issues (Environment Canada, 1987b). A comprehensive synopsis of the Canadian mandate and responsibilities, and of the environmental quality of the three coasts satisfies these goals.

This report consists of three sections. Chapter Two gives a perspective of national and international legislation and obligations. Chapters Three to Five address the quality of Pacific, Arctic, and Atlantic coasts and marine waters, respectively. Chapter Six presents an overview of Canada's marine environmental quality and identifies some next steps. An early summary of the report's main findings was given by Wells et al. (1987).

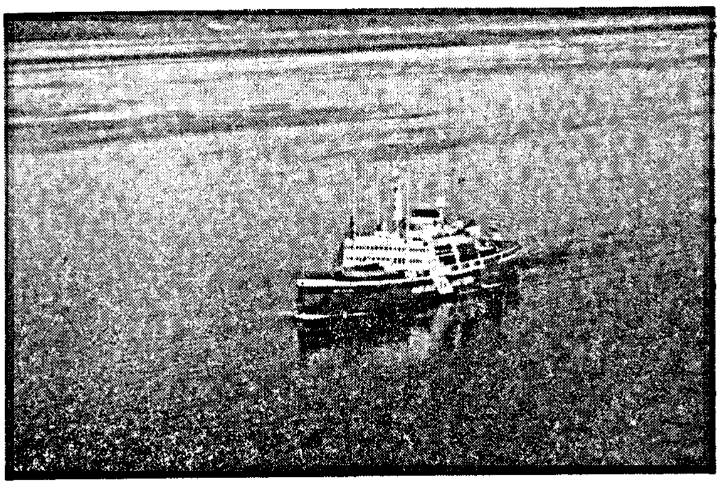
The report focuses on threats to marine environmental quality from toxic chemicals, industrial emissions, and anthropogenic physical changes. This reflects the approach adopted by the contributors, and in no way presupposes that MEQ can only be evaluated in this manner.

Figure 1.2 Guiding framework for assessment of marine environmental quality



Chapter Two

National and International Perspectives



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The health of the oceans can only be protected by the universal efforts of all nations working together. Canada has been an avid protector of this global commons for the past two decades. Internationally, Canada has promoted the preservation and protection of the marine environment by developing and ratifying international treaties, conventions and agreements (Table 2.1), and by collaborating on many international research, training and advisory projects.

The principal sources of marine pollution are direct discharges from land including inputs from major rivers, deposition from the atmosphere, discharges from marine activities, and deliberate disposal of wastes. Relatively few international controls exist although Canada and other countries are actively cooperating in many areas. In all international negotiations, the strength of Canada's influence is underpinned by the credibility of our scientific, engineering, and managerial expertise and demonstrated commitment to the cause of environmental protection and conservation.

National Perspective

The current approach to environmental quality in Canada is sectoral in nature. The constitution does not make specific reference to the environment. As specified in the *British North America Act* and confirmed in the *Constitution Act*, federal jurisdiction concerning the environment includes responsibility for navigation and shipping, protection and management of fisheries and marine mammals, lands reserved to indigenous peoples, and national concerns relating to peace, order, and good government. At least 23 federal legislative acts relate to the marine environment, and are administered by six departments (Table 2.2). In its ruling on the Crown Zellerbach case, the Supreme Court of Canada (1988) confirmed marine pollution as being a federal matter. The Court ruled that the *Ocean Dumping Control Act* (now the *Canadian Environmental Protection Act* (CEPA), Part VI) was valid legislation even within British Columbian coastal waters under provincial jurisdiction.

Provincial jurisdiction applies to lands, wildlife, forests, minerals, inland waters and land covered by inland waters, and to matters of a local or private matter. At least twenty relevant provincial or territorial acts are administered by six of the eight coastal provinces and two territories (Table 2.3). Provincial jurisdiction enables municipal and regional levels of government to establish bylaws. Territorial government jurisdiction also applies to all matters of a local or private nature.

These jurisdictional overlaps, particularly in the nearshore coastal zone area, require cooperation and collaboration between all levels of government. At the federal level, coordination of the 14 primary departments and agencies administering or utilizing the 75 programs relating to the oceans is facilitated through the Interdepartmental Committee on Oceans, chaired by the Deputy Minister of the Department of Fisheries and Oceans (hereinafter referred to as Fisheries and Oceans or DFO). Other mechanisms for coordination exist between other levels of government, industry, and academia such as the new National Marine Council and the Canadian Council of Environment Ministers (CCEM).

Environment Canada and Fisheries and Oceans, along with other federal departments, have primary responsibilities relating to the quality of the marine environment. Fisheries and Oceans has the mandate for coordination of ocean policies and programs (DFO, 1987b). The *Oceans Inventory* documents set out the roles of particular federal departments and agencies in the oceans sector (DFO, 1986a, b, c;

Table 2.1 Examples of Canadian commitments to international conventions and agreements for marine environmental quality

Conventions
Migratory Birds Convention Treaty (1916)
International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL, 1954)
International Convention on Civil Liability for Oil Pollution Damage (CLC Convention, 1969)
International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND Convention, 1971)
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention, 1972)
International Convention for the Prevention of Pollution from Ships, 1973 as modified by its Protocol of 1978 (MARPOL 73/78)
Convention on the Conservation of Wetlands of International Importance (Ramsar Convention, 1981)
Convention on Long Range Transboundary Air Pollution (1981)
United Nations Convention on the Law of the Sea (UNCLOS, 1982)
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989)
International Convention on Oil Pollution Preparedness, Response and Cooperation (1990)

Agreements
Declaration of the United Nations on the Human Environment (Stockholm Declaration) and Action Plan on the Human Environment (1972)
International Polar Bear Management Agreement (1973)
World Conservation Strategy (1981)
Canada-Denmark Marine Environmental Cooperative Agreement (1983)
Canada-USSR Agreement on Scientific and Technical Cooperation in the Arctic and the North (1984)
UNEP "Montreal Guidelines" on Protection of the Marine Environment Against Pollution from Land-based Sources (1985)
Legal Principles for Environmental Protection and Sustainable Development (Brundtland Commission, 1987)

DFO, 1987b). The *Oceans Policy for Canada* commits the federal government to sustainable development with four goals:

- to maintain prosperous, dynamic oceanic industries which offer secure, steady employment and economic development benefits, particularly for Canada's coastal regions;
- to encourage world-class expertise and capability in oceans-related science, technology, and engineering, which together form the basis for future economic development of the oceans;
- to ensure ocean resources and the ocean environment are soundly managed and protected for future generations of Canadians; and
- to assert and protect Canada's sovereignty and sovereign rights over its ocean resources (DFO, 1987a).

Fisheries and Oceans is responsible for managing fisheries and fish habitat within the 320 km fishing limit and for investigating oceanic processes. The long-term objective of the *Policy for the Management of Fish Habitat* is an overall net increase in the productive capacity of fish habitat (DFO, 1986d). The *Multi-Year Marine Science Plan* recognizes marine environmental quality as one of the seven marine strategic issues (DFO, 1988).

Environment Canada is responsible for pollution prevention, reduction and control, and wildlife conservation in Canada's marine environments. It is responsible, together with Fisheries and Oceans, for coordinating marine environmental quality policies and programs in a manner consistent with the *Marine Environmental Quality Management Framework* (Environment Canada, 1987b; Environment Canada, 1988b) and the federal *MEQ Framework* (Environment Canada, 1990b). The first Framework provides a clear set of principles supporting attention to marine environmental quality:

- marine environmental quality is of national importance;
- Canadians have a right to a safe marine environment and a healthy economy based on that safe environment;
- knowledge of the marine environment and its unique ecosystems, and its timely application, is critical to solving today's problems and preventing those of tomorrow;
- a high level of marine environmental quality is essential to protecting Canada's coastal and offshore resource-based economies;
- Canadians have a right to know the state of the Canadian marine environment;
- the preservation and maintenance of marine environmental quality is the shared responsibility of countries, governments, industry and individuals;
- federal Ministers are responsible to Canadians for delivering marine environmental quality within their mandates;
- the Minister of the Environment, on behalf of the federal government, assumes the leadership of the federal team responsible for delivering marine environmental quality to Canadians; and
- consultation and cooperation with other countries and with all governments in Canada are crucial to delivering marine environmental quality to Canadians.

Environment Canada has responsibility for the marine environment through eight national statutes (Table 2.2), a number of the international agreements and conventions (Table 2.1), plus advisory roles to the *Canada Shipping Act*, *Arctic Waters Pollution Prevention Act*, *Oil and Gas Production and Conservation Act* and the *Transportation of Dangerous Goods Act*, among others.

Table 2.2 Examples of federal acts relating to marine environmental quality

Environment Canada

Fisheries Act, Sections 36/37
Canada Wildlife Act
Migratory Birds Convention Act
National Parks Act
Canadian Environmental Protection Act
Canada Water Act
International River Improvements Act
Hazardous Products Act

Department of Fisheries and Oceans

Fisheries Act
Coastal Fisheries Protection Act
Fisheries Development Act
Territorial Sea and Fishing Zones Act
Fish Inspection Act

Department of Energy, Mines and Resources

Oil and Gas Production and Conservation Act
Canada Petroleum Resources Act
Resources and Technical Surveys Act

Department of Indian Affairs and Northern Development

Oil and Gas Production and Conservation Act
Canada Petroleum Resource Act
Public Lands Grants Act
Arctic Waters Pollution Prevention Act
Territorial Lands Act

Transport Canada

Canada Shipping Act
Arctic Waters Pollution Prevention Act
Navigable Waters Protection Act
Transportation of Dangerous Goods Act

Department of National Health and Welfare

Canadian Environmental Protection Act
Food and Drugs Act
Department of National Health and Welfare Act

Recent Federal Policies/Policy Initiatives

Federal Environmental Quality Policy Framework (1986)
DFO Fish Habitat Management Policy (1986)
Energy/Environment Agreement (1986)
Federal Water Quality Policy (1987)
Canadian Arctic Marine Conservation Strategy (1987)
DFO Oceans Policy for Canada (1987)
DFO Canada's Oceans (1987)
Environment and Development: A Canadian Perspective (CIDA)(1987)
Science Policy for Canada
Enforcement and Compliance Policy (CEPA)(1988)
Multi-Year Marine Science Plan (1988)
Federal MEQ Management Framework (1990)
Green Plan (1990)

Conservation and Protection (C & P) has a major role in protecting the quality of Canada's seas. In cooperation with provinces, territories, municipalities and other federal agencies, C & P is involved in the review of coastal construction, in both nearshore and offshore environmental impact assessments, in the evaluation of shellfish growing areas, in ocean dumping control, in the preparation for and response to environmental emergencies, in control of water and air pollution from point and non-point sources, and in the study, assessment, control, and monitoring of toxic chemicals.

The Canadian Wildlife Service (CWS) is responsible for marine wildlife conservation and research, particularly for seabirds, migratory birds, polar bears and unique marine habitats. The Lands Branch (CWS) works on coastal land use that has important implications to marine environmental quality. The Inland Water Directorate (IWD) conducts work on flood damage control, groundwater quality, municipal water supplies, water quality monitoring and analyses, and water/sediment quality guidelines, and conducts research on major river basins and their estuaries.

Other federal departments have marine responsibilities (see Fisheries and Oceans Canada, 1986c; Environment Canada, 1990b) (Table 2.2). Energy, Mines and Resources Canada is responsible for managing offshore energy and mineral activities, including the associated environmental protection aspects. Through the Canada Oil and Gas Lands Administration, it controls hydrocarbon exploration in Hudson Bay, Hudson Strait, and waters south of 60° latitude. Lands north of 60° latitude are administered in cooperation with the Department of Indian Affairs and Northern Development (DIAND). DIAND has jurisdiction over lands, resources and affairs of the territories, and has general responsibility for coordinating federal activities in the North. Transport Canada administers several acts regulating shipping and the navigation of marine waters, including vessel discharges and transportation of dangerous goods.

Crown agencies such as the Canadian International Development Agency (CIDA) provide international support to projects in resource and environmental development and management. For example, CIDA supports the Environmental Manpower Development in Indonesia project which is designed to develop a process for environmental assessment and to foster environmental manpower development in Indonesia in cooperation with Canadian universities, industry, government and non-governmental groups. The International Centre for Ocean Development (ICOD) cooperates with and supports developing countries and regions in utilizing and managing their ocean resources through the use of comprehensive and environmentally-sound management strategies.

Canada has also worked together with its neighbours on regional initiatives. For example, in the Gulf of Maine, the Provinces of Nova Scotia and New Brunswick, the States of Maine and New Hampshire, and the Commonwealth of Massachusetts signed an *Agreement on Conservation of the Marine Environment of the Gulf of Maine between the Governments of the Bordering States and Provinces* in December 1989. The Agreement is a cooperative effort designed to protect the ecological integrity, resources, and uses which depend upon the health of the Gulf of Maine marine ecosystem. Likewise, Canada, along with the eight Arctic-rim countries, plus Britain, France, Germany, and Poland, are shortly expected to sign a treaty to facilitate collaboration to protect the environment and mitigate the effects of shipping and industrial accidents in the Arctic region. It is hoped that the exchange of scientific and legal information related to the region will foster collaboration in the development of technologies suited to the polar climate and assist in the management of the common environment.

Table 2.3 Examples of provincial and territorial acts relating to marine environmental quality

British Columbia

Environment and Land Use Act
Water Act
Health Act
Environment Management Act
Waste Management Act
Utilities Commission Act

New Brunswick

Clean Environment Act
Crown Lands Act
Quarryable Substances Act

Newfoundland

Provincial Affairs and Environment Act
Waste Material (Disposal) Act

Nova Scotia

Beaches and Foreshores Act
Beaches Act
Environmental Protection Act
Health Act
Water Act
Dangerous Goods and Hazardous Wastes Management Act

Prince Edward Island

Environmental Protection Act
Water and Sewage Act

Quebec

Environmental Quality Act

Northwest Territories

Environmental Protection Ordinance

Most recently, Canada has launched its "Green Plan" (Government of Canada, 1990). Marine elements include remedial action plans for the Fraser River and Atlantic harbours and coasts, and more international efforts to combat threats to marine environmental quality.

International Perspective

Internationally, Canada has promoted the protection and conservation of the marine environment through government and non-governmental organizations, developing and ratifying international conventions, and bilateral and multilateral agreements (Table 2.1), and collaborating in international research projects.

The United Nations Conference on the Human Environment, Stockholm, June 1972, was a major rebirth of legal recognition of broad, global environmental problems and the need for coordinated international action to provide solutions. The Conference recognized the necessity of protecting habitats and ecosystems, not merely from overexploitation and pollution of the water, flora and fauna in them, as legitimate policy objectives. The Stockholm Declaration on the Human Environment provided guiding principles and general obligations that have subsequently been adopted in internationally binding agreements. Principles 7 and 21 include obligations to preserve the marine environment:

> Principle 7 • States shall take all possible steps to prevent pollution of the seas by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate use of the seas.
>
> Principle 21 • States have in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

These principles were developed in the 1982 United Nations Convention on the Law of the Sea (UNCLOS). UNCLOS represents the culmination of major international efforts to balance matters relating to sovereignty, fisheries, seabed resources, and pollution prevention in the oceans. Canada was a key figure in its creation. Part XII of UNCLOS provides a framework for the protection and preservation of the marine environment. It contains provisions on: general state obligations to protect and preserve the marine environment from pollution using the best practicable means, general obligations on states to balance their sovereign resource rights with a duty to protect and preserve the marine environment so as not to infringe upon the sovereignty of other states, the monitoring of pollution causing activities, global and regional cooperation, and the relevance of economic factors to the environmental obligations of developing states. Canada follows the institutional and legislative requirements of UNCLOS through international agreements to which it is signatory (Table 2.4).

Part XIII of UNCLOS is dedicated to marine scientific research, in particular with respect to pollution of the marine environment. Its primary objective is the establishment of "appropriate scientific criteria for the formulation and elaboration of rules, standards and recommended practices and procedures for the prevention, reduction and control of pollution of the marine environment."

Canada is currently working actively within the UNCLOS Preparatory Commission to ensure universal acceptability of the Law of the Sea. Recent activities have concentrated on deep sea-bed mining, a source of disagreement among many countries at the original discussions. Canada is participating in international discussions that seek to establish guidelines and regulations to protect the marine environment from activities on the sea-bed beyond the limits of national jurisdiction.

Canada was a participant in the World Conservation Strategy (WCS) for living resource conservation for sustainable development prepared by the International Union for the Conservation of Nature and Natural Resources in 1980 (IUCN, 1980). The major objectives of the Strategy are: the maintenance of essential ecological processes and life-support systems, the preservation of genetic diversity, and the sustainable utilization of species and ecosystems. Although Canada has not yet developed a unified national conservation strategy, it has established individual strategies and policies for natural resource sectors (e.g., fisheries, forestry, agriculture) and some cross-sectoral strategies (e.g., federal policy on land use and federal water policy).

The World Commission on Environment and Development (1987) (WCED, 1987), i.e., the Brundtland Commission, proposed institutional and legal changes at the national, regional, and international levels in six priority areas:

- getting at the sources;
- dealing with the effects;
- assessing global risks;
- providing the legal means;
- making informed choices; and
- investing in our future.

The Commission concluded that "sustainable development, if not survival itself, depends on significant advances in the management of the oceans." It identified three imperatives of ocean management:

- the underlying unity of the oceans requires effective global management regimes;
- the shared resource characteristics of many regional seas make forms of regional management mandatory;
- the major land-based threats to the oceans require effective national actions based on international cooperation.

Specific measures proposed to improve ocean management included: strengthening the capacity for national action through a review of legal and institutional requirements for integrated management of a nation's exclusive economic zone (EEZ) and a statement of national priorities and goals, and advancing the Law of the Sea, primarily through ratification of UNCLOS.

Many organizations (Table 2.5) are working towards the prevention, reduction, and control of marine pollution. The United Nations Environment Programme (UNEP) has an Ocean and Coastal Areas Programme that attempts to control marine pollution through the cooperation of countries bordering regional seas. Canada has participated in a review of environmental threats to the oceans with the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) (GESAMP, 1990). Canada took an early initiative to control land-based pollution of the seas by hosting a UNEP-sponsored conference in Montreal in 1985 that produced the *Montreal Guidelines* (UNEP, 1985). A follow-up Canadian conference on MEQ was held in 1988

Table 2.4 Examples of implementation of the 1982 United Nations Convention on the Law of the Sea (UNCLOS) principles

Pollution Source	Implementation of Principles
Land-based pollution	Montreal Guidelines for the Protection of the Marine Environment against Pollution from Land-Based Sources (UNEP)
Vessel-source pollution	International Convention for the Prevention of Pollution from Ships
	International Convention for the Prevention of Pollution of the Sea by Oil
	International Convention on Civil Liability for Oil Pollution Damage
Pollution by dumping at sea	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
Pollution from seabed activities	Seabed Working Group of UNCLOS
Pollution from or through the atmosphere	Convention on the Protection of the Ozone Layer Convention on Long-range Transboundary Air Pollution

Table 2.5 Examples of governmental and non-governmental organizations concerned with marine pollution

Arctic Ocean Sciences Board
Food and Agricultural Organization of the United Nations (FAO)
Intergovernmental Oceanographic Commission (IOC)
International Council of Scientific Unions (ICSU)
International Arctic Committee
International Atomic Energy Agency (IAEA)
International Maritime Organization (IMO)
International Council for the Exploration of the Sea (ICES)
Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)
Organization for Economic Cooperation and Development (OECD)
United Nations Development Programme (UNDP)
United Nations Educational, Scientific and Cultural Organization (UNESCO)
United Nations Industrial Development Organization (UNIDO)
United Nations Environment Programme (UNEP)
World Health Organization (WHO)
World Meteorological Organization (WMO)
World Bank

(Wells and Gratwick, 1988). Canada is pursuing international negotiations to advance the UNEP initiative on land-based sources of marine pollution.

As a member of the Organization for Economic Cooperation and Development (OECD), Canada is cooperating on a Coastal Zone Management Project and is contributing data and information to the upcoming OECD *Environmental Data Compendium*. Canada has also prepared the marine chapter of the upcoming *OECD State of the Environment Report*.

The Canadian government recognizes the current inadequacies of international controls, legal instruments, and technologies to deal with marine oil spills, particularly on the high seas. At the Paris Economic Summit, Group of Seven (G-7) leaders called upon the International Maritime Organization (IMO) to put forward proposals for further preventive action to reduce pollution from oil spills. In partnership with other nations in the IMO, Canada has contributed to the International Convention on Oil Pollution Preparedness, Response and Cooperation, London, 1990 (not yet in force, March 1991). These efforts are particularly important following recommendations of the Brander-Smith Report (Brander-Smith et al., 1990) concerning Canada's capability to respond effectively to spills of oils and chemicals in Canadian waters.

The London Dumping Convention has proven to be a valuable forum for international discussion of marine environmental protection, and Canada has been an active player in its evolution. Presently, Canada chairs a steering committee examining the future role of the Convention, including the possibility of broadening its scope.

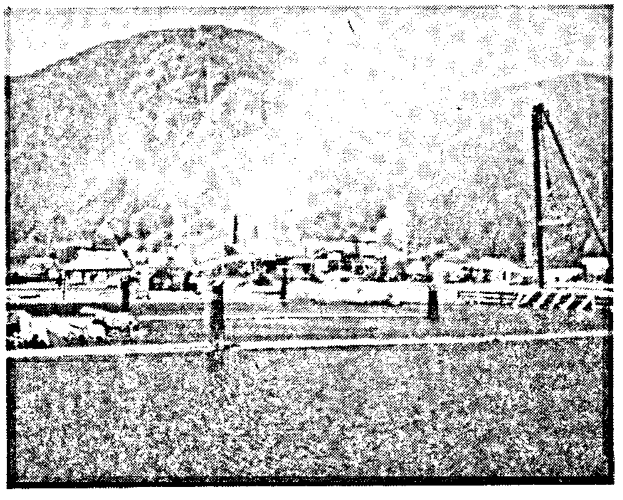
Heavy metals and persistent synthetic chemicals often are deposited in large amounts from the atmosphere and bioaccumulate and may cause adverse effects in marine ecosystems. In particular, the Arctic waters contain anomalously large concentrations of these contaminants which pose a threat to the ecology, natural resources, and peoples of the North. In April 1990, Canada hosted the second meeting of the eight circumpolar nations in Yellowknife on the impact and control of land-based pollution on Arctic marine waters. Agreement was reached to prepare a framework for an *Arctic Environmental Protection Strategy*. The initiative is being led by Finland and is continuing with a ministerial-level conference in spring, 1991.

Summary

The oceans are part of the global commons, shared by all, exploited by many, without a single country or organization having overall responsibility for their protection. Canada's commitment to maintaining a high level of marine environmental quality is demonstrated by the wide array of relevant national and provincial policies, legislation, committees, and international obligations being pursued. Recently, Canada developed a federal *MEQ Management Framework* (Environment Canada, 1990b) that focuses on federal government program responsibilities for the conservation and protection of marine environmental quality. A national MEQ management framework is being proposed next, in cooperation with the coastal provinces, industries, universities, and the public. These frameworks will provide a basis for new national and regional actions on marine environmental quality for Canada's seas that will ultimately benefit the global marine environment.

Chapter Three

The Pacific



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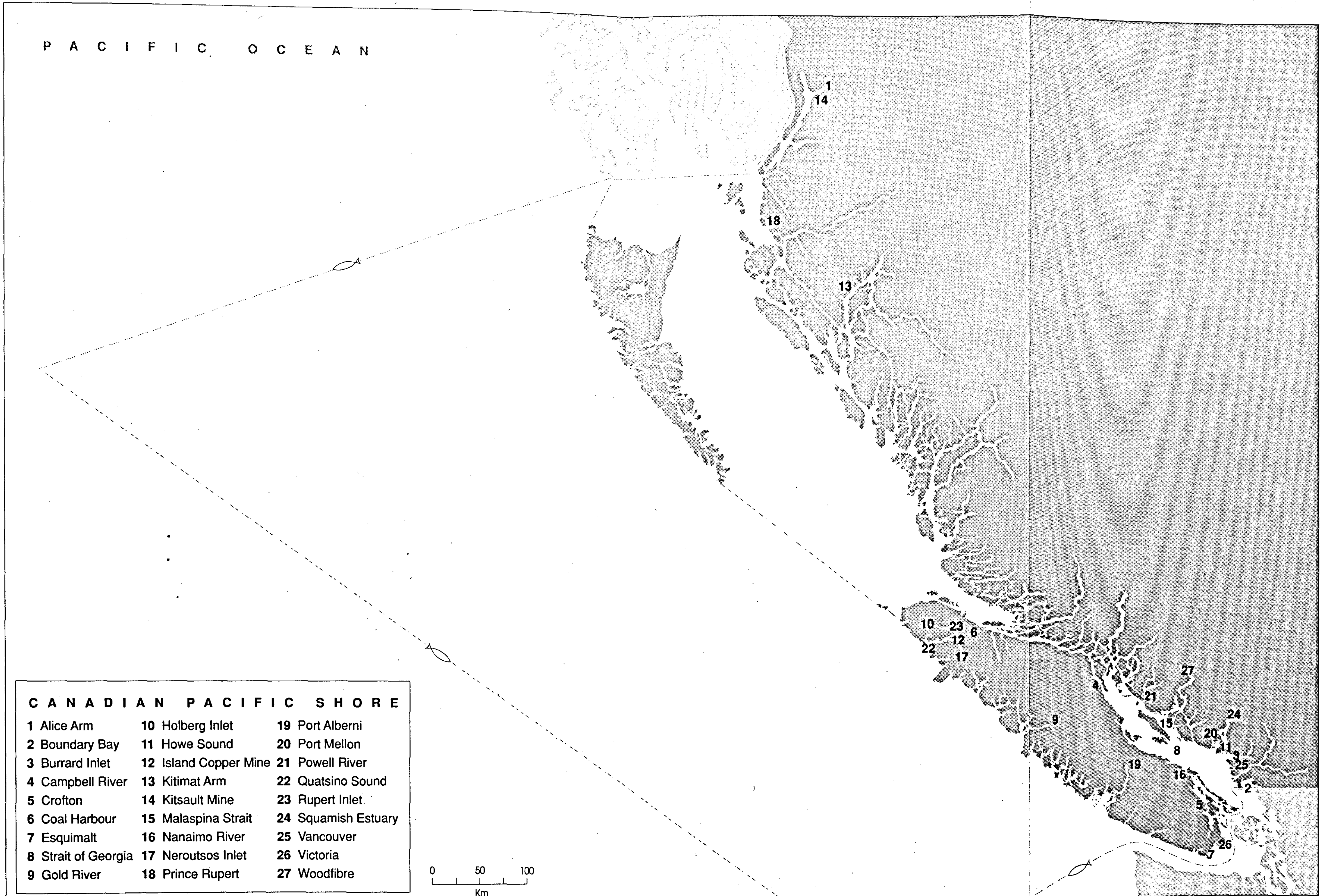


Figure 3.1 Map of the Pacific Coast

Introduction

Canada's west coast has 25,711 kilometres of shoreline marked by many islands, productive estuaries, and deep fjords. Development of forestry, mining, and fisheries, the three largest primary resource industries in British Columbia (B.C.), has resulted in dispersed human populations and industrial centres (Figure 3.1). Tourism, the province's second largest industry, thrives in both populated and remote areas but requires clean air and water, abundant natural resources, and unsullied scenic vistas. A new industry, salmon farming, has emerged as a major component of B.C.'s coastal economy. The concentration of industries in several resource-rich estuaries has created the need for intensive environmental management and protection based on a clear understanding of the status of and threats to marine environmental quality (See Langford et al., 1988).

Marine environmental quality means different things to each user: thriving ecosystems with abundant resources for commercial and sports fishermen and wildlife enthusiasts; clear water for recreational boaters; clean water for industrialists and aquaculturists; safe and aesthetically pleasing beaches for bathers and tourists; uncontaminated seafood for consumers; unobstructed shipping lanes and safe anchorages for marine transportation, and so on. This report treats the subject from the narrower perspective of pollutant levels in seawater, sediments, and animal tissues. It examines major sources of pollution, specific substances, and geographic areas of concern on the West Coast. The effects of pollutants on federally managed coastal fisheries, marine mammals, and migratory birds on the B.C. coast are also assessed.

Pollution Sources

Dredging and Ocean Dumping

Since ocean dumping applications are screened rigorously to ensure the disposal of only clean dredge spoils, and considering such spoils are already present in the ocean, they are not, by definition, a pollution source. On the contrary, occasional rejection of applications because of excessive contamination is a consequence rather than a cause of pollution. Such pollution must be controlled at its land-based source. Nevertheless, the definition of "clean" changes with time, and is not the same as in 1975 when Canada's *Ocean Dumping Control Act* was passed. Some materials approved for ocean dumping have and continue to include trace levels of contaminants. Hence this pollution *prevention* program is included under the heading of pollution sources.

The Regional Ocean Dumping Advisory Committee (RODAC) for the Pacific and Yukon Region reviews applications to dump materials at sea. RODAC is authorized to issue permits under Part VI of the *Canadian Environmental Protection Act* (CEPA) (Government of Canada, 1988), formerly the *Ocean Dumping Control Act*, subject to conditions necessary to protect fisheries and other uses of the sea. In addition to observing regulations pertaining to dumping under the CEPA, RODAC has developed regional guidelines for dioxins and polycyclic aromatic hydrocarbons. Recent studies indicate the presence of these contaminants in dredged materials near pulp mills and in industrial harbours.

Although ocean dump sites have been established at 126 sites in B.C. coastal waters, most dumping has occurred at only 24 sites since 1982 (Sullivan, 1987) (Figure 3.2). Between 1975 and 1987, the total annual quantity of dumped materials varied between

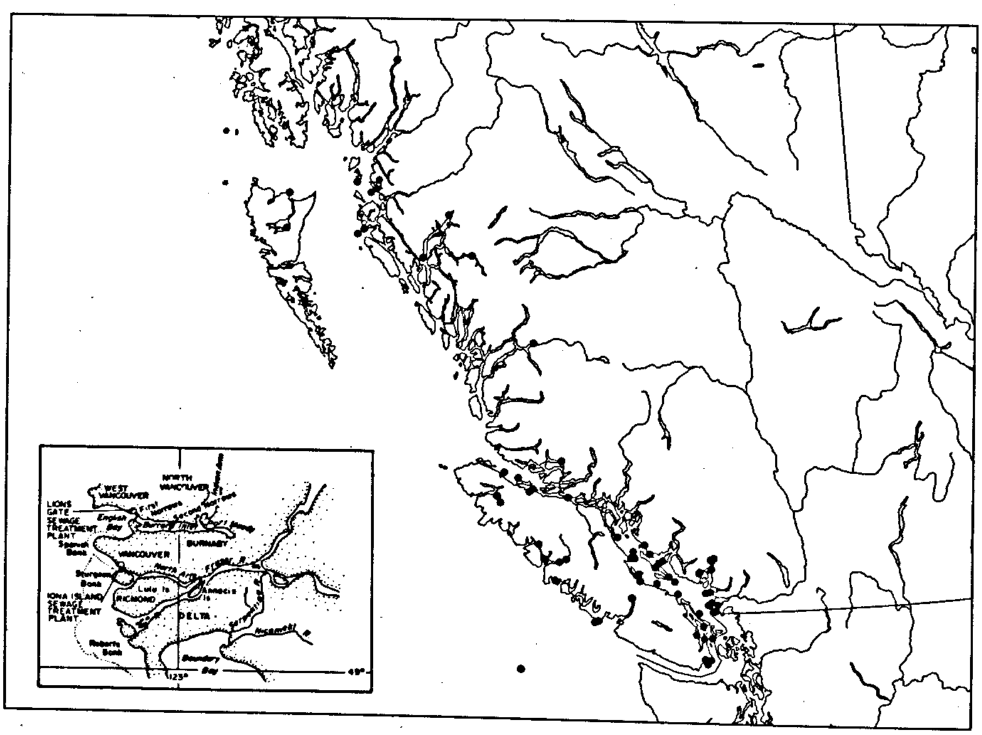
1.1 and 3.6 million cubic metres. The dumped material comprises almost exclusively dredge spoils (97 percent of total dumped material from 1975 to 1987). Dredge spoils are primarily from Fraser River channel maintenance and harbour dredging, and forest industry operations, i.e., wood wastes (Environment Canada, 1989; Environment Canada, 1988a) (Figure 3.3). The greatest quantity of material has been dumped at the Point Grey (Waldichuk, 1989a) and Sandhead dump sites, located near the densely populated Lower Mainland area of the province.

Underwater visual observations and benthic community studies using bottom trawl nets and grab samples have revealed limited information on the effects of ocean dumping. These studies noted changes in the number of species, number of individuals, and biomass at the Alberni dump site (Levings et al., 1985). However, there was no evidence of biomagnification of metals.

Sediments around pulp mills with high mercury and cadmium levels (e.g., Powell River and Port Alberni) and in harbours with high levels of trace metals and other substances restricted under CEPA (Part VI) pose a disposal problem during dredging. Trace metals and organic compounds contaminate sediments in Vancouver and Victoria Harbours and False Creek. RODAC often rejects applications to dump spoils from these areas in ocean dump sites. Alternative disposal options are being sought.

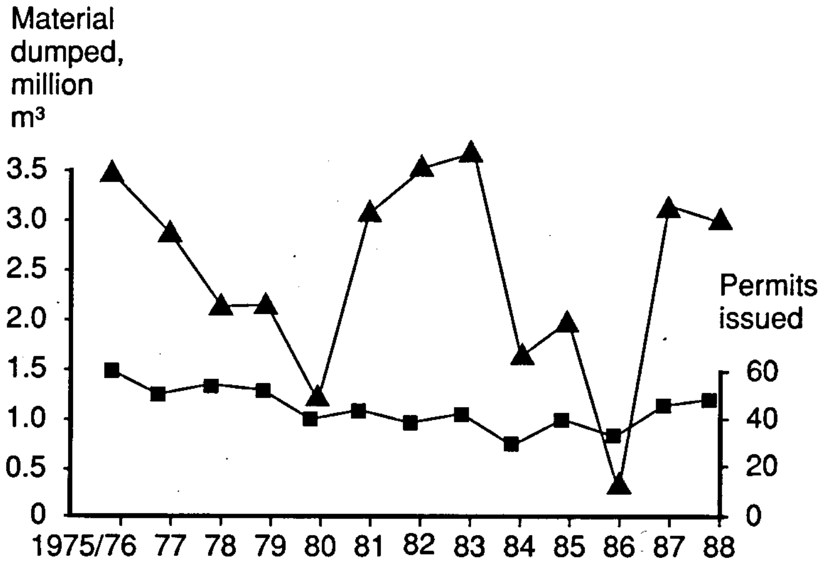
Fish and invertebrate sampling at ocean dump sites has been limited to the Point Grey location. Muscle tissue of finfish species had non-detectable levels of cadmium although higher levels were observed in shrimp. Fish and crab tissues samples contained the highest mercury concentrations. They were, however, still below Health and Welfare Canada's 0.5 mg/kg wet weight guideline for fish.

Figure 3.2 Ocean dumpsites, including inactive sites, off the B.C. coast



Source: Environment Canada, Vancouver; Inset, Waldichuk, 1983.

Figure 3.3 Total amount of material dumped at sea and permits issued per year in B.C., 1976 to 1988

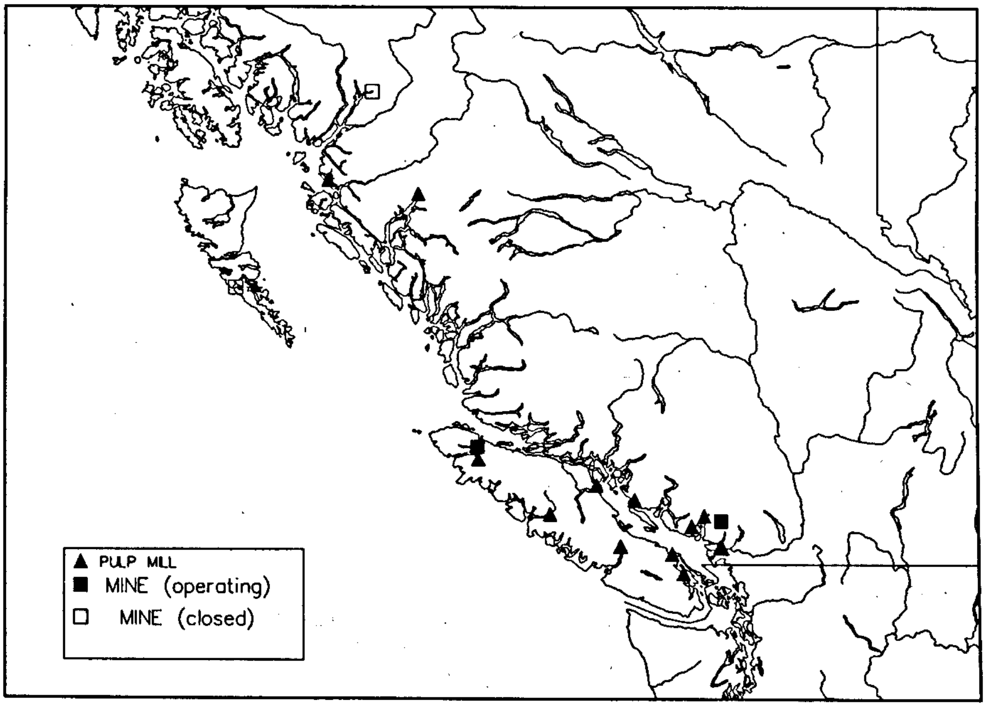


Source: Kay, 1989b.

Mining

Ten coastal mines have operated in B.C., although only one, the Island Copper Mine, Vancouver Island, discharging into Rupert Inlet, is still in operation (Figure 3.4). Although all of these mines discharged tailings directly to the marine environment, none has been subject to the *Metal Mining Liquid Effluent Regulations*. The Regulations were implemented after these mining operations commenced. The Kitsault Mine in Alice Arm operated under special federal regulations with which it was in "substantial compliance" during its brief period of operation in 1981-1982 (Burling et al., 1983).

Figure 3.4 Mines and pulp mills on the B.C. coast



Source: Environment Canada, Vancouver.

Unconfined disposal of mine tailings (i.e., without impoundment) results in the massive discharge of solids to the immediate environment. Between October 1971 and September 1985, the Island Copper Mine discharged 135 million tonnes of tailings (data from Island Copper Mine Ltd. annual reports). These tailings have smothered benthos and modified benthic habitat throughout Rupert Inlet and in parts of Holberg Inlet, Neroutsos Inlet and Quatsino Sound. Mine tailings have been observed up to 33 km from the mine's outfall, affecting approximately 66 km^2 of benthic habitat in the three inlets and Quatsino Sound (Waldichuk and Buchanan, 1980). At Tasu Sound, Queen Charlotte Islands, mine tailings cover approximately 8.4 km^2 of benthic habitat, and at Alice Arm the tailings extend over approximately 9.0 km^2 of bottom (from L. Harding, 1983).

A variety of marine species showed bioaccumulation of some metals at all the mines studied (reviewed by Kay 1986a), but not to levels that would cause ecological or health risks (Ellis, 1984). For example, Futer and Nassichuk (1983) found that metals had not accumulated in the edible tissues of crab and eulachons collected from Alice Arm.

Acute toxicity in routine bioassay tests has not been a feature of mine tailings discharges in British Columbia, except for occasional plant upsets (Kay, 1986b).

Municipal Effluents

In 1986, the provincial government registered approximately 256 marine sewage discharges. These accounted for approximately 20 percent of the effluent discharged to B.C. coastal waters from all sources (Figure 3.5). As of March 1990, there were 307 permits/applications for sewage discharges. Impacts of sewage discharges include lowered dissolved oxygen concentrations, deposition of organic matter around outfall sites, bacterial pollution, and metal and other contaminant loadings. Sampling indicates elevated concentrations of some trace metals and organic chemicals near municipal sewage outfalls in many locations (Lorimer, 1984).

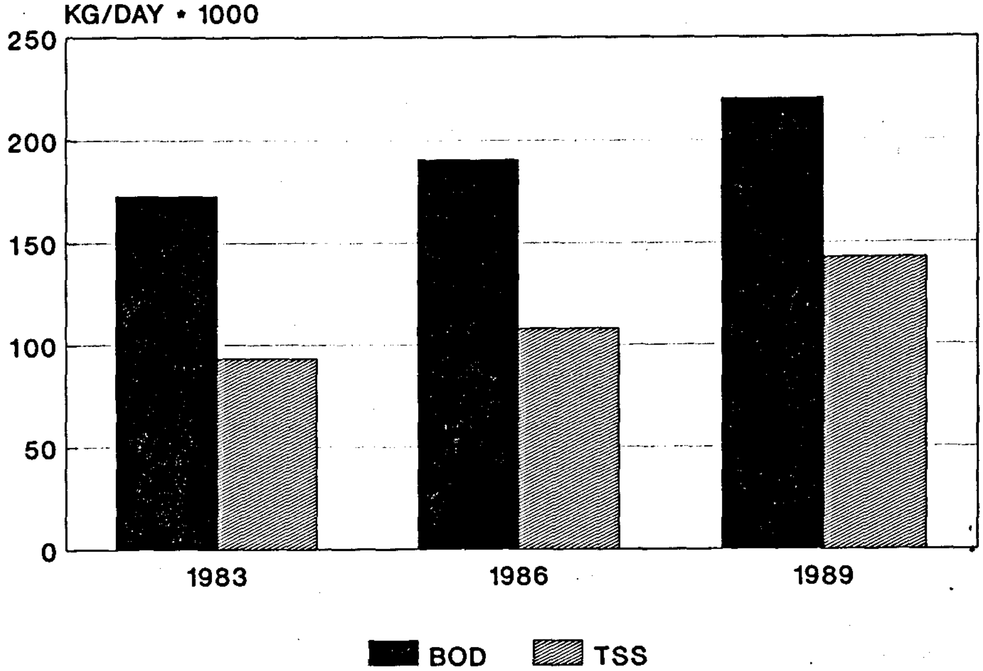
The most obvious impact of sewage discharges is the closure of shellfish-growing areas to harvesting. Municipal discharges are the sole cause of approximately 15 percent of all shellfish harvesting closures in British Columbia coastal waters. They are implicated in a further 78 percent of multiple source discharges (B.H. Kay, unpubl. data). Other sources of contamination are agricultural runoff, non-point source urban runoff, and unidentified sources of contamination.

In 1988, new shellfish closures due to bacterial contamination totalled 41,380 hectares. The federal Department of Fisheries and Oceans (DFO) closed a further 11,035 ha or 177 km of coastline as a safety precaution around wharves and sewage outfalls, although exploitable shellfish resources were not present in most cases. There has been no assessment of the productivity of the closed areas, and many have limited or no shellfish resources of commercial value. Bacterial contamination was responsible for the closure of approximately 70,500 hectares along 730 km of coastline (2.7 percent of the B.C. coastline) to shellfish harvesting in 1989 (Figure 3.6).

Pulp and Paper Effluents

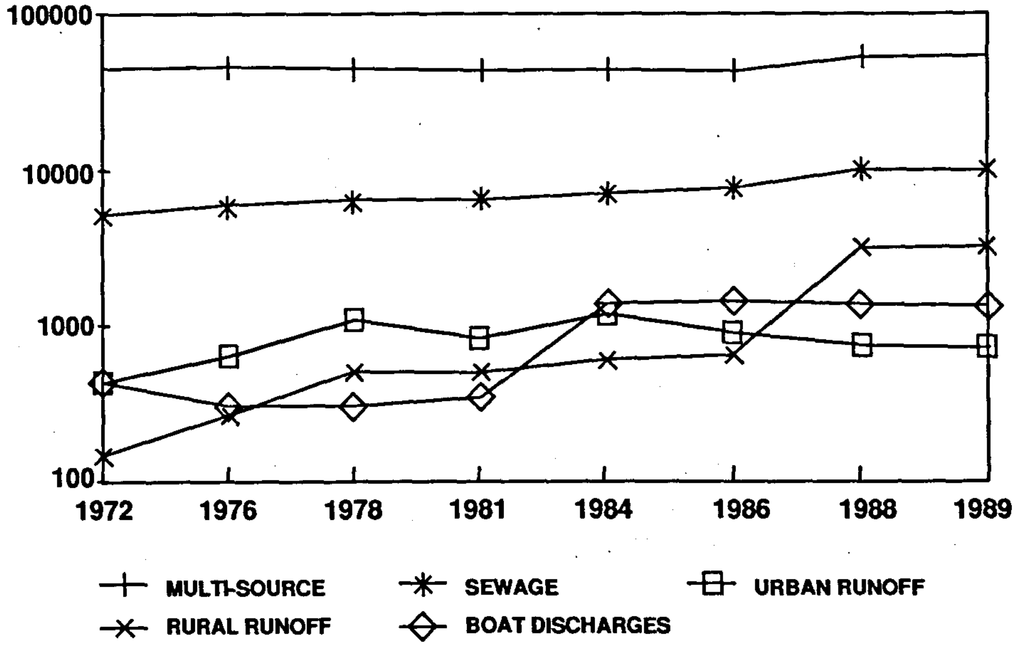
Ten pulp and paper mills operate along the coast of British Columbia (Figure 3.4) and discharge effluents to estuarine or coastal waters. A mill at Kitimat discharges to the Kitimat River upstream of the estuary. A mill at Ocean Falls closed in 1979. Pulp and

Figure 3.5 Municipal discharges to B.C. coastal waters



Source: MUNDAT and MUD databases, Environment Canada, Vancouver.

Figure 3.6 Trends in B.C. shellfish closures due to bacterial contamination, 1972-1989



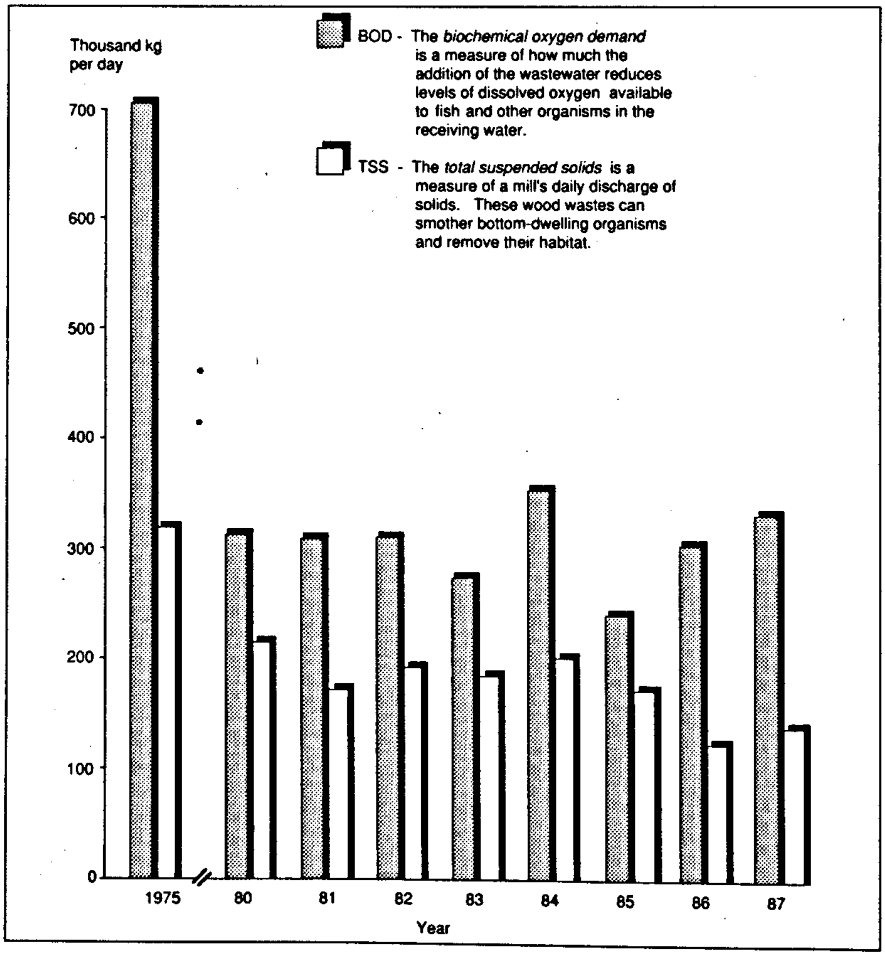
No. closures:156; Area: 70,997 ha

Source: Environment Canada, Vancouver.

paper mills discharge large volumes of effluents containing chemicals from the pulping and bleaching processes as well as wood fibres and other solid wastes. The four types of impacts on marine habitats of such effluents are: damage to intertidal communities primarily due to toxicity, smothering of benthic communities due to suspended solid (wood fibre) deposition, depletion of dissolved oxygen in the water column by effluent biochemical oxygen demand (BOD) and sediment oxygen demand, and uptake of toxic chemicals (Waldichuk, 1983).

The implementation of environmental controls in the pulp and paper industry between 1975 and 1980 has substantially reduced BOD and total suspended solids (TSS) in pulp mill effluents (Figure 3.7). Both BOD and TSS are routinely measured. The construction of settling ponds and in-plant controls has reduced BOD and TSS of the effluents. Since 1980, however, the combined daily average contribution of BOD and TSS to the marine environment from the pulp and paper sector has increased slightly (Kay, 1986a, b). Only one coastal mill, at Port Alberni, has installed biological treatment facilities, although several others had secondary plants under construction by the end of 1990.

Figure 3.7 Total suspended solids (TSS) and biochemical oxygen demand (BOD) for B.C. coastal pulp mills, 1975-1987

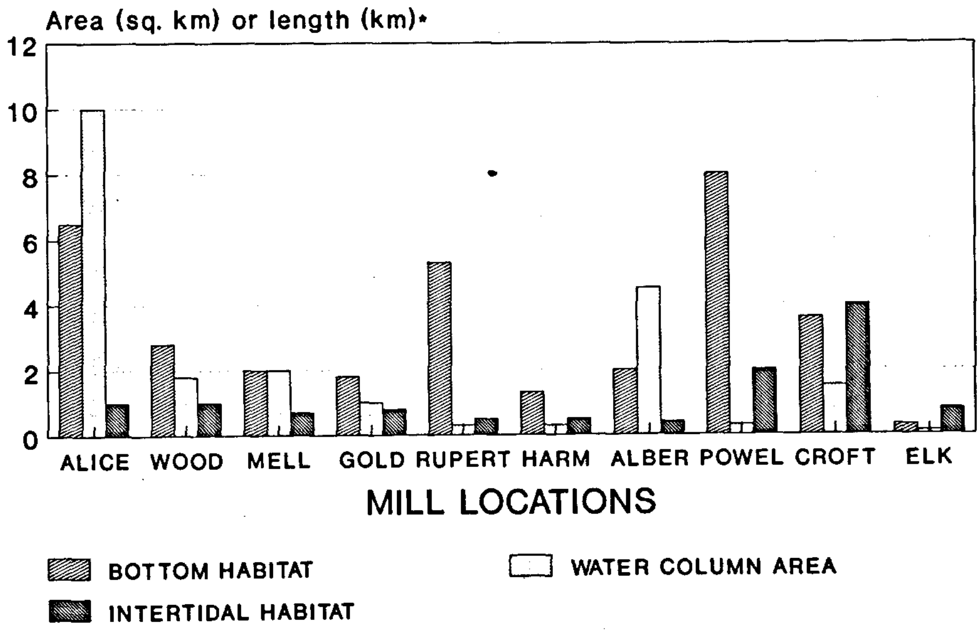


Source: Kay, 1989b.

Resin acids from the wood and chlorinated lignins and other chlorine-containing compounds formed in the bleaching process cause between 70 and 100 percent of the toxicity of pulp mill effluent (Leach and Thackore, 1977; D. McLeay and Associates Ltd., 1987). Nine of the ten B.C. coastal mills using the chlorine bleaching process produce a wide variety of organochlorine compounds, including chloroguaiacols, chloroveratrols, chlorocatechols and dibenzo-*p*-dioxins (see *Dioxins* below). Although these and other unidentified chlorinated organic compounds have a wide variety of effects on marine ecosystems in other parts of the world, these effects have yet to be confirmed in Canada. The effects include toxicity at very low concentrations, skeletal deformations, and low fecundity in fish, and reduced inshore fish and invertebrate populations (Colodey, 1989; Colodey et al., 1990).

During the late 1970s and early 1980s, most coastal mills installed long outfalls and diffusers. This resulted in significant recovery of intertidal communities, except for effects from other causes such as log-booming and occasional spills. Figure 3.8 shows the number of kilometres of intertidal habitat affected at each coastal mill. The quantities are based on a review of company monitoring reports (Grooms, 1986) supplemented by observations during 1986 at each mill by 1986 (Environmental Protection, unpubl. data).

Figure 3.8 Zone of impact of B.C. pulp mills on water, and intertidal and bottom habitats



Legend: Alice - Port Alice
Wood - Woodfibre
Mell - Port Mellon
Gold - Gold River
Rupert - Prince Rupert
Harm - Harmac
Alber - Port Alberni
Powel - Powell River
Croft - Crofton
Elk - Elk Fall

* Intertidal in km; others in square km.

Source: Environment Canada, Vancouver.

At Neroutsos Inlet, site of a sulphite pulp mill, studies detected *in situ* toxicity as measured by fish mortality or avoidance reactions up to ten km from the location of surface-discharged effluents (McGreer and Vigers, 1979). Oyster beds became less productive in the area around the Crofton mill and the oysters had a poor condition factor based on plumpness (Davis et al., 1976).

Heavy deposition of fibre beds reduces the benthic communities in both number and diversity. However, in zones of light deposition, the abundance of pollution-tolerant species increases (Pomeroy, 1983; McGreer, 1984; Waldichuk, 1988b). Figure 3.8 shows the extent of bottom habitat area affected by fibre deposits at B.C. coastal pulp mills up to 1986, as indicated by increased organic content of sediments.

Before 1970, pulp mill effluents contained significant quantities of zinc and mercury. Pulp mills discontinued the use of mercury-based slimicides and zinc-based brighteners for ground wood and newsprint in 1960 and 1973 respectively. Sediments around some B.C. coastal mills continue to show elevated levels of these metals (Kay, 1986a, b). Concentrations of the metals in biota, except zinc in oysters, particularly at Crofton, are usually low.

Depletion of dissolved oxygen (DO) threatens marine life when natural inputs of oxygen are less than the amount consumed by natural plant and bacterial respiration and pulp mill effluent BOD. Natural inputs of oxygen include wind-driven aeration, plant photosynthesis, freshwater runoff, and ocean mass movements. According to Davis (1975), DO saturation remaining at or below 57 percent for more than a few hours may severely affect the anadromous salmonids. Using this level and DO values associated with the presence of pulp mill effluent, as indicated by elevated colour, Colodey (Environmental Protection, unpubl. data) calculated the areas of probable impact on pelagic organisms of up to 10 km^2 using 1986 data (Figure 3.8).

Both federal and provincial governments have announced new regulations that will require secondary effluent treatment and restriction on dioxins and furans at all mills. This will primarily involve the modifications to the bleaching process to reduce chlorine use. Federal regulations will take effect in 1994.

Spills and Related Environmental Accidents

The number of reported marine spills increased from 268 in 1984 to 574 in 1988 (Kay, 1989b). Most of the spills were classified as minor, although there were one to four major spills each year. However, 22 major spills were recorded during 1988, including the *Nestucca* Bunker C fuel oil spill of late December 1988 (Waldichuk, 1989b). This spill heavily oiled 2-3 km of the 150 km of affected coastline (Harding and Englar, 1989). Most (79 percent) of the spills were petroleum-related, with effluents ranking second (7 percent); however, process waste spills from pulp mills account for the largest volume by far.

The source of 42 percent of the recorded spills could not be identified. The transport (12 percent), pulp and paper (8 percent), fishing (6 percent), and petroleum-petrochemical (6 percent) sectors account for most spills. It should be noted that the number of reported spills from the pulp and paper sector has increased tenfold from 1.5 percent (4 in 1984) to 16 percent (92 in 1988) (Environment Canada, Pacific and Yukon Region, unpubl. data).

Aquaculture

Oyster farming and harvesting of wild clams have long been a mainstay of many local coastal economies, with steadily increasing production and strong demand. Oyster aquaculture industry production was valued at $3.9 million (1988 data). This figure is expected to be significantly higher for 1989 and 1990 (B. Kooi, pers. comm., 1991). By December 1990, DFO had issued 413 shellfish tenure leases totalling 1,517 ha, and all the farms were in operation. In addition, DFO issued five licenses for marine plant farms. Three farms totalling 48 ha harvested kelp and a red seaweed, knorri.

Since 1984, the salmon farming industry has expanded rapidly. By December 1990, there were 210 finfish tenure leases, mostly salmon, and 110 operating grow-out farms totalling 1,456 hectares.

Although salmon farms require clean seawater, they introduce enormous quantities of nitrogenous wastes to marine waters (Gillespie, 1986). These wastes degrade benthic habitat under the net pens, including habitat of important bivalve shellfish species such as geoducks. Wastes may contribute to the frequency and severity of algae blooms. In 1989 such a bloom in Agamamnom Channel caused the loss of $2 million worth of farmed salmon through suffocation. In addition, biocides and other chemicals used to treat salmon or their nets (see *Organotins* below) may find their way into the marine environment. Bacterial pollution associated with the aquaculturalists' homes and fish food has resulted in closures of adjacent bivalve harvesting areas. In B.C., these concerns have not been quantified, although government regulators apply rigorous aquaculture guidelines and siting criteria, including biophysical mapping of much of the southern coastline. Salmon farmers are also required to monitor water quality.

Specific Substances

Metals

Heavy metals such as arsenic, cadmium, copper, mercury, and lead can be toxic. In uncontaminated marine sediments, trace metals tend to locate within mineral lattices or bind tightly to organic molecules. Hence they are often not biologically available (see Moore and Ramamoorthy, 1984; Waldichuk, 1985). Similarly, dissolved metals from riverine or effluent sources tend to precipitate out of solution upon entering seawater. Although these chemical forms of metals pose little direct threat to marine life, under certain conditions they can enter solution or become transformed into biologically available forms and become toxic.

Environmental Protection has collected sediments for trace metal analysis at some 75 locations along the B.C. coast. These included industrial or municipal effluent discharge sites and ocean dumping sites (L. Harding, Environmental Protection Survey database, unpubl. data), as well as areas remote from pollution sources (Harding and Thomas, 1987). Fish and invertebrate tissues were also sampled at most of these sites. Sampling revealed relatively uncontaminated sediments, and there was no evidence of generalized biomagnification of trace metals in marine food webs. However, the surveys showed that localized contamination of sediments and biota does occur. Metal contamination is also discussed in later sections.

Many studies in B.C. have shown that invertebrates living in close association with sediments that contain high levels of trace metals incorporate them into their tissues (Kay, 1986a). In addition, laboratory studies demonstrate the toxic effects on these animals (McGreer and Munday, 1982; Waters, 1985). This bioaccumulation is the uptake pathway for predators, which includes stocks of commercial fish. For this reason, increases in heavy metals above background levels are one indication of deterioration in marine environmental quality.

Cases of widespread damage to marine ecosystems or to human consumers of fish or shellfish contaminated by metals are well-known world-wide (e.g., Minimata), but rare. Still, the absence or reduction of marine animal populations often characterizes localized areas of severe trace metal contamination. In one instance (see *Howe Sound* below), an inlet was closed to fishing to protect human consumers of fish from mercury contamination. In no cases, however, have trace metals been confirmed as causing human illness or fish stock reduction in B.C. waters.

PCBs

Polychlorinated biphenyls (PCBs) are highly persistent in the environment and accumulate in living tissues if ingested in even minute amounts. There is some evidence that they cause cancer and birth defects in mammals. Although their effect on humans is not completely known, the ecological damage caused by their extreme persistence and moderate toxicity was sufficient to result in implementation of tight use controls in many areas of the world during the 1970s. The Health and Welfare Canada guideline for PCBs in fish and shellfish is 2.0 mg/kg wet weight. In this section, all concentrations are dry weight unless otherwise specified. Although considerable recent data have been collected on PCBs in the B.C. coastal environment, the lack of published PCB data severely constrains an adequate understanding of their status in British Columbia (Waters, 1988).

PCBs have low solubility in water and concentrate in sediments. Sediment data show that levels of PCBs in areas removed from industrial activity range from non-detectable (< .005 mg/kg) to approximately 0.1 mg/kg. Higher levels have been observed near pulp and paper mill discharges (maxima of 1.5 to 5.5 mg/kg at four coastal mills) and harbour areas (up to 2.2 to 17.0 mg/kg at various locations in Vancouver and Victoria Harbours). Levels of .005 to 1.30 mg/kg have been measured in Fraser River Estuary sediments, with the highest levels adjacent to a paperboard mill in the Lower Fraser River (Hall, 1985). Samples of marine sediments of the Fraser River Estuary show PCB levels of up to 3.8 mg/kg (Garrett, 1982).

Pulp and paper mill effluents are one source of PCBs. Sampling recorded PCB levels of 1.5 mg/kg in sediments in Northumberland Channel near Nanaimo, 5.5 mg/kg in Alberni Inlet near Port Alberni, 1.7 mg/kg in Malaspina Strait near Powell River, and 4.5 mg/kg near Woodfibre in Howe Sound. These levels are thought to be the result of past releases, rather than recent ones (Garrett, 1985).

Industrial harbours have many sources of PCBs. Examples of localized "hot spots" for PCBs in sediments include 16.8 mg/kg in Coal Harbour, 17.0 mg/kg at Burrard Yarrows Shipyards, 14.4 mg/kg at Vancouver Wharves, 6.2 mg/kg at Benson's Shipyard, 2.2 mg/kg near Burrard Shipyard, and 4.1 mg/kg at Vancouver Shipyard, all in Burrard Inlet. Sampling revealed concentrations up to 3.65 mg/kg in inner Victoria Harbour

(Garrett, 1985). Much higher levels were found in nearshore sediments adjacent to a former paint plant (Environment Canada, unpubl. data), but these contaminated sediments were removed in 1986.

In 1977, a major spill of about 800 litres of PCBs into Porpoise Harbour near Prince Rupert resulted in PCB levels of up to 75 mg/kg dry weight in sediments. For biota collected along the shoreline, concentrations up to 72.9 mg/kg were found in Tanner crab legs (*Chionoecetes bairdii*). Beyond the immediate spill area, elevated PCB levels were confined to biota in Porpoise Harbour. Dungeness crabs (*Cancer magister*), monitored annually since the clean-up, show mean tissue levels well below the 2.0 mg/kg guideline set by Health and Welfare Canada. Contaminated sediments were capped to prevent further dispersal and contact with aquatic organisms, and annual monitoring indicates that the major areas of contamination have been contained (Kay, 1986b).

Scientists have identified PCBs in some Pacific marine species. Garrett (1985) reviewed levels of PCBs in fish and crab species from the Fraser River Estuary. PCB levels were highest near the Iona sewage treatment plant outfall. Edible crab leg muscles had levels ranging from 0.056 - 0.213 mg/kg. Garrett discerned mean PCB levels of 0.364 mg/kg in flounder fillets, 0.044 mg/kg in salmon fillets, and 0.244 mg/kg in speckled sanddab fillets. In less contaminated parts of the estuary, that is, areas away from the industrialized North Arm region, levels ranged from undetectable to 0.014 mg/kg in fish and crab tissues. In Vancouver Harbour, Garrett reported a mean PCB concentration of 0.200 mg/kg in crabs, while mussels collected in False Creek contained 0.014 - 0.017 mg/kg of PCBs.

Chlorophenates (Neutralized Chlorophenols)

More than 80 percent of the lumber currently shipped overseas is unseasoned and requires chemical protection against sapstain and mould. Until recently, mills used chlorophenates almost exclusively; however, the B.C. government has announced regulations to control chlorophenate releases. Most companies have switched to environmentally safer alternatives.

Chlorophenates (CPs), although extremely toxic to marine life, are moderately unstable in the marine environment and can degrade with exposure to sunlight and oxygen. They are of concern primarily because of their high acute toxicity. Moreover, their manufacture often produces minute amounts of extremely toxic and persistent contaminants known as polychlorinated dibenzo-*p*-dioxins (PCDDs; hereafter referred to as dioxins). Dioxins are difficult to measure in low concentrations. As a result, scientists consider levels of chlorophenates and related compounds to indicate both the short-term toxicological threat of CPs and the long-term threat of accumulation of dioxins in the marine environment (see *Dioxins and Furans* below). The B.C. Ministry of Environment and Parks' water quality objective for CPs in marine sediments of the Fraser River is 0.010 mg/kg dry weight.

A 1978 study of chlorophenates (trichloro-, tetrachloro- and pentachlorophenols) detected them in sediment and biota collected from all examined sites and in seawater from all sites but one (Environment Canada, 1979). Gorge Inlet in Victoria Harbour had the highest sediment concentrations of chlorophenates. The highest levels in biota were recorded in sculpin liver samples collected from the Nanaimo River Estuary. Generally, chlorophenate levels in edible crab tissue were low, not exceeding 0.02 mg/kg tetrachlorophenol. Seawater concentrations ranged from non-detectable to 0.007 mg/L. Marine levels of CPs cannot be readily interpreted in terms of environmental or health threats because of the absence of environmental standards.

A review by Garrett and Shrimpton (1988) of 1973-1985 data showed chlorophenates concentrated most highly in fish and sediments in the heavily industrialized Lower Fraser River and in southern coastal areas adjacent to wood treatment facilities. They reported mean concentrations of tetra- and pentachlorophenols of 0.04 - 0.09 mg/kg in various fish species, with the maximum reaching 2.1 mg/kg and 1.6 mg/kg, respectively.

Chlorophenol spills in recent years have had a measurable impact on the marine environment. In 1985, following a spill from a wood treatment facility at Campbell River, sampling detected pentachlorophenol and tetrachlorophenol levels of up to 4.6 mg/kg and 3.5 mg/kg, respectively, in marine invertebrates (Colodey, 1985). In March 1984, a spill of about 45,000 litres of pentachlorophenols and tetrachlorophenols entered Hyland Creek, the Serpentine River, and the marine waters of Mud Bay near Vancouver. The effect on the marine environment was much less severe and of shorter duration than in Hyland Creek. Some estuarine-dwelling fish (flounders and sculpins) were found dead among the thousands of dead freshwater fish that accumulated near the mouth of the Serpentine River.

Maximum total chlorophenate concentrations of 22.9 μg/l were observed in marine waters four days after the spill, but dropped below detectable levels within ten days. Chlorophenates were never detected in marine sediments as a result of the spill. Clam tissue concentrations of chlorophenates were low, decreasing from a maximum of 0.108 mg/kg to below detectable levels two months after the spill (Colodey, 1986). Burd et al. (1987) found no impact of the spill on estuarine or marine benthic infaunal populations.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are components and products of incomplete or pyrolytic combustion, and occur both anthropogenically and naturally. Anthropogenic sources include oil refineries, aluminum smelters, car exhaust, and creosote used to treat wharf pilings. All PAHs are toxic to some extent, and several are carcinogenic to many animals, including fish and mammals. Many PAHs bioaccumulate appreciably but most are rapidly metabolized. However, metabolites of PAHs can be more harmful than the parent compounds; some metabolites are carcinogenic.

Samples of shellfish collected from several commercial growing areas in British Columbia had detectable levels of PAHs. Geoducks from the Courtenay area had a level of 0.009 mg/kg of the most carcinogenic PAH, benzo[a]pyrene (B[a]P) (DFO, unpubl. data). This compares with 0.043 mg/kg found in mussels from Burrard Inlet (Dunn and Stitch, 1976).

Concentrations of B[a]P in sediments also showed wide variations between harbour and non-harbour sites, with average levels in harbour sites being about 260 times greater (0.105 versus .0004 mg/kg). PAHs have been found in Dungeness crab digestive glands and English sole livers from Burrard Inlet, but not in the edible muscles of these species (Goyette and Boyd, 1989). There is evidence that PAHs cause tissue abnormalities such as liver tumours observed in English sole (*Parophrys vetulus*) from Vancouver Harbour (Goyette et al., 1988). The high frequency of liver lesions in English sole from Burrard

Inlet and high sediment concentrations of PAHs, led RODAC, Pacific and Yukon Region, to set stringent guidelines on allowable concentrations of PAHs in dredged sediments to be dumped at sea.

PAH levels were also measured in sediments of Kitimat Arm near the Alcan aluminum smelter during 1978 and 1979. The highest level, detected near the smelter, was 10.0 mg/kg (Cretney et al., 1983). The company has taken steps to reduce PAH discharges since 1978 by switching from wet to dry scrubbers (Kay, 1989a). Subsequent measures of PAHs are still high, however (D. Goyette, unpubl. data, 1991).

Organotins

Organotin compounds (e.g., tributyltin oxide or TBTO) are used in the production of polyester resins, polyvinyl chloride plastics, and anti-fouling paints and other coatings. They are toxic to larval forms of marine life, notably shellfish, in the parts per trillion range. Organotins are a known cause of shell thickening and stunting in certain species of adult oysters. Organotins are suspected to have caused growth abnormalities in cultured oysters growing near salmon farms where tin-based anti-foulants were used briefly on net pens (Harding and Kay, 1988). Sediments collected off various shipbuilding/repair facilities and bulk loading terminals in Vancouver, Victoria and Esquimalt Harbours, and the Lower Fraser River Estuary in 1984 and 1985 showed a considerable range of contamination between sites (C. Garrett, Environmental Protection, unpubl. data). In a review of 256 sites in Canada, the ten highest concentrations of tributyltin were in different areas of Vancouver Harbour; the highest concentration (10.78 mg/kg) occurred near a shipyard (Maguire et al., 1986). The government never approved TBTO for use on salmon net pens, and products containing it were removed from B.C. markets upon discovery of the problem. Agriculture Canada has also announced restrictions on its use on boat and ship hulls (Agriculture Canada, 1990).

Dioxins and Furans

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) occur as contaminants in chlorophenols. Combustion of some chlorinated organic chemicals and chlorine bleaching of kraft pulp in the manufacture of paper also create PCDDs and PCDFs. They are extremely toxic and persistent in the environment. Of the 75 known congeners, 2,3,7,8-TCDD is the most toxic, and is the only congener for which Health and Welfare Canada has published guidelines (20 parts per trillion (ng/kg)) for the level in fish.

The 1984 spill of chlorophenols in Hyland Creek, which discharges into Boundary Bay in south Georgia Strait, included trace amounts of dioxins and furans but not TCDD (Colodey, 1985). Sampling following the spill detected no dioxins or furans in sediments from Boundary Bay and a reference site in the south Strait of Georgia. However, crab samples from Boundary Bay contained traces of TCDD and measurable levels of other dioxin congeners and furans. Sidestripe shrimp (*Pandalopsis dispar*) and English sole from Boundary Bay also contained low parts per trillion levels of octachlorinated dibenzo-*p*-dioxin. A reference crab hepatopancreas sample from Indian Arm of Burrard

Inlet contained 10 ng/kg TCDD and over 300 ng/kg of furans and other dioxin congeners. English sole and sidestripe shrimp from Burrard Inlet contained trace to very low ppt (ng/kg) levels of octachlorinated dibenzo-*p*-dioxin.

In 1987, samples of sediments and fish and invertebrate tissues from marine waters near most coastal pulp mills and other industrial sites in B.C. were analyzed for dioxins and furans (Norstrom et al., 1988b). A News Release by the Ministers of Environment Canada, Fisheries and Oceans Canada, and Health and Welfare Canada on 16 May 1988 also provided data. The majority of fish samples contained no detectable residues of 2,3,7,8-TCDD. Where 2,3,7,8-TCDD was detected, levels were well below the 20 ppt (ng/kg) established for this congener under the *Canadian Food and Drug Regulations*. Similarly, except for a few isolated samples that contained relatively higher levels, residues of the less toxic dioxin and furan congeners in fish ranged from non-detectable to 20 ppt. Except one sample of oysters, 2,3,7,8-TCDD residues in shellfish were less than 20 ppt and in many instances were non-detectable. One sample of oysters from near the Crofton mill, an area already closed to shellfish harvesting because of bacterial contamination, contained 31 ppt of 2,3,7,8-TCDD. Residues of 2,3,7,8-TCDD in crab digestive glands from several areas ranged up to 100 ppt; however, single samples from Port Mellon, Woodfibre and Prince Rupert contained 662, 356, and 487 ppt 2,3,7,8-TCDD, respectively.

Less toxic dioxin congeners ranged from non-detectable to 1,514 ppt in most crab samples, but contained up to 4,682 ppt in isolated instances. Furans ranged from non-detectable to 2,605 ppt, except three samples from Port Mellon, Woodfibre, and Prince Rupert where residues of 2,3,7,8-TCDF ranged from 18,890 ppt to 24,986 ppt. Scientists cited dioxins created in the bleaching process of kraft pulp production as the major source of contamination.

Further sampling confirmed these elevated levels. On 30 November 1988, DFO closed some crab, prawn and shrimp fisheries in the vicinity of these three mills. It also conducted further analyses for dioxins and furans in crustaceans and molluscs. As a result, DFO, in consultation with Health and Welfare Canada, closed shellfish fisheries on 23 November 1989. These closures included crustacean shellfish harvesting in the vicinity of pulp mills in Kitimat, Gold River, Crofton, Nanaimo, Powell River, and Campbell River. There was also a closure for crab fishing in Cowichan Bay, where there is no pulp mill, but where a major sawmill operation exists. The closure at Kitimat included some bivalve shellfish species. It is noteworthy that although the Kitimat pulp mill uses no chlorine for bleaching, its effluent does contain some of the dioxin congeners implicated in the closures. Other industries in the area such as an aluminum smelter, sawmills, and a methanol plant are not significant sources of dioxin. Five of the closures were extended in 1990 based on new data supplied by the companies involved. The total area closed to harvesting of certain species is approximately 90,000 hectares.

A 1982-83 study of dioxins and dibenzofurans in eggs of Great Blue Herons (*Ardea herodias*) showed that one colony near Crofton had levels high enough (up to 450 ng/kg) to affect hatching success (Elliott et al., 1988a). In 1987 and 1988, this colony did not fledge any young. Although dioxins were present, the study did not rule out other causes for the reproductive failure. The study identified a nearby pulp mill as a likely source of the dioxins. Research is continuing on herons in the Strait of Georgia.

Other Organic Chemicals

Numerous other toxic, persistent, or bioaccumulative substances enter B.C. coastal waters through storm effluents and discharges. These include a variety of pesticides, phthalate esters (used in the production of polyvinyl chloride plastics), solvents, and chlorinated benzenes, notably hexachlorobenzene (HCB). Other persistent halogenated pesticides, a legacy of past global use or current use in Third World countries, are widely distributed by ocean currents and air currents (see *Seabirds* below).

Studies on the presence of such toxic chemicals are limited to the Lower Fraser River and Estuary and, to a limited extent, False Creek, Burrard Inlet, and McMicking Point near Victoria. Low levels of various pesticides have been detected in some Fraser River fish, and a survey of three Vancouver sewage treatment plants identified 57 trace organic compounds (Rogers et al., 1984). Although the levels of these contaminants are not thought to be significant at present, they indicate bioavailability and the potential for uptake by marine organisms. They would be a threat to marine ecosystems if scientists found them to be increasing or persistent in the tissues of organisms.

Geographic Concerns

There are several geographic areas of concern along the Pacific coast (Table 3.1), some of which are discussed below.

The Lower Fraser River and Estuary

The Lower Fraser River, one of the most heavily urbanized/industrial areas in B.C., receives large quantities of wastes from several sources. Surveys have identified significant concentrations of PCBs, chlorinated phenols, PAHs, various pesticides and metabolites, phthalate esters and other organic contaminants, as well as several trace metals (see Hall, 1985). Sources of these contaminants include municipal sewage treatment plants, wood treatment plants, pesticide plants, bulk loading facilities, chemical plants, refineries, pulp and paper mills, landfills, and storm sewers.

The Standing Committee on the Fraser River Water Quality Plan (1987) thoroughly reviewed the environmental quality of the estuarine portion of the Lower Fraser River. The Committee concluded that, based on the limited available data, provincial water quality objectives were being met, although specific areas of degradation existed. The worst area was the North Arm, where water flow is low and discharges of effluents are large. Degradation of environmental quality in the Main Stem was not significant, and the quality of the Main Arm was intermediate between the Main Stem and the North Arm. Toxic contaminants requiring attention included chlorophenols, PAHs, and dioxins. Chlorophenols enter the estuary from pulp and paper mills upstream (Carey and Lam, 1990).

On Sturgeon and Roberts Banks, trace metals in both sediments and biota remained elevated near the Iona sewage treatment plant (Harding et al., 1988). The study did not detect PCBs and pentachlorophenols, but did detect PAHs at trace levels. Samples of sediments and tissues on Roberts Bank and in deep water off Iona showed background levels of trace metals.

Table 3.1 Some Pacific Coast Geographic Concerns for MEQ

Location	Concerns
Lower Fraser River and Estuary	• organic contamination • PAH and dioxin contamination • pulp and paper contaminants • contaminated fish species
Vancouver Harbour	• metal contamination • organotins and PCB contamination • contaminated fish species
False Creek, Vancouver Harbour	• sediment contamination • PCB and PAH contamination
Howe Sound	• contaminated fish species • pulp and paper contamination • industrial aerial and effluent contamination • ocean dumping • mercury contamination
Kitimat Arm	• aluminum smelter contamination • contaminated fish species • sediment contamination
Rupert Inlet and Alice Arm	• mine tailings disposal • metal contamination of sediments and biota
Neroutsos and Alberni Inlets	• mine tailings disposal • sediment contamination • pulp and paper contamination
Prince Rupert	• dioxins and crab fishery • metal contamination of foreshore • municipal sewage disposal
Victoria Harbour	• municipal sewage disposal • contaminated sediments
Southeast Coast of Vancouver Island	• bacterial contamination of shellfish
Gulf Islands	• bacterial contamination of shellfish • contamination from Fraser River plume

Vancouver Harbour and False Creek

Vancouver Harbour contains a diverse and abundant bottom fauna (Goyette and Thomas, 1987). Although DFO closed bivalve shellfish harvesting because of bacterial pollution, crabs are fished commercially in Port Moody Arm and recreational fishing occurs throughout the Harbour (Reynard, 1986). As noted in *Specific Substances*, elevated levels of certain metals, organotins, and PCBs occur in several locations in Burrard Inlet. Contamination is most pronounced in the vicinity of shipbuilding and ship repair facilities (heavy metals, organotins, PCBs) and refineries (phenols, PAHs) (Waters, 1985; Goyette and Boyd, 1989). Very high levels of contamination occur in the sediments of Coal Harbour (Waters, 1985). Heavy commercial fishing traffic and shipping through Vancouver Harbour, some of which serve the refineries in Port Moody, result in frequent small oil spills that affect aquatic birds; this occurred during 1988-89 (Waldichuk, 1989c).

Studies have revealed high concentrations of zinc, copper, and cadmium in sediments adjacent to ore concentrate loading facilities in Vancouver Harbour. Large amounts of concentrate enter Burrard Inlet at this site through direct spillage and storm drainage (Waters, 1985). A major Environment Canada assessment of Vancouver Harbour showed a high (up to 75 percent) prevalence of tumours and other liver lesions in English sole (Goyette et al., 1988). These findings resulted in an agreement between three levels of government and the Vancouver Port Corporation on a clean-up plan.

Before its development for Expo 86, studies identified False Creek as one of the most highly contaminated water systems in British Columbia. Elevated levels of several metals, including mercury, lead, cadmium, arsenic, copper, and zinc, were detected throughout False Creek (Brothers and Sullivan, 1984). Dredging during preparation of the Expo site contaminated the sediment. Some of this dredged material was re-deposited within False Creek; some was dumped at the Deep Ocean Dumpsite 144 km off the West Coast, and RODAC approved some relatively clean material for dumping at Point Grey.

Environment Canada investigators detected elevated PCB levels from leaking bridge bearing-lubricants in False Creek sediments under the Granville Street Bridge and in soil under the Burrard Street Bridge in 1978 (C. Garrett, Environmental Protection, unpubl. data). These contaminated sediments have since been removed and transported to a storage facility in Edmonton. Elevated PCB and PAH levels have also been identified in sediments of the east basin of False Creek. Management of contaminated sediments and protection of fishery resources from contaminated leachates are continuing problems in False Creek.

Victoria and Esquimalt Harbours

Victoria and Esquimalt Harbours receive contaminant inputs similar to those of Vancouver Harbour, but on a smaller scale. Sediments collected in these inner harbours contained elevated levels of PCBs and mercury, lead, cadmium, copper, and zinc (Environmental Protection, unpubl. data). Analysis has revealed dioxins in the soil of former sawmill operations in both Victoria and Esquimalt Harbours. Outside Victoria Harbour, municipal outfalls discharge sewage effluent at Macaulay Point, McMicking Point, Clover Point, and Finnerty Cove (Lorimer, 1984). Effects include bacterial contamination and elevated levels of trace metals and organic contaminants. Victoria is currently consolidating these systems into one outfall at Clover Point, and has announced plans for treatment.

Howe Sound

Sources of toxic chemicals in Howe Sound include effluent and aerial emissions from a chlor-alkali plant, a ship and barge terminal facility, a sawmill, two bleached kraft pulp mills, a sodium chlorate plant, an abandoned copper/zinc mine, two sewage treatment plants, a landfill site, storm sewers, and a resin glue extender manufacturing plant. An ocean dump site at Watts Point receives dredging spoils, primarily from the Squamish Estuary and the Woodfibre pulp mill (Sullivan, 1987).

Howe Sound has a long history of pollution. In 1971, officials closed fishing in Howe Sound due to excessive levels of mercury in fish and shellfish. Mercury levels in Howe Sound returned to acceptable levels in the early 1970s following major reductions in mercury losses from the chlor-alkali plant (cf., IEC Beak Consultants Ltd., 1983). Officials have subsequently lifted the fishing closure. Recent studies have shown that mercury levels in the sediment are still high (up to 16 mg/kg) in some areas of the Squamish Estuary (Moody and Moody, 1985), exceeding levels found in most other B.C. marine locations. Approximately one percent of the mercury is in a biologically available form (Thompson et al., 1980).

Scientists detected very high levels of cadmium in the sediments of Thornborough Channel adjacent to the Port Mellon pulp mill, in addition to elevated lead and PCB levels. Sediments off Woodfibre contained high levels of PCBs and mercury (Sullivan, 1983).

The Britannia copper/zinc mine, closed since 1974, still discharges mine drainage water. Monitoring revealed elevated copper and zinc levels in surface waters and sediments of Howe Sound in the vicinity of the mine (Goyette and Ferguson, 1985).

In 1988 and 1989, the Department of Fisheries and Oceans closed portions of Howe Sound again because of unacceptable levels of dioxins in crabs, prawns and shrimp (See *Dioxins* above).

Kitimat Arm

Studies have identified significant releases of fluoride and PAHs from the Alcan aluminum smelter located in Kitimat Arm (Cretney et al., 1983). While investigation did not determine PAH loadings to the environment from the smelter, it detected elevated PAH concentrations in both sediments and marine organisms collected near the smelter. A disorder in bivalves from Kitimat Arm (involving the invasion of tissue by immature haemocytes) and its relationship to possible elevated PAH levels has been investigated (Brown et al., 1983).

Fisheries and Oceans Canada closed an area at the head of Kitimat Arm in 1989 to crab and bivalve shellfish harvesting because of dioxin contamination (See *Dioxins* above).

Rupert Inlet and Alice Arm

Since 1971, a copper mines has discharged tailings to Rupert Inlet. Currently, the mine discharges approximately 55,000 metric tonnes of tailings and 93,000 tonnes of waste rock daily. Inspection has revealed changes in habitat up to 18 km from the mine's outfall. A further impact of waste rock disposal is in-filling of the Inlet. It is estimated that the depth of tailings in the trough of Rupert Inlet will reach 46 metres during the life of the mine. Elevated copper levels, indicating traces of tailings, extend 33 km from the mine. The short-term effects of this discharge are benthic smothering and bioaccumulation of trace metals in some biota, notably seaweeds and mussels near the loading docks. Although there are insufficient data to provide conclusive evidence, scientists believe the mine tailings covering the rocky bottom habitat of the prawn (*Pandalus platyceros*) have an impact on the population of this species in Rupert Inlet (Waldichuk and Buchanan, 1980). Long-term impacts of bioaccumulation of metals are not expected. Observation has revealed recolonization to communities typical of soft-bottom substrates in areas of light deposition.

In Alice Arm, the Kitsault mine tailings replaced natural sediments during brief mine operations in 1968-72 and 1981-82. Kitsault tailings were not toxic and did not affect the burrowing ability of several subtidal and intertidal invertebrates (Reid and Baumann, 1974). However, in laboratory tests on a variety of species, lead from the tailings bioaccumulated to a considerable degree (Guthrie, 1985; McLeay et al., 1984). In the Alice Arm environment, lead accumulated significantly in subtidal bivalves (Goyette and Christie, 1982; Goyette and Thomas, In Preparation) and in king crabs, *Paralithodes camtschatica* (Thompson et al., 1986) with the opening of the mine. Following closure of the mine, observers noted rapid recolonization of benthic infauna occurred, but complete ecosystem recovery was much slower (Kathman et al., 1984).

Neroutsos and Alberni Inlets

Each day pulp mills discharge approximately 87,000 cubic metres of sulphite effluent and 168,000 cubic metres of kraft effluent to Neroutsos and Alberni Inlets, respectively. The discharge at Neroutsos Inlet has depressed the dissolved oxygen concentrations below levels necessary to maintain healthy fish populations during certain periods of the year (Colodey and Pomeroy, 1985). Fish kills have occurred repeatedly in the inlet in recent years. Studies have documented *in situ* toxicity as measured by fish mortality and avoidance reactions up to ten kilometres from the mill at Port Alice (McGreer and Vigers, 1979).

A similar dissolved oxygen problem exists in Alberni Inlet. However, the quality of surface water has been adequate for salmon migration because of well-defined stratification of Somass River water overlying the more saline bottom waters (Colodey et al., 1988). However, the thickness of the oxygenated layer was reduced to about a metre and the water below three metres has frequently reached concentrations of less than 2.5 mg/L in 1985 (Waldichuk, 1988c). The water quality has continued to decline gradually in this inlet with increasing mill production. Several years of lower than normal river runoff and warm temperatures have exacerbated this decline. In addition, reduced pre-spawning survival of the 1990 run of sockeye salmon (*Oncorhynchus nerka*) was thought to be due to poor water quality caused by the mill (Environment Canada and DFO, unpub. report).

Prince Rupert

Studies have recorded very high trace metal levels along the city foreshore. A fire in a metal mine concentrate storage warehouse some years ago caused large volumes of runoff as firemen hosed the facility (Environmental Protection, unpubl. data). The runoff flowed through the city sewage system to the ocean, likely causing the elevated metals level.

In 1984-85, Prince Rupert consolidated its shoreline sewage outfalls into three long outfalls to diffuse sewage effluent into deep (200 m) water. This resulted in decreased levels of bacterial contamination along the foreshore. In nearby Porpoise Harbour, DFO briefly closed crab fishing in 1977 because of a PCB spill and again in 1988 because of the presence of dioxins (see *Dioxins* above).

Muchalat Inlet (Gold River), Discovery Passage, Northumberland and Stuart Channels, and Malaspina Strait

Dioxin and furan contamination of the marine environment in these areas (see *Dioxins* above) will warrant continuing assessment for many years. Regulations to eliminate dioxins and furans from pulp mills will become effective in 1994, and all mills have begun installing the necessary process and treatment facilities. However, it is not known when dioxin levels will decline sufficiently for the fishery closures in these areas to be lifted. Further, the environmental effects of these contaminants here, as elsewhere, are unknown.

Assessment

This section assesses the implications for valued ecosystem components of losses in marine environmental quality identified in the preceding sections. Nassichuk (1985) lists salmon, herring, groundfish, and shellfish, in that order, as being the most valuable fisheries on the Pacific Coast. Marine mammals and sea birds are important aesthetically, culturally, and ecologically and for tourism.

Salmon

Salmon (*Oncorhynchus* spp.), the most commercially valuable living resource of the Pacific marine environment, requires clean, well-oxygenated surface water (normally the top 100 m) with abundant zooplankton populations and populations of smaller fish, such as herring, anchovy, and needlefish. Juveniles typically rear in nearshore and intertidal habitats. Some species spend considerable time in estuaries. Kay et al. (1986) found no evidence of population declines on the West Coast attributed to chemical pollution. While noting threats of habitat loss and pollution, Pearse (1982) found that the principal factor affecting Pacific salmon stocks was overfishing.

Two causes of habitat loss due to pollution have been identified in the marine environment: (1) low dissolved oxygen in Neroutsos and Alberni Inlets, and (2) acute toxicity in intertidal habitats at Port Alice (Neroutsos Inlet), Gold River (Muchalat Inlet), Woodfibre (Howe Sound), and Sturgeon Bank (Fraser River Estuary).

Widespread contamination of the marine ecosystem by extremely low, even undetectable, levels of organic chemicals (see *Pulp and Paper Effluents* above and *Seabirds* below) are as yet an undefined threat. In particular, the occurrence of organochlorines in marine waters near pulp mills needs further investigation.

Environmental Protection does not regularly sample salmon in its field studies. Further, there is no regular monitoring of contaminants in salmon caught in Canada and sold in local markets. As a result, levels of contaminants cannot be quantified.

Dissolved Oxygen

In Alberni Inlet, although oxygen depletion caused by pulp mill effluent has reduced salmon habitat in deeper waters, the surface layer is usually sufficiently oxygenated by the Somass River to ensure passage of salmon (Colodey et al., 1988). The situation merits close monitoring, however, because of the one to two metres deep oxygenated surface layer and the low oxygen (< 2.5 mg/L) at depths below three metres during August when peak migration of sockeye salmon occurs (Waldichuk, 1988c). Other studies have noted the gradual increase in loss of habitat (Colodey et al, 1988).

In Neroutsos Inlet, pulp mill effluents cause severe oxygen depression under certain conditions of oceanographic and meteorological stability. The depression eliminates juvenile salmon-rearing habitat over one to two kilometres, and may delay migration of a small (± 6000) run of chum salmon in some years. Water quality improved dramatically after refinements to waste treatment systems in 1977; it worsened in 1985 and is currently very poor at certain times of the year.

Toxicity

Toxicity due to pulp mills (ten locations) and municipal effluents (one location) affects approximately 17.5 km, or about 0.06 percent of all intertidal habitats along the British Columbia coastline. As pulp mills and municipalities improve waste treatment facilities and install long outfalls to disperse effluent away from sensitive intertidal habitats, these losses have declined. Studies in Sweden and elsewhere (see Colodey, 1989) have shown that chlorinated organic compounds can have a wide range of effects on marine fish and invertebrates over an extensive area. If research confirms these effects in Canada, the area affected will be much greater than indicated above.

Herring

Herring (*Clupea harengus pallasi*) require clean, well-oxygenated water with abundant zooplankton populations, particularly in nearshore environments. They spawn on kelp in shallow water. Investigation revealed that pulp mill effluent in Porpoise Harbour, near Prince Rupert, severely affected a significant herring population. Conversion of the mill from the sulphite to the kraft process and installation of a diffuser resulted in recovery of the stock. Investigation of the effects of organochlorines on herring and herring spawning near pulp mills is required. Oil spills have threatened herring spawning beds in B.C. waters, but not seriously affected them. Although municipal sewage effluents can be toxic to herring eggs and larvae (Coastline Environmental Services, 1984), effects on populations are improbable because of the distribution of herring spawning areas in relation to municipal outfalls.

Benthic Organisms

This diverse group of organisms have some common habitat requirements: they live close to or in contact with marine sediments and feed on benthic infauna, epifauna or detritus. Three threats to them are identified: (1) smothering of bottom habitat with mats of wood fibres (pulp mills) or tailings (mines), (2) creation of toxic conditions in or near sediments, and (3) uptake of toxic chemicals. Uptake of contaminants threatens both ecosystem health and human health.

Smothering of Bottom Habitats

Wood fibres from pulp mill effluents at ten coastal mills have affected approximately 33.8 km^2 of benthic habitat (average of 3.4 km^2/mill) (Figure 3.8). This area increased during the early 1980s as mills installed long outfalls to divert effluents from sensitive intertidal habitats. No significant increase or decrease is expected now. Recovery of habitat is thought to occur over many decades.

Tailings deposition from mines is associated with a further 83.4 km^2 of benthic habitat smothering, primarily (66 km^2) at the Island Copper Mine, Rupert Inlet. Recovery on cessation of discharge is known to occur within several years, but benthic communities are permanently altered to those favouring soft-bottom substrates.

Toxic Conditions In Sediments

Very little information is available because government laboratories have only recently conducted sediment bioassays, and very few studies considering local sediment toxicity have been published. Toxicity has, however, been observed in sediments from several coastal areas, including Vancouver Harbour (Goyette and Boyd, 1989). A number of ocean dumping applications have recently been rejected because of failed sediment bioassays, evidence of toxic conditions at several coastal locations.

Sediment toxicity at many locations can be inferred from biological effects thresholds in relation to levels of contaminants. Apparent Effects Thresholds or AETs, derived from extensive benthic community analyses and sediment bioassays in Puget Sound, represent the level of each contaminant above which adverse biological effects were always observed. Separate AETs have been published for oyster larvae, amphipods, luminescent bacteria (Microtox®), and benthic communities. In a review of published reports, Waters (1988) found that trace metals (mercury, cadmium, copper, and lead) in marine sediments at False Creek, Howe Sound, Squamish Estuary, Sturgeon Bank, McMicking Point, Macaulay Point, Anyox, Alice Arm, and Prince Rupert Harbour often exceeded their AETs derived by Tetra Tech, Inc. (1986). From all coastal locations sampled, mercury exceeded the AETs 27 percent of the time, copper 13 percent of the time, and lead six percent of the time (L. Harding, Environmental Protection, unpubl. data). PCB levels exceeded the Puget Sound AET at Campbell River, Alberni Inlet, Ganges Harbour, Esquimalt Harbour, and Port Mellon. Effects on bottom fish, crabs, shrimp, and prawns are not known, nor are data available to demonstrate increasing or decreasing trends in the PCBs.

Bioaccumulation

Although studies have identified elevated (above background) levels of trace metals and organics in specimens of various species at many locations (see *Specific Substances* above), the implications of bioaccumulation are difficult to interpret. Possible effects include sublethal toxicity at the individual, population, or ecosystem levels, and threats to human health. The effects of contaminants on benthic animals have rarely been measured in B.C. waters, but may include changes in community structure.

There is no regular monitoring program for contaminants in groundfish and invertebrates caught in Canadian waters and sold in local markets. Threats to human health are assessed by comparing levels of contamination in edible tissues with guidelines for contaminants in fish. In recent years, potential threats have resulted in the temporary closure of fisheries: (1) discharge of mercury in Howe Sound prior to 1971, (2) a PCB spill in Porpoise Harbour in 1977, and (3) a pentachlorophenol spill in a creek discharging to Boundary Bay in 1984. As noted under *Dioxins* above, DFO imposed new closures as a result of discharges of dioxins and furans from pulp mills in Howe Sound and Porpoise Harbour in 1988, and Discovery Passage, Northumberland Channel, Stuart Channel, Kitimat Arm, Muchalat Inlet, and Malaspina Strait in 1988, 1989, and 1990. These closures are still in effect (March, 1991).

Shellfish

Molluscan bivalve shellfish (clams, mussels, scallops and oysters) considered safe for human consumption must be harvested from areas with approved sanitary water quality and must meet natural toxin and pathogen guidelines. Shellfish-growing waters exceeding bacterial contamination standards are closed to harvest, causing a significant loss of production. The B.C. mollusc shellfishery is valued at $28.7 million wholesale a year (B. Kooi, pers. comm., 1991; 1988 data). Over 70,500 hectares, or about 2.8 percent of the B.C. coastline, were closed due to bacterial contamination in 1988. Each year, while areas are re-opened as sources of pollution are eliminated, new areas are closed due to new pollution sources. On balance, the total closed area increases slightly (0.15 percent) annually.

Commercial bivalve harvest areas are usually remote from industrial pollution sources. They are assumed to be free of chemical contaminants, although no regular monitoring programs exist in British Columbia. Duncan (1984) reviewed the contaminant levels in bivalves collected near municipal outfalls and showed considerable uptake in some non-commercial areas.

Paralytic shellfish poisoning (PSP) occurs regularly along the Pacific coast and results in occasional harvesting closures, although human deaths have been very rare. Naturally occurring blooms of dinoflagellate phytoplankton cause PSP. Although nutrient enrichment by sewage has caused such blooms in other parts of the world, this is not thought to be the case in B.C. waters.

Seabirds

Studies between 1971-1985 detected a number of organochlorines in seabirds, and more recently, DDE and pentachlorophenols have been found at trace levels (Noble and Elliott, 1986; Elliott et al., 1989a). Studies have shown that eggs of the Great Blue Heron (*Ardea herodias*) are a valuable indicator of the presence of toxic substances in coastal waters and that levels of organochlorines in the Strait of Georgia declined during the period 1977-1987 (Whitehead, 1989). Although dioxins were significantly higher in eggs of the herons in 1987 than in 1986 near the Crofton pulp mill, it was not conclusively proven that they were the cause of reproductive failure (Elliott et al., 1989b).

PCBs were highest in cormorant eggs from the Fraser River Estuary and the Strait of Georgia. Dieldrin, heptachlor epoxide, oxychlordane, and HCB levels were consistently present at low ppb levels in most seabird eggs. Comparison of recent samples (collected in 1983 and 1986) and samples collected earlier (during 1970, 1973, and 1979) show significant decreases in all contaminants measured. The evidence does not suggest that West Coast seabird populations are affected by toxic chemicals, although observations revealed unexplained reductions in breeding colonies. Contaminant mobilization from fat reserves during years of food shortage may put Rhinoceros auklet chicks and other fish eating species at risk of organochlorine poisoning.

The *Nestucca* oil spill of 1988, in which 30-50,000 seabirds are estimated to have died (Harding and Englar, 1989), showed that some seabird populations are at risk in the event of a major oil spill. Increased tanker traffic magnifies the risk.

Marine Mammals

No studies have been conducted yet on the effects of pollutants on marine mammals in British Columbia. There was conjecture that the 1984 spill of chlorophenate compounds in Hyland Creek and Boundary Bay contributed to the deaths of several gray whales (*Eschrichtius robustus*) in the Strait of Georgia and adjacent U.S. waters (see *Chlorophenates* above). However, Colodey (1986) showed that the chlorophenate levels in tissues of several of the whales were probably too low to be of toxicological significance. In nearby Puget Sound, Calambokidis et al. (1984) found that several synthetic chlorinated organic chemicals were detectable in seals, sea lions, and whales, mostly at low concentrations. PCBs in harbour seals, however, exhibited biomagnification (higher in seals than in the fish they eat) and may have contributed to the reproductive disorders observed in the early 1970s. Similar studies have not been done in western Canada, but scientists know that populations of seals, sea lions, killer whales, and gray whales are increasing (M. Bigg, pers. com., September, 1988).

A network of volunteers established the Stranded Whale and Dolphin Program of British Columbia to investigate cetacean strandings. The first report (Baird et al., 1989) listed 22 strandings in British Columbia in 1987. The Report cited starvation of juveniles following separation from their mothers, parasite infection, net entanglement, neonatal mortality (in killer whales), and gastritis as causes of death. One male false killer whale (*Pseudorca crassidens*) that beached on Denman Island in May 1987 had very high levels of pesticides and heavy metals (Baird et al., 1988). This was the first occurrence of a false killer whale in Canada.

Summary - Marine Environmental Quality on the Pacific Coast

The sources of pollutants in the West Coast marine environment are ocean dumping of dredged material, municipal effluents, mine tailings, pulp and paper mill discharges, and spills and related environmental accidents. Environmental contaminants of concern include heavy metals, PCBs, chlorophenates, PAHs, organotins, dioxins, and other organic chemicals. Geographic areas of concern are the Fraser River Estuary, False

Creek, Vancouver Harbour, the Victoria Area, Howe Sound, Kitimat Arm, Rupert Inlet, Alice Arm, Neroutsos Inlet, Alberni Inlet, Prince Rupert Harbour, Porpoise Harbour, Muchalat Inlet, Cowichan Bay, Stuart Channel, Northumberland Channel, Malaspina Strait, and Discovery Passage.

Signs of widespread ecosystem stress have been detected and degradation of nearshore environments is pronounced in many inshore waters. Localized contamination of both sediments and biota also occurs. Adverse effects include loss of fish habitat, toxicity, bioaccumulation of toxic chemicals in fish, and shellfish harvesting closures. More widespread, but very low levels of chlorinated organic chemicals also occur in migratory seabirds and marine mammals that forage offshore and in other parts of the Pacific.

Two types of areas have been closed to fisheries because of contamination. Shellfish-growing areas are closed due to bacterial contamination, and waters near pulp mills are closed for harvest of certain species due to dioxin contamination.

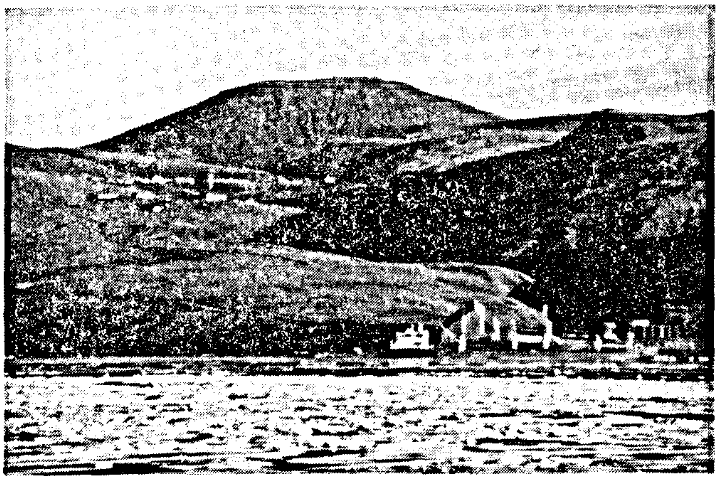
On the positive side, installation of a deep outfall off Sturgeon Bank, for effluent from the Iona Island sewage treatment plant in April 1988, reduced bacterial contamination (faecal coliforms) of beaches, e.g., Wreck Beach in outer Burrard Inlet. Undoubtedly, fish habitat on Sturgeon Bank has also improved in the vicinity of the open trench that formerly carried effluent from the treatment plant into the Fraser River Estuary. Similarly, the city of Victoria is consolidating its numerous shoreline outfalls into one long outfall and is planning for improved treatment.

Installation of clarifiers and in-plant controls at coastal pulp mills resulted in major reductions in the area of severe water quality degradation. Installation of diffusers and long outfalls at most pulp mills has allowed recovery of shoreline biological communities. In addition, most mills are installing secondary treatment facilities and removing dioxin in advance of announced new federal and provincial regulations.

The shortage of long-term monitoring programs precludes establishing many trends in environmental quality. Marine environmental quality indices are largely absent, except for bacterial standards for shellfish growing waters, residue and effects data for birds and fish, and guidelines for some chemical contaminants in fish products for human consumption. Overall, the quality of the Pacific coastal marine environment has been assessed descriptively in this report, and clearly shows where many of the threats exist. A more comprehensive and quantitative status and trends analysis of marine environmental quality is needed for this region in the 1990s.

Chapter Four

The Arctic



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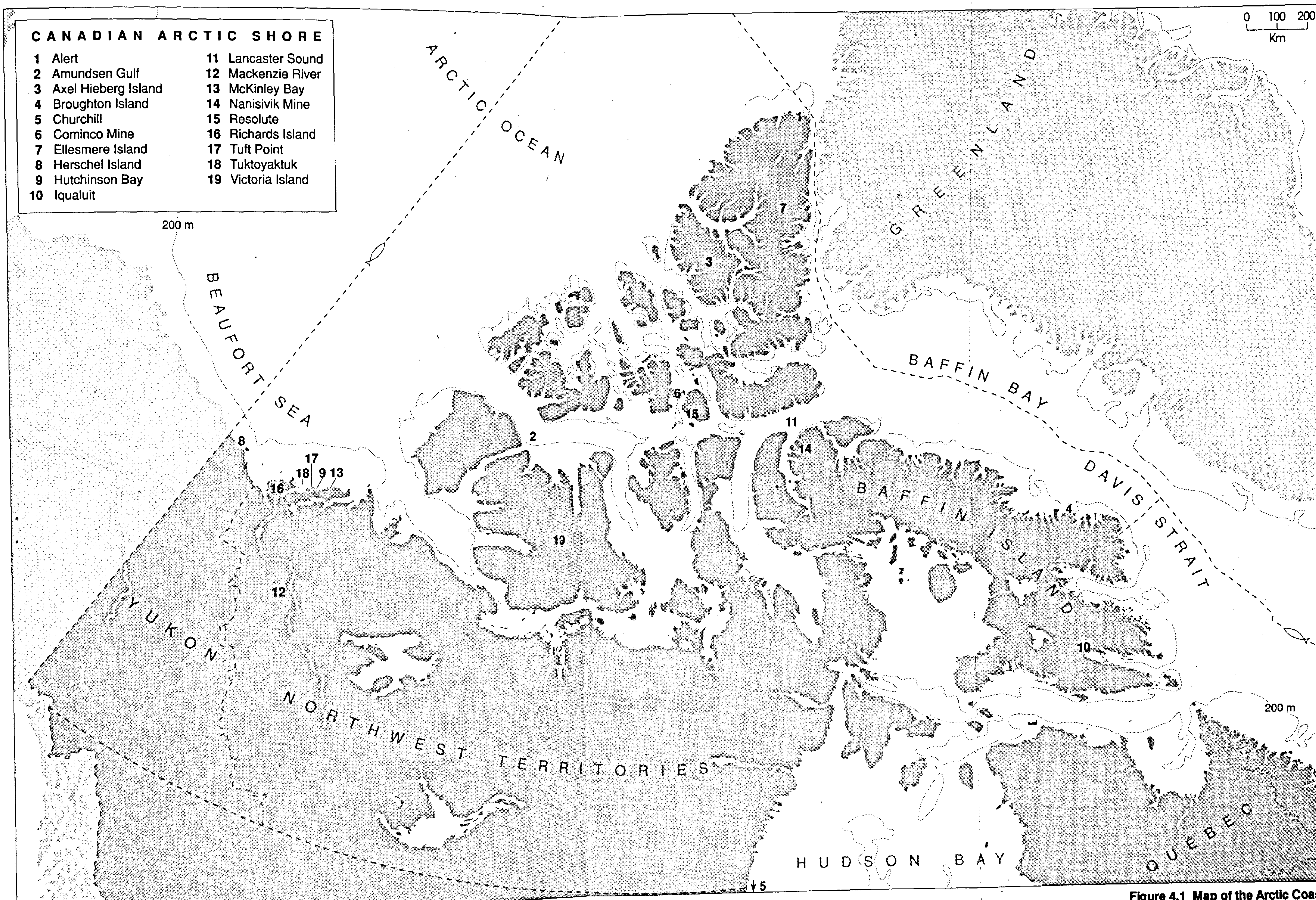


Figure 4.1 Map of the Arctic Coast

Introduction

The Arctic Ocean and subarctic seas of Canada cover a vast area, from the Beaufort Sea in the west to Baffin Bay/Davis Strait in the east, and from north of Ellesmere Island to Hudson Bay in the south (Figure 4.1). The coastline stretches 160,000 km, twice that of the Pacific and Atlantic regions combined. The Arctic marine environment supports several uses, most of which are associated with hydrocarbon exploration and production, transportation, and natural resource harvesting.

Human uses of the Canadian Arctic marine environment can be broadly divided into historical uses (harvesting of fish, waterfowl, and marine mammals) and recent industrial-municipal uses, e.g., shipping, oil exploration, and development, dredging of marine sediments, and disposal of waste materials in offshore areas. Inuit still harvest whales, polar bears, seals, walruses, geese, ducks, char, and whitefish from nearshore areas along the south and central Arctic coasts. Although many communities are now supplied with non-traditional foods, Inuit supplement their diet with traditional foods. Some communities or families depend almost entirely on harvested marine mammals, birds or fish for food and income. The catalyst for the recent industrial use of nearshore and offshore areas was the discovery of oil in the Arctic Islands and southern Beaufort Sea during the 1960s. Associated vessel traffic and increased interest in transiting northern waters (both on and below the water surface), together with increasing industrial, municipal, and air-borne contamination, have raised concern about maintaining the quality of Arctic coastal and offshore marine environments (Table 4.1).

Pollution Sources

Anthropogenic inputs to Arctic waters originate primarily from specific point sources (e.g., offshore drilling sites, vessels, effluent discharges). This generalization becomes somewhat blurred by the fact that these inputs may, after entering the marine environment, be transmitted in the case of vessel noise, or dispersed throughout the water column or over wide areas. Thus, the effects of a point source input may extend well beyond its origin. In addition, the extent of the non-point atmospheric impact of contaminants to the Arctic is being realized through recent research. All of these inputs can have an impact on marine environmental quality.

Dredging and Ocean Dumping

Since 1959, approximately 173 dredging operations have been carried out in the southern Beaufort Sea region, primarily at Tuktoyaktuk Harbour, McKinley Bay, and Tuft Point, and at Churchill Harbour, Hudson Bay (Taylor et al., 1985; Sackmann et al., 1986; Environmental Protection, Yellowknife, files 1990). In addition to harbour development, operators dredged in the Beaufort Sea to construct artificial islands and subsea berms and to excavate glory holes or seafloor excavations intended to protect well heads from ice scour. Arctic Mobile Caissons (MACs) used in offshore drilling operations also fill their core with dredged material. After completion of drilling operations, the sand fill must be removed in order to float the structure to a new location. Between 1973 and 1985, 28 surface-piercing islands and 14 subsea berms were constructed from a total of 38,380,000 cubic metres of dredged material (Taylor et al.,

Table 4.1 Major pollutants, their sources and impacts on Arctic marine systems

Pollutant	Source	Origin and Transport	Impact on Arctic Marine Systems
Petroleum	Municipal Wastes	Long distance	Unknown
	Industry via Rivers	Local	Potential local effects
	Oil Spills, Production and Transportation, Shipping	Local	Severe in coastal marine habitats
Metals	Industrial centers	Long distance atmospheric	An emerging problem
	Mining	Local	Local effects
Pesticides, other persistent chemicals	Widespread Use Globally	Long distance	Global problem
Sewage	Municipal Wastes	Local	Only local effects
Agricultural	Fertilizer runoff	Primarily local	Not a major Arctic problem
Noise	Seismic Exploration Drilling Shipping Aircraft Helicopters	Local	Impact unknown, but is a cause for concern
Plastics	Shipping	Long distance	A serious problem
Fishing nets, etc.	Fishing Industry	Local	Also a problem

Source: Modified from Alexander, 1986.

1985; Sackmann et al., 1986). Beaufort Sea dredging activity peaked in 1981 when 17 dredging operations excavated a total of 9,976,000 cubic metres of sediment (Sackmann et al., 1986). Between 1974 and 1985, seven dredging projects were carried out in Churchill Harbour for harbour improvement and maintenance.

Dredged material has been sidecast, transported to nearby offshore dumping sites, or pumped onshore to be used as landfill. Studies have indicated that Beaufort Sea dredging has resulted in localized, short-term increases in suspended sediment concentrations and turbidity, as well as alteration of benthic habitats at the dredging and dumping sites (Thomas et al., 1985). Resuspension of contaminants is a concern if dredging occurs in areas subject to accumulation of drilling wastes, hydrocarbons or untreated sewage (ESL Environmental Sciences Ltd., 1982; Thomas et al., 1985; Martin et al., 1986). While oil companies constructed most islands and berms from newly dredged materials, several islands incorporated material from abandoned islands and berms. Good quality aggregate is not abundant in the Beaufort Sea area. These construction practices may result in the transfer of drilling waste residues, various hydrocarbon compounds, and miscellaneous chemicals spilled at the original island sites to the new locations. This contamination may have a long-term cumulative impact on the marine environment.

Oil Exploration

Between 1973 and 1989, oil companies drilled 130 offshore wells in the Beaufort Sea, Arctic Islands, Davis Strait, and Hudson Bay (Turney et al., 1986; COGLA files). At each of these sites, they discharged drill cuttings and spent drilling fluids, consisting of drilling muds and specialized additives in an aqueous or oil medium, into adjacent waters. Approximately 1,500 cubic meters of drilling mud and 200-400 cubic metres of formation cuttings may be discharged during the drilling of a typical 400 metre deep well (ESL Environmental Sciences Ltd., 1982). In the Arctic Islands, records show 22 wells discharged approximately 12.2 tonnes of drilling mud for each 100 metres of well depth (Sackmann and Smiley, 1985). Periodically, drilling operators or support companies also dumped solid wastes such as scrap metals or excess unused drilling mud additives into Arctic waters.

The Canada Oil and Gas Lands Administration (COGLA)* oversaw the disposal of drilling waste under the provisions of the *Oil and Gas Production and Conservation Act*. Specifically, COGLA established the *Guidelines for the treatment and disposal of wastes from petroleum exploration and production installations on Canadian offshore frontier lands*, in brief the "Offshore Waste Treatment Guidelines." Usual offshore disposal practices call for the return of conductor hole cuttings directly to the seafloor. Standard operating procedures return cuttings and drilling fluids generated by drilling below conductor hole depth to the surface. Operators treat the cuttings before their disposal into the water column. Oil-free drilling fluids are diluted to achieve a 25:1 ratio of water to fluid, after which it is discharged into the ocean. At Arctic Island locations, drilling rigs situated on built-up sea ice discharge drilling effluents 10 metres below the ice bottom. Typically, operators dilute and discharge oiled cuttings and oil-based fluids contaminated by diesel fuel in the same manner as oil-free fluids. Operators used an average of 23,000 litres of diesel as a lubricant to free sticking drill pipe at 18 wells. The authorities issued one company an Ocean Dumping Permit to dump cuttings contaminated with a low toxicity oil-based mud at a location where it was discharging the same muds as part of a normal drilling operation.

* COGLA is to be dismantled, as per the Budget Speech, February 1991.

In terms of potential biological effects, the drilling mud formulation is probably more important than actual volumes of discharged drilling muds. The principal environmental concerns associated with offshore disposal of drilling fluids are the toxicity of drilling mud constituents and possible localized accumulation of trace metals in sediments and biota (ESL Environmental Sciences Ltd., 1982). Based on data from two Beaufort Sea wellsites (Thomas, 1978), levels of cadmium, chromium, and zinc in drilling muds exceed background concentrations in the Beaufort Sea, but not in world oceans. However, drilling mud mercury levels exceed the range found in the Beaufort Sea and world oceans. It is known that trace metals in drilling muds are rapidly diluted after muds are discharged into the water column (Ayers et al., 1980; ESL Environmental Sciences Ltd., 1982). Most studies indicate restriction of measurable biological effects to an area within 300 m to 500 m of the discharge point. Hydrocarbons and metals are at background levels within five to six km of the wellsite (Thomas et al., 1983c).

The major components of water-based drilling fluids approved for use in Arctic waters (such as barite, bentonite, modified lignosulfonate, and potassium chloride) are of low acute toxicity with 96 hour median lethal concentration (LC50) values ranging between 1,170 ppm and 100,000 ppm (Indian Affairs and Northern Development Canada, 1986). One exception is caustic soda, which has been used extensively (in terms of both volume and frequency of use) and has a reported 96 hour LC50 of 105 ppm. Caustic soda is, however, rapidly neutralized in seawater. Some minor or infrequently used additives, such as surfactants, corrosion inhibitors, and biocides, are more toxic. These additives have 96 hour LC50 values ranging from 1 ppm to 120 ppm. The higher acute toxicity of diesel (NAS/NRC, 1985) is of particular concern given the relatively large quantities used during differentially-stuck pipe situations (Sackmann et al., in preparation; Turney et al., 1986).

Whole drilling muds are generally less toxic than individual components due to neutralizing reactions and adsorption of soluble components to clay particles within the muds. Most 96 hour LC50 values for whole muds discharged into Arctic waters exceeded 10,000 ppm for marine organisms, although some ferrochrome lignosulfonate mud formulations had measured LC50s of 500 ppm (Neff, 1982; Thomas et al., 1983c).

The operation of shorebases to support offshore oil and gas drilling activities has had localized impacts on the marine environment (Packman and Shearer, 1988). Tuktoyaktuk Harbour, McKinley Bay, and Herschel Island act as staging areas for the resupply of ships and drilling rigs with drilling consumables and fuel. They also provide drydock facilities for ship repairs. Chronic fuel spills are the primary source of contaminants, but runoff from work yards also contributes to marine pollution. Measurements indicate that the highest levels of chromium, copper, mercury, nickel, and lead are at the shorebase areas along the Tuktoyaktuk Peninsula. However, it is difficult to differentiate between the contribution from industrial activities and that of the Mackenzie River which is a significant source of metals and hydrocarbons. The highest total PAH and n-alkane concentrations in the Beaufort Sea are in Tuktoyaktuk Harbour followed by McKinley Bay (Thomas et al., 1983b; Dobrocky Seatech Ltd., 1985). Overall, oil drilling and effluent discharges in Arctic waters have only localized biological effects (ESL Environmental Sciences Ltd., 1982).

Operators have drilled 42 wells offshore in the Arctic islands, and two wells each in both Davis Strait and Hudson Bay. They have not, however, studied the environmental impacts of the wells. It is quite likely, however, that the effects would be localized, as in the Beaufort Sea (Packman and Shearer, 1988).

In 1983, 1984 and 1985, Shoreline Drift Waste Surveys were conducted on the southern Beaufort Sea coast to assess the potential environmental impacts from drift wastes, primarily plastics, to monitor the effectiveness of clean-up programs conducted by industry, and to recommend appropriate disposal options (Shearer et al., 1985; Shearer and Bourque, 1987). The results of the surveys indicated that over 90 percent of the drift wastes sighted along the Beaufort Sea shoreline had originated with the oil and gas industry. While the study concluded that the wastes were accidentally lost, the quantity and types of drift waste were regarded as having a negative aesthetic effect in areas that would otherwise not be influenced by human presence (Shearer et al., 1985). The study concluded that the observed wastes had minimal biological impact. Nonetheless, oil industry operators conducted clean-up programs. Additional monitoring surveys were conducted in 1989 and 1990.

Mining

Two lead-zinc mines discharge tailings effluent indirectly into marine waters. One mine (Cominco Limited - Polaris Operations) is on Little Cornwallis Island, near Garrow Bay; the other mine (Nanisivik Mines Limited) is near Strathcona Sound on the north coast of Baffin Island.

Mine tailings effluent discharged from the Polaris and Nanisivik mining operations delivers dissolved lead, zinc, cadmium, and copper to ocean waters via outflow streams from tailings lakes (Cominco Ltd. - Polaris Operations, 1981-1988). Polaris discharges dewatered mine tailings into a meromictic lake where a surface freshwater layer is separated from a deeper saline layer. The mine normally discharges tailings beneath the surface layer through a submerged effluent pipe. However, dissolved metals may contaminate the lake through accidental surface discharges of tailings, or by diffusion of metals from below. Polaris releases water from the tailings lake between the months of June and September into a small outflow stream (Garrow Creek) which flows into Garrow Bay.

The Nanisivik mine discharges tailings effluent into a typical freshwater lake. During summer months (July to September), water from the lake is "decanted" into Twin Lakes Creek, which in turn drains into Strathcona Sound. Studies attributed elevated concentrations of metals in Garrow Creek (Polaris operations) to tailings effluent discharges. In contrast, a water quality monitoring program at Nanisivik implicated several sources of metal contamination in runoff and streams flowing into Strathcona Sound. Water quality studies (Fallis, 1982; Thomas et al., 1983a; Indian Affairs and Northern Development Canada, 1983; Arctic Laboratories Ltd., 1986) showed that tailings lake discharges contained low levels of lead, cadmium, and zinc. Elevated levels of cadmium and zinc in the outflow stream may originate with discharges from a nearby open-pit operation or leaching of exposed ore deposits. Elevated levels of lead and zinc near the Nanisivik loading dock may be due to spills of lead-zinc ore concentrate.

Municipal Effluents

Municipal use of the marine environment is restricted to discharges of untreated or primary-treated sewage into coastal waters. Seven communities collect liquid sewage and transfer it to holding ponds or lagoons. Two communities, Resolute and Rankin Inlet, discharge liquid sewage directly into the ocean through outfall pipes (Cameron et al., 1982a, b; Dusseault and Elkin, 1983a, b). Therefore, sewage effluents enter marine waters directly, or by percolation through lagoon substrates and leaching into surface drainage systems. Communities on open coasts may discharge raw sewage directly onto the shoreline. At present, there is no completed chemical analysis of treated or untreated sewage from coastal Arctic communities although preliminary assessments are under way (Stanley and Associates and Dobrocky Seatech, 1987). A public health concern may exist at communities which harvest shellfish from contaminated waters or butcher marine mammals on contaminated shorelines. At present, however, the possible relationship between sewage disposal practices, consumption of contaminated meats, and the incidence of enteric diseases in Arctic peoples is unknown.

A community dump (West 40) in Iqualuit, although primarily used for domestic waste, has been known to be a disposal site for industrial chemicals. During the spring snow melt, runoff from this site enters Frobisher Bay. There have been several aviation fuel spills in a watershed that runs through another dumpsite in Iqualuit (North 40) and drains into Frobisher Bay. Inorganic and mixed organic compounds may have contaminated the Apex dumpsite. Runoff from this site drains into Tarr Inlet.

Residents from the hamlet of Rankin Inlet recently expressed their concern that tailings from an abandoned nickel mine could have health effects. The nickel mine operated between 1957 and 1962 and deposited 400,000 tonnes of tailings on tidal flats adjacent to the community. Recent analysis showed high concentrations of chromium, magnesium, copper, and nickel in the contaminated tailings (Rescan Environmental Services Ltd., 1990). Although information on the effects of the tailings on local biota is lacking, the government has set up an interdepartmental working group to look at methods to ensure more adequate reclamation of the tailings and to prevent the mobilization of contaminants through acidification, leaching or wind erosion (A. d'Entremont, pers. comm.).

Fuel Shipment and Transfer

An annual sealift of fuel and supplies to remote northern communities and industries is a continuing source of fuel spills, perhaps the largest anthropogenic source. Approximately 200,000 tonnes of diesel, aviation fuel, and heating oil are shipped through the Arctic annually. Most of these fuels are destined for the eastern Arctic. Between 1972 and 1988, the Northern Spills Reporting Service recorded 212 accidental spills of hydrocarbons (diesel oil, jet fuel, gasoline, and crude oil). Estimates of total quantity spilled (excluding spills of less than 10 litres) ranged between 1,592,505 and 1,677,652 litres (Northern Spills Reporting Service, 1972-88). The Service included spills entering marine waters from ocean-going vessels, offshore wellsites, onshore tank farms, and other shore-based facilities in these totals. The majority of spills occurred at Tuktoyaktuk, Churchill, and Iqualuit. However, only one transport vessel operating in the Arctic, *M.V. Arctic*, is double-hulled, spill response plans are virtually nonexistent, and there are no adequate docking facilities in most communities. These factors increases the likelihood of significant petroleum spills in nearshore waters (Porter, 1990).

Elevated sediment hydrocarbon concentrations are apparent in Tuktoyaktuk Harbour (alkanes range from 4,400 to 31,000 ng/g; PAHs range from 160 to 2,600 ng/g). Studies have documented hydrocarbon uptake in Arctic flounder and starry flounder liver, bile, and muscle tissues; elevated levels are attributed primarily to anthropogenic sources (Packman and Shearer, 1988). This has resulted in mixed function oxygenase (MFO) enzyme activity and may be responsible for the increased occurrence of liver lesions and degenerative liver cells. Studies have not confirmed, however, a cause-effect relationship (Thomas and Hamilton, in preparation). Studies have not been conducted at Churchill or Iqualuit, or at any smaller communities.

At present, the annual input of accidentally spilled hydrocarbons to the Beaufort Sea is far outweighed by the annual input of hydrocarbons, some occurring naturally, by the Mackenzie River (Thomas et al., 1986a).

In addition, new information on the short- and long-term fate and effects of dispersed versus shore-stranded crude oil was gathered from the Baffin Island Oil Spill Project (BIOS)(Sergy, 1986 and 1987a, b). The Project also compiled data on the effectiveness of selected shoreline clean-up techniques. The BIOS Project showed the hazards of dispersed oil and hydrocarbons from large stranded slicks to subtidal arctic biota (Sergy, 1987b).

Shipping

Besides the contribution to spills made by shipping, vessel traffic related to sealifts or in support of industrial operations generates underwater noise from ice-breaking and propeller cavitation (i.e., depressurization of bubbles against the propeller). Underwater sound produced by propeller cavitation is unnatural, and may interfere with echolocation and communication by marine mammals, or cause localized avoidance reactions to vessels (ESL Environmental Sciences Ltd., 1982).

Losses of sound energy ("propagation losses") due to absorption and scattering are generally low in Arctic waters (Milne, 1967; Verrall, 1981). Water depth and substrate material also affects propagation losses. Noise levels are lower in shallow areas compared to deep water areas, particularly in areas with sand or mud sediments. Thus, propagation of vessel noise may be less of a concern in the shallow, silty-bottom areas which characterize the southern Beaufort Sea compared to deeper regions such as Lancaster Sound or Baffin Bay.

This issue concerns native hunters who harvest the bowhead whales (*Balaena mysticetus*) and annually hunt the beluga whales (*Delphinapterus leucas*) as they congregate during the summer months in the Mackenzie River Estuary and in bays along Tuktoyaktuk Peninsula. Bowhead and beluga whale responses to industrial noise have not been extensively studied, although researchers noted a short-term avoidance response to vessel traffic (Finley et al., 1984; Miller and Davis, 1984; Richardson et al., 1985). It is unknown whether these species will adapt to increased vessel traffic or noise from concentrated industrial activities. Marine mammals might avoid large areas around offshore activities and move to areas less accessible to hunters (LGL Limited, 1986).

Non-point Source Pollution

Atmospheric transport appears to be a major pathway for sulphur dioxide, heavy metals and organohalogen compounds to the Arctic region. The so-called 'Arctic Haze' (composed of airborne industrial contaminants from southeastern Asia, Europe, the USSR, and North America) was first reported in 1956 (Patton et al., 1989). Only recent investigations, however, have determined that an atmospheric pathway may be the major link to bioaccumulation of organochlorines in Arctic marine organisms. Bidleman et al. (1989) conducted simultaneous analysis of organochlorines in air, seawater, snow, zooplankton, and benthic amphipods in the high Arctic. These investigations provided evidence of a link between atmospheric deposition of organic contaminants and biomagnification through the polar food chain. The Arctic food chain can quickly assimilate these contaminants. High levels of contamination could occur in animal species which store large amounts of energy-rich substances, i.e., body fats (Patton et al., 1989). Atmospheric transport may be implicated in the elevated levels of organohalogens found in local foods. For example, elevated concentrations of PCBs, chlordane, DDT, HCB, and HCH are present in polar bear (*Ursus maritimus*) livers (Norstrom et al., 1985; Wong, 1985). This problem is described further below.

Water quality stations have been established throughout the Mackenzie River and Delta. However, reliable information on the sediment flux, water quality, and hydrological regimes in relation to potential oil and gas development (e.g., pipelines and processing facilities) is scarce. One important aspect of assessing the potential impacts from the upstream petroleum industry is to improve the understanding of the behaviour of the Mackenzie River plume into the Beaufort Sea. This understanding is important in modelling spills and differentiating between biogenic hydrocarbons (natural seeps or non-petrogenic hydrocarbons) and anthropogenic (petroleum) hydrocarbons. The Northern Oil and Gas Action Plan (NOGAP) studies contaminant transport in the Mackenzie River (NOGAP Strategic Planning Document, 1990).

Specific Substances

Metals

Temporary elevations in zinc and lead levels have been measured in Strathcona Sound seawater near the mouth of Twin Lakes Creek, which drains the Nanisivik mine tailings lake (Thomas et al., 1983a; Arctic Laboratories Ltd., 1986). Higher concentrations of dissolved zinc and lead correlated with the early summer periods of stream discharge. Ocean sediments adjacent to the tailings outflow creek and loading dock showed increased levels of lead, zinc, cadmium and arsenic compared to pre-operational concentrations. Metal loadings may be due to leaching of mineralized areas, spills of ore concentrate, and discharges of metals-contaminated tailings water into the outflow creek (Thomas et al., 1983a; Indian Affairs and Northern Development Canada, 1983; Arctic Laboratories Ltd., 1986).

In Beaufort Sea sediments, sampling recorded the highest levels of chromium (120 mg/kg), mercury (0.322 mg/kg), and lead (40 mg/kg) in Tuktoyaktuk Harbour. The highest level of copper (59 mg/kg) was observed in Hutchison Bay, nickel (96 mg/kg) in McKinley Bay, and zinc (917 mg/kg) at a continental shelf location northwest of Pelly Island (Thomas et al., 1982; Packman et al., 1986). None of the observed mercury values exceeded the maximum limit of 0.75 mg/kg permitted under the *Ocean Dumping Control*

Act, now Part VI of the *Canadian Environmental Protection Act* (Government of Canada, 1988). However, cadmium levels in 47 samples in the vicinity of Tuktoyaktuk Peninsula exceeded the CEPA (Part VI) limit of 0.6 mg/kg.

Elevated concentrations of mercury, lead, zinc, cadmium, nickel, and copper present in sediments near offshore wellsites were probably caused by discharges of waste drilling fluids (Thomas, 1978; Crippen et al., 1980; Environmental Sciences Ltd., 1982; Thomas et al., 1983c). Metal concentrations returned to background levels within 100 metres (Crippen et al., 1980) to a few kilometres (Thomas, 1978; Mariani et al., 1980; Menzie et al., 1980; Thomas et al., 1983c) from the well. Concentrations varied with the distance and direction of effluent transport by ocean currents.

Organics

Total PAH levels in southern Beaufort Sea water ranged from 13 to 45 ng/l, and varied inversely with salinity (Wong et al., 1976). PAH concentrations in its nearshore waters are more variable than in deep water, possibly due to PAH inputs from the Mackenzie River which are estimated at 0.6 to 6.4 x 10^5 kg annually (Thomas et al., 1986a).

Analyses of sediment samples from three shorebases on Tuktoyaktuk Peninsula (Hutchison Bay, Tuktoyaktuk Harbour, and McKinley Bay) found mean total PAH and n-alkane concentrations to be highest at Tuktoyaktuk Harbour (104 ng/g and 15,793 ng/g, respectively), followed by McKinley Bay (35 ng/g and 9,990 ng/g, respectively) and Hutchison Bay (42 ng/g and 6,410 ng/g, respectively) (Thomas et al., 1983b; Dobrocky Seatech Ltd., 1985). A sediment sampling program for nearshore areas of the Beaufort Sea (Mudroch, 1987) found mean PAH levels to be highest in the vicinity of Richards Island while mean n-alkane concentrations were highest in the Herschel Island area. Sampling revealed low concentrations of biogenic and petroleum hydrocarbons, biphenyls, and breakdown products of pesticides in the sediments of abandoned artificial islands (Fowler and Hope, 1984).

Hydrocarbon concentrations in most nearshore Beaufort Sea sediments do not exceed natural levels (Packman et al., 1986). In the vicinity of Herschel and Richards Islands, a correlation between industrial activities and elevated hydrocarbon concentrations is difficult to show as the Mackenzie River provides a significant natural hydrocarbon flux to the southern Beaufort Sea area (Thomas et al., 1986a). However, elevated PAH and n-alkane levels in Tuktoyaktuk Harbour are attributed mainly to anthropogenic inputs (e.g., spills or leakages of petroleum products from vessels and shore facilities).

Contaminants in Biota

Long-range transport of contaminants via atmospheric circulation, ocean currents, and riverine inputs is a source of contamination to the Arctic Ocean, its biota, and human users of its resources. Researchers are only now determining the magnitude of this problem. Analysis of samples revealed the presence of environmental contaminants in the Arctic region in the mid-1960s. It is only recently, however, that public and scientific interest has resulted in significant levels of research and investigation.

Virtually all of the organochlorine contaminants found in southern Canadian biota are found in Arctic biota but at lower levels. Scientists have found organochlorine residues in fish, seabirds, seals, whales, polar bears, and humans. In 1986 and 1987, the Canadian Polar Continental Shelf Project gathered samples of air, snow, ice, suspended and dissolved particulates in sea water, plankton, benthic crustaceans, and surficial ocean sediments from an ice island off Axel Heiberg Island in the high Arctic. The samples contained various organochlorines such as hexachlorocyclohexanes and DDT compounds, and PCBs plus derivatives at detectable but not quantifiable concentrations (Hargrave et al., 1988). Scientists conclude that atmospheric transport is a major source of organochlorines to the Arctic Basin (Patton et al., 1989; Hargrave et al., 1989a).

While concentrations in the physical environment are low, there is evidence that some of these contaminants are concentrated through the food web, i.e., biomagnification is occurring (Norstrom et al., 1988a). PCBs and DDT are the only organochlorines monitored systematically in Arctic marine mammal tissues (Wagemann and Muir, 1984). Scientists measured levels over a wide geographical area during the mid-1970s. In comparison, recent analyses of ringed seal (*Phoca hispida*) blubber collected at Holman Island in the Western Arctic shows significant declines of PCBs to less than 2 ppm wet weight, and of DDE but not DDT concentrations (1 ppm wet weight) (Addison et al., 1986a).

Sampling showed toxaphene and hexachlorocyclohexane (HCH) isomers to be the major organochlorines in Arctic cod muscle tissue collected from the eastern and central Arctic. Organochlorine body burden data for Arctic marine mammals (Wagemann and Muir, 1984; Norstrom and Muir, 1986; Muir et al., 1988) indicate that PCB and DDT levels in Arctic whale and seal blubber are significantly less than in areas such as the North Sea, eastern North America, and the Great Lakes. Data showed the highest mean concentrations of DDT and PCBs (both 5 ppm wet weight) in narwhal blubber from Pond Inlet and Pangnirtung, N.W.T. (Wong, 1985; Addison et al., 1986a). Beluga whale blubber samples from the Mackenzie River delta had a total DDT level of 3.9 ppm (Wong, 1985).

The samples had mean concentrations of 0.018 and 0.010 ppm, respectively (Muir et al., 1988). Other samples revealed elevated levels of mercury in the livers of beluga whales (Mackenzie River delta), ringed seals (Somerset and Holman islands), and bearded seals (*Erignathus barbatus*) (Victoria Island). It was concluded body burdens of contaminants in Arctic marine mammal tissues are generally lower than those reported in species from eastern North America (Wong, 1985).

Much new work has been reported. It is now known that the major contaminants found in polar bears (*Ursus maritimus*) are PCBs and several components and metabolites of chlordane. The polar bear, which occupies the highest trophic level in the Arctic, acts as an indicator of the bioaccumulation of persistent contaminants. Sampling determined that the geographical distribution of most organochlorines in polar bear tissues is lowest in the high Arctic, intermediate in Baffin Bay, and highest in Hudson Bay (Muir et al., 1988; Norstrom and Muir, 1988; Norstrom et al., 1988a). However, the specific distribution of TCDD and OCDD gives an opposite picture, with Hudson Bay having the lowest levels and the central high Arctic having the highest levels in both ringed seals and polar bears (Norstrom et al., 1990). Researchers attribute this to 'Arctic Haze' from Eurasian sources (Norstrom et al., 1990). Between 1969 and 1984, levels of chlordane increased fourfold, levels of DDT did not change, and levels of the other organochlorines, including PCBs, doubled in polar bear fat from Hudson Bay and Baffin Bay (Norstrom et al., 1988a; Norstrom, 1990). A major finding of this new work is that no apparent biomagnification of 2,3,7,8-TCDD, OCDD, or 2,3,7,8-TCDF occurred from seal to bear fat, similar to previous findings for DDT, but that total PCBs and hexachlorobenzene biomagnified 6- to 17-fold (Norstrom et al., 1990).

It is known that seals and whales bioaccumulate organochlorines more effectively than any other animal, largely due to their layer of blubber which functions as a depot for organochlorines (Norstrom, 1990). Hence, the polar bears diet of ringed and bearded arctic seals exposes it to relatively high levels of organochlorines. The biomagnification or food chain build-up of organochlorine compounds from fish to seals to polar bears is also established (Norstrom and Muir, 1988; Muir et al., 1988; Norstrom, 1990). Table 4.2 presents biomagnification factors which show much variation with compound, site in food chain, and sex, but clearly, biomagnification of some organochlorines is occuring.

Table 4.2 Biomagnification factors for the food chain– Arctic cod to Ringed seal to polar bear

Compound	Fish to Seal		Seal to Bear		Fish to Bear
	Male Seals	Female Seals	Male Seals	Female Seals	
S-PCB	8.8	3.7	7.4	13.9	49.2
PCB homolog					
Cl_4	2.5	1.2	<0.2	<0.4	<0.5
Cl_5	11.3	5.1	1.9	3.1	13.9
Cl_6	23.0	9.7	9.3	18.3	170.6
Cl_7	17.0	6.9	19.8	38.6	263.4
Cl_8	>3	>1.4	24.6	47.2	>67
Cl_9	-[2]	>109	-	>109	-
S-DDT	20.2	8.2	0.3	0.5	3.6
S-CHLOR	7.3	4.7	6.6	9.5	44.2
S-HCH	1.5	1.6	9.3	1.7	2.7
S-CBz	0.2	0.2	15.5	17.4	3.4
Dieldrin	2.4	2.2	4.8	5.5	11.4
p,a'-DDE	62.2	17.6	0.3	0.7	10.7

[1]Ratio of tissue concentrations on a lipid weight basis.

[2]Cl_9 PCBs not detected in fish muscle (<2 µg/kg lipid wt) or seal blubber (0.5µ/kg lipid wt).

Source: Muir et al., 1988.

Table 4.3 Organochlorine concentrations in livers and eggs of Arctic seabirds, 1975-1977. Samples marked with an * are geometric means. All other samples are a single analysis of N samples, as indicated.

Collection Site and Species	N	Year	Tissue	Fat%	Chemical Residues in ppm (wet weight)										
					DDE	DDD+DDT	Dieldrin	Hept. ep.	Oxychlor	Cis-chlor	Mirex	HB	B-HCH	PCB 1:1[a]	PCB/DDE
Prince Leopold Island															
Northern Fulmar	3*	75	Liver-Ad.	5.6	0.228	0.017	0.01		0.114			0.023		0.888	3.89
Northern Fulmar	7	75	Liver-Ad.	4.2	0.25	0.025	0.02	0.01	0.17	0.005	0.01	0.026		1.08	4.32
Northern Fulmar	2*	76	Liver-Ad.	8.0	0.605	0.245	0.01		0.26			0.073		2.113	3.49
Northern Fulmar	7	76	Liver-Ad	8.1	0.50	0.03	0.02	0.01	0.22		0.02	0.058	0.005	1.97	3.94
Black-legged Kittiwake	10	75	Liver-Ad.	5.4	0.05	0.02	0.02	0.01	0.04	0.01	0.01	0.03	0.005	1.31	26.2
Black-legged Kittiwake	5	76	Liver-Ad.	6.9	0.05	0.015	0.02	0.01	0.04	0.005	0.02	0.05	0.01	2.37	47.4
Black-legged Kittiwake	5*	76	Liver-Ad.	9.2	0.11			0.013	0.05	0.006		0.07	0.005	3.30	30.0
Black-legged Kittiwake	6	76	Egg	9.7	0.38	0.035	0.02	0.04	0.08	0.005	0.02	0.091	0.01	5.73	15.1
Thick-billed Murre	10*	75	Liver-Ad	4.5	0.059	0.004	0.008	0.001	0.005	0.001		0.027	0.001	0.203	3.44
Thick-billed Murre	10*	76	Liver-Ad.		0.191	0.002	0.002	0.001	0.013	–		0.071	0.002	0.404[a]	2.12
Thick-billed Murre	8*	77	Liver-Ad.		0.115		0.005	0.001	0.009	–		0.035	0.001	0.260[a]	2.26
Thick-billed Murre	10	76	Liver-Yg.	10.5	0.17	0.01	0.02	0.01	0.03	0.005	0.005	0.130	0.01	0.48	2.82
Thick-billed Murre	2*	76	Liver-Yg.		0.035		0.002	0.003	0.002	0.003		0.024		0.144[a]	4.11
Thick-billed Murre	12*	77	Liver-Yg.		0.037	0.001	0.002	0.001	0.004	0.003		0.019	0.001	0.095[a]	2.57
Thick-billed Murre	12*	75	Egg	12.6	0.297		0.019	0.002	0.018	0.001		0.097	0.004	0.708	2.38
Thick-billed Murre	10	76	Egg	14.3	0.34	0.01	0.06	0.01	0.03	0.005	0.005	0.127	0.01	0.23	0.68
Thick-billed Murre	10*	77	Egg	12.6	0.377		0.016	0.004	0.024	0.001		0.109	0.011	0.854	2.27
Seymour Island															
Ivory Gull	10	76	Egg	5.8	0.464	0.035	0.024	0.012	0.061	0.011	0.004	0.043	0.005	1.63	3.51
King Eider	1	76	Egg	8.9	0.02	0.005	0.005	0.005	0.005	0.005		0.01	0.005	0.06	3.0

** Samples marked with an * are geometric means. All other single analysis of N samples, as indicated.

PCB values marked (a) are PCB 1260

Source: Noble and Elliott, 1986.

Legend:
Ad-Adult
Yg-Young
Cis-chlor-Cis-chlordane
Hept.ep-Heptachlor epoxide
B-HCH-Beta-Hexachlorocylohexane
Ocychlor-Oxychlordane
HB-Hexachlorobenzene

Increased levels of PCBs and other contaminants in polar bears gives cause for concern, particularly as levels of such compounds are generally decreasing in seals and seabirds. However, there are no indications that polar bear populations are declining. Other factors, e.g., eating patterns, likely influence the levels of PCB concentrations in polar bears and will require further research (Norstrom, 1990).

Natural levels of mercury in water and sediment, and patterns of atmospheric deposition, result in consistently high levels in polar bear livers in the western Arctic (Braune et al., 1990). This pattern for mercury concentrations in polar bears has been verified using hair analysis (Renzoni and Norstrom, 1990).

Seabird samples were collected from Seymour Island and Prince Leopold Island in the high Arctic from 1975 to 1977 to assess levels of organochlorine compounds in tissues and eggs, and to determine whether these compounds had affected seabird health (Noble and Elliott, 1986; Nettleship and Peakall, 1987) (see Table 4.3). PCBs were the most common contaminant found in tissues of all species. Concentrations ranged from 0.06 ppm wet weight in King Eider (*Somateria spectabilis*) eggs to 5.73 ppm in the eggs of Black-legged Kittiwakes (*Rissa tridactyla*). DDE, the primary DDT pesticide metabolite, was also present in all samples. Levels ranged from 0.02 ppm in King Eider eggs to 0.605 ppm in the livers of adult Northern Fulmars (*Fulmaris glacialis*). Noble and Elliott (1986) concluded that most Arctic seabirds are considerably less contaminated than similar species sampled further south. The data form an important baseline for high Arctic seabirds against which future organochlorine levels can be compared.

Another potential source of PCBs and mixed organic pollutants near coastal areas in the eastern Arctic are active DEW Line sites (e.g., Cape Dyer, Cape Hooper, Hall Beach) and abandoned sites (e.g., Resolution Island, Cape Christian, Rawley Island). The 1985 federal clean up of abandoned DEW Line sites discovered local contamination by PCBs.

This raised concerns about the possibility of contaminants in local peoples diets. A study examined the diet and levels of PCBs in the people of Broughton Island in the Baffin Region of the eastern Arctic (Kinlock and Kuhnlein, 1986). The study recorded levels of PCBs in the blood higher than the acceptable level recommended by Health and Welfare Canada (1 mg PCBs/kg body weight) in 18.8 percent of the population. Blubber of seals, narwhals, and other whales, is likely the major dietary source of PCBs, as all Inuit foods tested were PCB contaminated (Waldichuk, 1989d). Subsequently researchers have concluded that the benefits of Inuit foods and breast feeding to residents of Broughton Island are greater than the risk from PCBs in such foods (Waldichuk, 1989d).

Geographic Concerns

There are a number of geographic areas of concern in the Arctic (Table 4.4). In contrast to the other coastlines, these areas are either site-specific due to very localized activity, or very wide in nature due to the widespread input of low-level chemical contamination.

Table 4.4 Some Arctic coast geographic concerns for MEQ

Location	Concerns
Tuktoyaktuk Harbour	• sediment contamination • hydrocarbon spills • drilling mud disposal • municipal sewage disposal
Western Arctic	• industrial noise and cetaceans • hydrocarbons and fisheries • drilling mud disposal • long-range air-borne pollutant transport • municipal sewage disposal • hydrocarbon development
Lancaster Sound	• habitat protection • impact of ice-breaking vessels • industrial noise and cetaceans • mine tailings/effluent discharge • municipal sewage disposal • long-range air-borne pollutant transport
Hudson Bay	• oil spill contingency planning • integrated management plan

Tuktoyaktuk Harbour

Tuktoyaktuk Harbour supports a subsistence fishery for broad whitefish (*Coregonus nasus*) and Arctic cisco (*Coregonus autumnalis*) in addition to its use as an industrial harbour and staging area. Chronic and episodic spills or discharges of hydrocarbons, drilling chemicals and other wastes in the area may, over the long term, affect the abundance and/or species composition of epibenthic invertebrates. These invertebrates are an important food source for fish. Anthropogenic compounds may also accumulate in epibenthic organisms and taint or contaminate fish harvested for domestic use. Finally, some harbour sediment samples contained high concentrations of mercury, approximately 200 ppb (Thomas et al., 1986b). The source of mercury has not been identified.

Western Arctic

The western Arctic bowhead whale (*Balaena mysticetus*) population summers in the Beaufort Sea and Amundsen Gulf. Available data indicate that ship passage near or through bowhead groups disturbs the animals (Richardson et al., 1983). It is unknown whether bowhead whales will adapt to multiple ship passes and/or noise from concentrated industrial activities. They might begin to avoid a relatively large area around offshore industrial developments. A significant number of beluga whales congregate in the Mackenzie Estuary and bays along the Tuktoyaktuk Peninsula after the breakup of landfast ice. Like bowhead whales, beluga whales tend to avoid point sources of disturbance. It is unknown whether vessel or industrial activities in the vicinity of Kugmallit Bay or the Mackenzie Estuary will alter beluga whale use of these areas. In addition, the impact of such activities on marine mammals and seabirds present in polynyas is unknown (Struzik, 1989).

Continued input of hydrocarbons from industrial activities constitutes a long-term concern in the southern Beaufort Sea region. To date, the Mackenzie River has been the largest natural source of hydrocarbons to the Beaufort Sea region. The Mackenzie contributes an estimated 1.8×10^7 kg hydrocarbons per year (Thomas et al., 1986a). In contrast, anthropogenic sources (e.g., accidental spills of fuels and oils, hydrocarbons entrained in discharged drilling wastes) have been relatively minor to date. Such spills contributed an average of approximately 196,000 litres annually between 1972 and 1988 (Northern Spills Report Services, 1972-1988). However, localized damage to marine organisms can occur from spills, and contamination of shallow waters and beaches can persist for years (Percy and Wells, 1984; Engelhardt, 1985; Sergy, 1987b).

Future oil and gas exploration and production activities may increase inputs of hydrocarbons to the Beaufort Sea. In the short term, there are indications that petroleum operators may use and dispose of oil-based drilling products at Beaufort Sea exploration wells more frequently than in the past. Between 1985 and 1987, operators used oil-based muds at three offshore locations and a diesel water-based mud mixture at another two wellsites. In addition, they disposed of oil-contaminated cuttings most frequently at offshore locations rather than onshore disposal sites. Operators may use diesel oil during flow tests to maintain hydrostatic pressures and prevent freezing in the test ring at many Beaufort Sea oil wells. Although the diesel drillstem fluid is burnt off, residual diesel oil may enter the marine environment due to incomplete combustion and flare boom spills.

In the longer term, operators might use oil-based drilling muds extensively during drilling of delineation wells or production platforms. A Beaufort Sea production scenario involving 16 exploration and 23 production wells results in an estimated anthropogenic flux of hydrocarbons of approximately 1.3×10^7 kg, or 72 percent of natural inputs (Thomas et al., 1986a). As well as hydrocarbon inputs from the use of oil-based drilling muds, development of the Beaufort Sea oil reserves may result in chronic spills from vessels and tankers or pipelines (depending on the selected mode of oil transportation), and major spills if uncontrollable blowouts occur.

Lancaster Sound

Lancaster Sound is an unique and very productive biological region for invertebrates, fish, seabird, and waterfowl populations. It is a major migration route and concentration area for beluga, narwhals, walrus, and seals. Inuit in the region are highly dependent upon hunting, trapping, and fishing as sources of food and income (FEARO, 1980). Petroleum operators have leased several areas within Lancaster Sound for possible exploration drilling. However, the government has had a moratorium on drilling activities since 1979. Should exploration drilling take place, various activities (aircraft and supply vessel traffic, drill waste discharges, chronic hydrocarbon spills, major accidents, etc.) may degrade unique marine habitats.

As in the western Arctic, the impact of industrial and shipping activities on polynyas in Lancaster Sound which support seabird and marine mammal populations remains largely unstudied (Struzik, 1989). The activity might cause wildlife and fish to avoid habitual offshore and coastal areas. Although vessel traffic through the Northwest Passage (mainly oil and ore concentrate shipments) is relatively low at present, the potential for year-round travel exists. Equally important, ice-breaking vessel traffic, vessel and aircraft noise may compromise access to and use of traditional hunting areas or cause wildlife avoidance responses. The long-term preservation of the unique environmental features of Lancaster Sound requires a concerted effort by governments, industry, and local populations to manage their activities.

Hudson Bay

Oil and gas exploration in Hudson Bay ended in 1985. During the period of exploration, operators used Churchill Harbour as a support base. Effective environmental protection and conservation measures such as identification of sensitive areas and formulation of oil spill contingency plans and responses, were required for the area. Large numbers of waterfowl, especially geese, breed in the Hudson Bay lowlands. There are also very large seabird colonies, mainly Thick-billed Murres, *Uria lomvia*, at the junction of Hudson Bay and Hudson Strait (Brown et al., 1975). The eastern coast of the Bay, including James Bay, is threatened by the water diversions and dams constructed in Quebec. The potential marine effects of this freshwater loss to the productive estuaries and coasts of the Bay require further assessment.

Environmental management responsibilities for the marine waters of Hudson Bay are presently shared by Environment Canada, Environmental Protection (Ottawa, Winnipeg, Yellowknife), the Department of Fisheries and Oceans (Yellowknife, Winnipeg, Ottawa, Vancouver, Victoria), Canada Oil and Gas Lands Administration (Ottawa, Yellowknife), and several provincial ministries. Foreshore areas are managed by Indian Affairs and Northern Development Canada (Northwest Territories portion) and the environmental agencies of Manitoba, Ontario, and Quebec. This multiplicity of agencies and responsibilities has perhaps hindered progress towards an integrated and coordinated management plan for the Hudson Bay region, a plan urgently needed to ensure the sustainability of the Bay's ecosystems.

Assessment

Valued ecosystem components (VECs) are defined as resources or environmental features that are: (1) important to local human populations; (2) have national or international profiles; and (3) if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy (Indian Affairs and Northern Development Canada and Environment Canada, 1985)(See Table 4.3). This section describes VECs, the environmental disturbances that may be imposed on them, and some trends in Arctic marine environmental quality.

Table 4.5 Interaction between seabirds, fish and potential industrial disturbances

Disturbance	Interaction with Seabirds and Fish		
	Seabirds	**Anadromous Fish**	**Marine Fish**
Long-range Transport of Chemical Pollutants	Bioaccumulation of organochlorine pollutants may result in sublethal effects; biomagnification of pollutants as a result of feeding on contaminated prey	Same as for seabirds	Same as for seabirds
Chronic/Episodic Oil Spills	Some species highly sensitive and vulnerable to exposure; some mortality likely; effects dependent on timing and degree of oil spill; greatest risk occurs when populations congregate in coastal or offshore areas and when oil present in leads; potential destruction of habitat (e.g., staging areas)	Could be affected by chronic oil input in shallow coastal areas or at shorebases; some mortality if species remain in oil- contaminated area and oil is relatively unweathered; juveniles more sensitive than adults; possible tainting by ingestion of oil-contaminated benthos; loss of prey (benthos) may decrease subsequent habitat use; avoidance reaction may affect migration or distribution of species	Demersal species remaining and feeding in areas of chronic oil input could accumulate hydrocarbons; sensitive egg and juvenile stages could be locally affected; loss of prey (benthos) may decrease subsequent habitat use; avoidance reaction by pelagic species resulting in disturbance of migration and distribution
Dredging and Ocean Disposal	N/A	Mortality by fish entrainment dependent on timing and extent of dredging operation; avoidance reaction may affect migration or distribution; loss of prey (benthos) may decrease subsequent habitat use	Some mortality of demersal fish due to entrainment; avoidance reaction by pelagic species which may disturb migration or distribution; loss of prey (benthos) may decrease subsequent habitat use
Drilling and Production Waste Discharge	N/A	Avoidance of areas during periods of discharge; loss of prey (benthos) may decrease habitat use; possible tainting by ingestion of oil-contaminated benthos; effects on regional population would likely be significant	Same as for Anadromous fish

Fish and Shellfish

Important fish and shellfish species in the Arctic include broad whitefish, arctic cisco, least cisco, arctic char, lake fish, arctic cod, pacific herring, polar cod, capelin, clams, and scallops. Anadromous fish species, particularly arctic char and whitefish, are a very valuable resource. Environmental threats to both marine and anadromous species, described in Table 4.5, include destruction of bottom habitat (by dredging or drilling waste discharges) and bioaccumulation of contaminants in fish tissue. Fish that live close to or in contact with marine sediments and feed on benthic infauna and epifauna are particularly vulnerable to these threats.

Chronic water quality problems may exist near coastal communities discharging raw or primary-treated sewage into estuaries and fjords. Residents of most eastern Arctic communities harvest shellfish in nearshore waters. The potential for shellfish contamination with pathogenic organisms exists in these coastal communities, although the correlation between the incidence of human disease and sewage disposal practices is not known (Sackmann et al., in preparation). During high tide near the community of Iqualuit, Baffin Island, the potential for flooding of the sewage lagoon with runoff into Frobisher Bay is quite high (S. Heinze-Milne, pers. comm.). Bacteriological studies near the Pangnirtung, Baffin Island, dumpsite showed that clams in the area had high faecal coliform counts (Coleman et al., unpubl. data).

No studies have fully assessed the effects of mine waste discharges on fish of the eastern and high Arctic. The accumulation of trace metals (e.g., lead, zinc, cadmium, and arsenic) in marine benthic invertebrates collected in the vicinity of Nanisivik Mine makes this issue a valid concern (Fallis, 1982).

Seabirds

Arctic seabirds and waterfowl include three species of Loons (*Gavia* spp.), Northern Fulmars (*Fulmarus glacialis*), diving ducks (Common and King Eiders, Scoters, Mergansers, and Oldsquaw), Brant (*Branta bernicla*), Black-legged Kittiwakes (*Rissa tridactyla*), auks (Murres, Dovekies, and Black Guillemonts), and gulls. Table 4.5 summarizes potential environmental disturbances and impacts on such species.

The major environmental threat to seabirds is significant oil spills, particularly in ice leads and polynyas (Struzik, 1989). Seabirds are highly sensitive to oil exposure. Deaths and loss of habitat may occur depending on the time of year, quantity and type of oil, and area affected by the spill. Oil affects birds at two levels: directly, by breaking down their insulation and waterproofing and indirectly, from eating contaminated food (Brown, 1982). Some species are more vulnerable than others. For example, at the end of the breeding season, Thick-billed Murres migrate with their flightless chicks by *swimming* to Labrador (Nettleship and Birkhead, 1985). At this stage they are, of course, particularly vulnerable to oil exposure from surface spills.

There is also the threat to seabirds of increased chronic oil inputs from Beaufort Sea oil and gas production and tanker traffic in the eastern Arctic. In addition, organochlorines have accumulated in seabirds throughout the Arctic as a result of long-range atmospheric transport from other continents, and biological transport in migratory species returning from southern latitudes. Studies to assess the level and effects of this contamination are conducted periodically.

Table 4.6 Interaction between marine mammals and industrial disturbances

Disturbance	Interaction with Marine Mammals		
	Bowhead/Beluga	Seals	Polar Bears
Long-range Transport of Chemical Pollutants	Bioaccumulation of organochlorine pollutants which may result in potential sublethal effects; biomagnification of pollutants as a result of feeding on contaminated prey; narwhals also affected	Same as for whales	Same as for whales
Chronic/Episodic Oil Spills	Avoidance response to area of spills; possible sublethal and behavioural effects	Seals are both sensitive and vulnerable to spills but mortality is unlikely; most vulnerable to spills when oil present in leads during the spring; possible sublethal and behavioural effects	Exposure of oil to bears restricted to winter months; potential adverse effects if exposure occurs due to extreme sensi- tivity of bears to oil on contact or ingestion
Dredging and Ocean Disposal	Underwater Noise may disturb whales and cause short-term changes in migration/ distribution	Possible avoidance responses and temporary feeding disruption but no effects on survival or reproductive success; possible bioaccumulation of some contaminants (e.g., heavy metals) in bearded seals if feeding occurs in areas of dredging activity	Little interaction with species
Drilling and Production Waste Discharge	Possible avoidance response to areas of drilling and production waste accumulation and the associated turbidity plume; possible ingestion of contaminated prey	Possible avoidance response to areas of drilling and production waste accumulation; possible attraction of some seals resulting in possible ingestion of contaminated prey	No interaction with species
Marine Shipping	Underwater noise may disturb whales and cause avoidance responses and short-term changes in migration/ distribution; exclusion of whales from shipping corridor will be dependent upon frequency and number of vessel trips	Same as for whales	Noise and presence of vessels may cause avoidance responses and short-term changes in migration/ distribution; possible no interaction with species

Marine Mammals

Arctic marine mammals consisting of whales (bowhead, beluga, narwhal), seals (bearded, harp, and ringed), and polar bears represent the upper levels of the Arctic marine food web. Native people harvest marine mammals to supplement their diet. Bowhead whales, the only whale species not harvested by natives, have received international attention by being placed on the Endangered Species List of the Committee on the Status of Endangered Wildlife in Canada (COWISEC) (Burnett et al., 1989).

Table 4.6 summarizes potential industrial disturbances on marine mammals. Any increased industrial activity, such as Beaufort Sea oil and gas development and vessel traffic through the Northwest Passage can be expected to affect marine mammals. These effects include pollution and disturbance from increased underwater noise, and traffic in false leads (i.e., icebreaking-vessel paths) (Struzik, 1989).

Summary - Marine Environmental Quality on the Arctic Coast

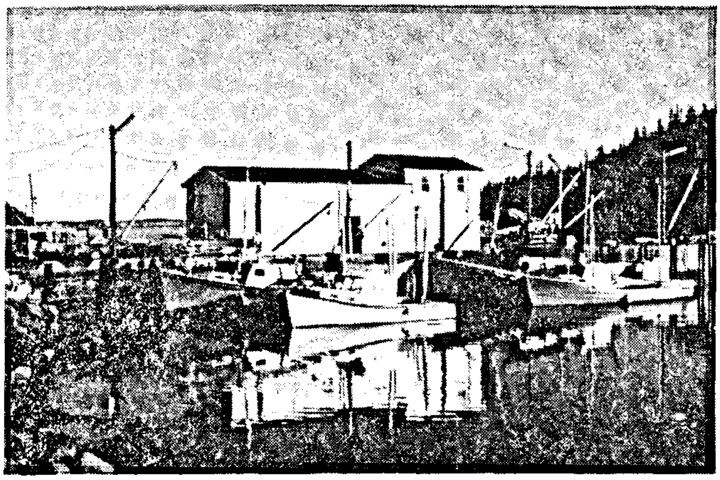
Site-specific industrial effluent discharges have resulted in elevated concentrations of trace metals, PAHs, and other hydrocarbons in Arctic marine sediments and biota. Sewage effluents from coastal communities may be linked to bacterial contamination of native foods and increased incidence of enteric disease, but this requires further study. Runoff from dumpsites located near Arctic coastal communities might cause chemical or microbiological contamination. The long-term effect of abandoned base metal mines on local Arctic marine ecosystems requires further study. Finally, studies now are linking long-range transport of contaminants by air and water to their elevated levels being found widely in marine mammal tissues and their food chains.

Concerns remain focused on the continuing input of hydrocarbons to offshore and nearshore areas, particularly those subject to chronic spills (such as Churchill Harbour, Iqualuit, and Tuktoyaktuk Harbour). Future concerns include the effects of oil-based drilling mud discharges and the risk of major spills during hydrocarbon exploration drilling or production in Lancaster Sound, the Arctic Islands, and the Beaufort Sea. Risk assessments of these threats are required. Alternative waste disposal practices must be explored in anticipation of the need to manage large quantities of inert wastes.

To date, Arctic marine environmental quality guidelines and objectives for selected geographic areas and substances have not been formulated, nor has a formal comprehensive and coordinated monitoring system been established yet (Environment Canada, et al., 1989). Consequently, existing baseline data have generally been restricted to site-specific information on individual marine components. Existing monitoring programs need to be expanded to provide time-series data on trace metal, organochlorine, and hydrocarbon levels near sources of contamination and widely throughout the Arctic. Sea ice cover and whale population data are also needed. As well, continuous, area-wide information on changes in critical marine environmental quality parameters are needed. Fulfilling the above should lead to a more comprehensive quantitative assessment of Arctic marine environmental quality in the 1990s.

Chapter Five

The Atlantic



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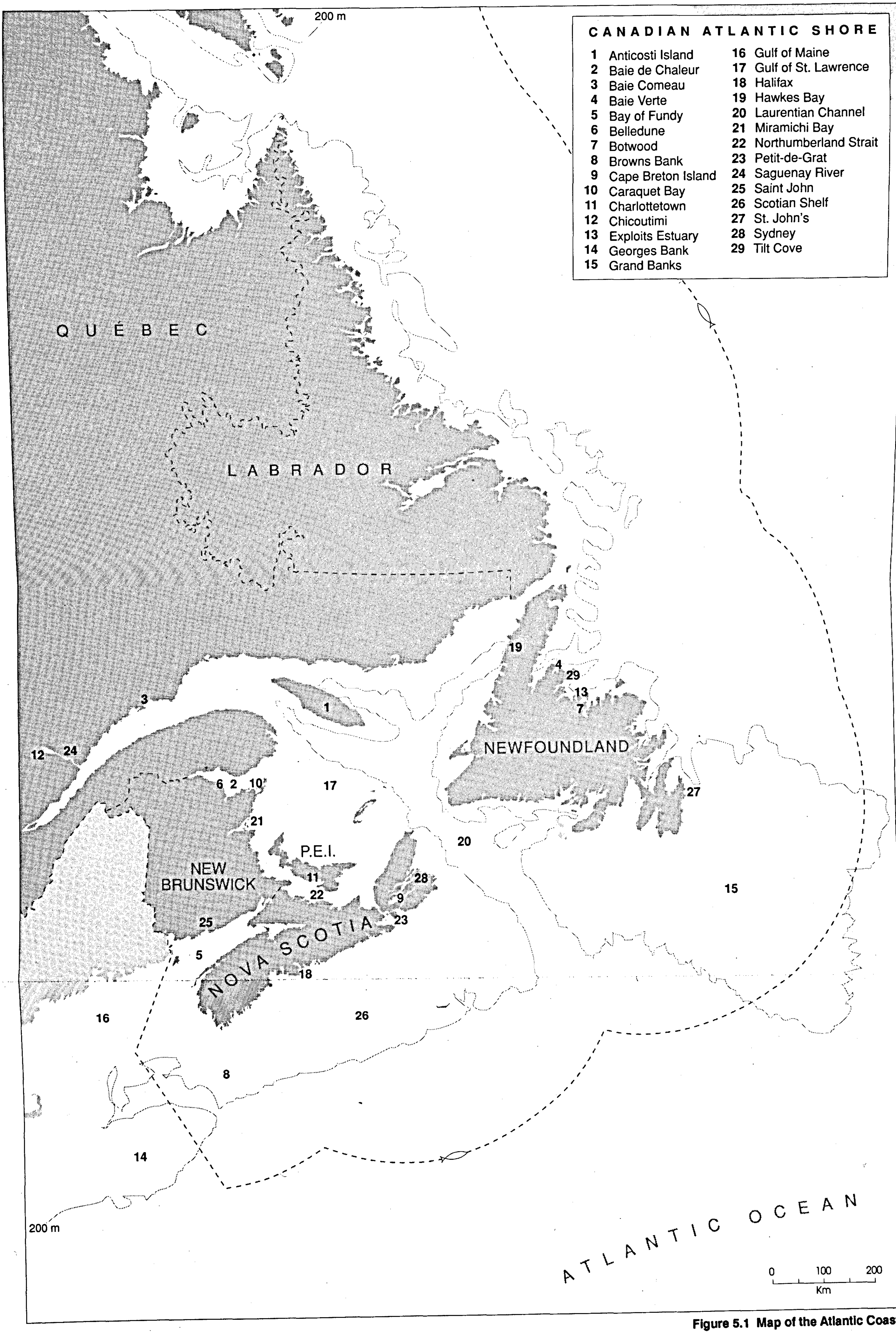


Figure 5.1 Map of the Atlantic Coast

Introduction

The Atlantic coastline of Canada (approximately 40,000 km) comprises the coasts of New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland and Labrador, and southern Quebec. Its waters extend eastward over 300 km to the limits of Canadian fisheries jurisdiction. The extensive continental shelf is 200 km wide off Nova Scotia, 500 km on the Grand Banks, and less than 100 km along the Labrador coast. These waters are very productive biologically. Areas such as the Grand Banks have supported fisheries for at least 500 - 600 years. The outflow from Hudson Bay and the southerly flow of the Labrador Current, the St. Lawrence River and the Gulf of St. Lawrence, and the tides of the Bay of Fundy influences the oceanography of the east coast of Canada. The warm, northeasterly-flowing Gulf Stream passes by hundreds of kilometres offshore. Sometimes it influences the waters of Georges Bank, Browns Bank, and parts of the Scotian Shelf through eddy action.

Coastal features include numerous bays, inlets, lagoons and fjords, and many islands (Figure 5.1). Major rivers and estuaries include the St. Lawrence, Saguenay, Churchill, Exploits, Miramichi, Saint John, St. Croix, and LaHave. There are also many smaller rivers and estuaries. Shorelines are varied, with many marshes, mudflats and sandy beaches interspersed with rocky headlands and cliffs. The Labrador coastline is largely rocky, with many cliffs, coastal mountain ranges, deep fjords, and estuaries.

The Atlantic coastal region has abundant stocks of fish, shellfish, and marine plants. These resources support a multi-billion dollar fishery and a rapidly expanding aquaculture industry. In 1984, about 1.3 million tonnes of fish were caught in Canadian waters of which about 85 percent was caught in the Atlantic region; nationally, exported fish were worth $1.59 billion (Scarratt, 1987). The aquaculture industry was worth approximately $13 million (1982), $18.5 million (1987), and $100 million (1988) (G. Harding pers. comm.). Residents and tourists alike use the coastal and offshore environments extensively for recreation and tourism. Both the coastal and offshore environments provide critical habitat for migratory and non-migratory birds and marine mammals.

Along the Atlantic coast, however, water, sediments, and biota are contaminated in many areas; natural habitats and their wildlife are rapidly diminishing in number, size, and diversity; fish stocks are often seriously depleted; and threats to human health sometimes occur. Some of this change occurred during settlement (Mowat, 1984), but much of it is recent and growing due to industrialization and the demand for natural resources. This chapter briefly describes major contamination and pollution sources, problems with specific substances, coastal development, contaminants in biota, and geographic concerns. It is an assessment of Atlantic marine environmental quality with an emphasis on contaminant issues rather than on those of fisheries and habitat protection, or other causes of environmental change.

Additional sources useful to the reader include: Sutterlin (1978); McCracken (1979); Wilson et al. (1980); Dickie and Trites (1983); Farrington et al. (1983); Hildebrand (1984); Wilson and Addison (1984); Bird and Rapport (1986); Eaton et al. (1986); Adam et al. (1986); Daborn and Dadswell (1988); Messieh and El-Sabh (1988); Strain (1988); Uthe and Zitko (1988); Waldichuk (1988a); and Wells and Gratwick (1988).

Pollution Sources

Municipal Effluents

Of the 1,583,000 people (circa 1986, Marsh, 1988) living in New Brunswick and Nova Scotia, about 30 percent are served by some level of wastewater treatment, either primary or secondary (Statistics Canada, 1986). Together both provinces release approximately 80,000 kg of high biological oxygen demand (BOD) materials and 105,000 kg of suspended solids daily (Eaton et al., 1986; Statistics Canada, 1986). The majority of discharges enter harbours, bays, estuaries, or rivers emptying into coastal regions. Cities such as Halifax, Saint John, and St. John's pour millions of litres of untreated sewage daily into local waters (P. Klaamas, pers. comm.; Waldichuk, 1988a; Fournier, 1990). In total, approximately 500 million litres of municipal waste are discharged daily into coastal waters of the Atlantic provinces, with only 30 percent receiving wastewater treatment. These effluents are the direct cause for approximately 20 percent of all shellfish closures in the Maritimes (Environment Canada, 1986d; Menon, 1988).

In the St. Lawrence River drainage area, only 8 percent of the region's 5.8 million people are served by some form of municipal wastewater treatment system (Statistics Canada, 1986). In May 1984, municipalities along the river and its estuary collectively discharged about 780,000 kg/day of BOD material, 687,000 kg/day of suspended solids, and 24,000 kg/day of phosphorus (Statistics Canada, 1986). In addition, some industries along the St. Lawrence River and Estuary discharge wastes directly into municipal wastewater collection systems. These complex wastes and municipal wastewaters flow downstream causing widespread contamination (e.g., Kaiser et al., 1990). In addition, the discharges have largely unknown biological impacts on the estuary and northern Gulf of St. Lawrence.

Chemical and microbiological contamination of clams, oysters, and mussels results from the release of untreated effluents to marine waters, with adverse localized impacts on their fisheries (Menon, 1988). In 1983, the Department of Fisheries and Oceans (DFO) closed 262 shellfish areas in the Atlantic provinces to harvesting, for a total of 140,000 hectares, or 22 percent of the soft-shell clam flats in the Scotia-Fundy area. Closures by 1989 had increased to 356 shellfish growing areas, comprising 151,700 hectares. Of the 419,100 hectares of inshore and estuarine waters classified for shellfish growing, 36 percent were closed for harvesting (Machell and Menon, 1989). Closures were primarily due to bacterial contamination from municipal wastewater effluents, but agricultural runoff, natural contamination (e.g., algal toxins), and a range of inorganic and organic contaminants also contributed (Menon, 1988; Messieh and El-Sabh, 1990).

Industrial Effluents

Approximately half of all major industrial effluents discharged in the Atlantic provinces enter directly into estuaries or the sea. The Gulf of St. Lawrence and the St. Lawrence Estuary receive many effluents from Quebec-based industries. Some of these are discussed below; others are described in Wilson et al. (1980), Wilson and Addison (1984), Eaton et al. (1986), and Waldichuk (1988a).

Pulp and Paper

Wood fibre, other high BOD materials, and a wide range of chemicals released from pulp mills to coastal waters smother benthic habitats, deplete oxygen in bottom waters, and cause toxicity to aquatic organisms (D. McLeay and Associates Ltd., 1987; Sprague and Colodey, 1989; Colodey et al., 1990). Sixteen coastal plants operated in the Atlantic provinces in 1988 (Colodey et al., 1990). Scientists have documented measurable impacts at eight mills. Most of the mills are older ones, and their original design did not provide for much treatment for their effluents prior to discharge (Waldichuk, 1988a). However, total daily discharge loadings from Atlantic mills were reduced 60 percent for BOD and 51 percent for TSS from 1969 to 1984 (Eaton et al., 1986). This was achieved through a combination of process changes, in-plant controls, and the addition of external treatment, mainly with aerated stabilization basins (Waldichuk, 1988a). In addition, there is increased concern about the impact of chlorinated organics in effluents from mills using chlorine for bleaching (Payne and Rahimtula, 1984). Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans have been detected in organisms downstream of plants (R.F. Addison, pers. comm.; Clement et al., 1987; Colodey et al., 1990). The federal government is revising regulations to reduce the many coastal impacts of such mills, and will support them with environmental monitoring guidelines (Environment Canada, 1990a). The regulations will take effect in 1994.

In 1982, twenty-nine mill operated along the St. Lawrence River and Estuary (Statistics Canada, 1986). The mills collectively discharged about 703,000 kg of BOD material per day and 336,000 kg of suspended solids per day in 1982. Discharges from pulp and paper mills along the St. Lawrence have decreased since 1973 (e.g., 891,000 kg of BOD and 684,000 kg of TSS per day in 1973)(Statistics Canada, 1986). In the Saguenay Fjord, pulp wastes have been detected through measures of enriched organic material in the sediments. The measurements provide an historical record of the industries' activities and discharges to the fjord (Smith, 1988).

Food Processing

There were over 300 fish processing plants operating along the Atlantic coast in 1984 (Eaton et al., 1986). Their effluents are high in BOD and contain suspended solids, oil and grease, bacteria, and inorganic or organic contaminants. Some plants continue to cause water quality problems, e.g., low oxygen in Blacks Harbour, discoloration at Shippegan Harbour.

Potato and meat processing effluents are a continuing concern in Nova Scotia and Prince Edward Island, and are controlled through *Fisheries Act* regulations and guidelines. In Charlottetown, for example, a meat processing plant discharges wastes after primary treatment to Charlottetown Harbour on the premise that the harbour and surrounding waters can assimilate the wastes (E. Norrena, pers. comm.). However, the plant's effluent is still in violation of the *Meat and Poultry Regulations* for BOD, being five times the regulated limit of 0.5 kg/ton. Also on P.E.I., Cavendish Farms potato plant is generally in compliance (P. Klaamas, pers. comm.).

Seven food processing plants operate along the St. Lawrence River from Cornwall to Montmagny. They discharge 13,000 kg/day of suspended solids, 32,600 kg/day of BOD material, 360 kg/day of phosphorus, and a variety of metals (Environment Canada, Quebec Region, pers. comm., 1986). Many other food processing plants dispose of untreated wastewaters through municipal sewage lines discharging directly to the river.

Other Industrial Effluents

Refineries, chlor-alkali plants, steel plants, primary aluminum smelting plants, chemical manufacturing plants (including fertilizers), and power plants, among others, also discharge wastewaters into Northwest Atlantic waters (Eaton et al., 1986; Waldichuk, 1988a).

The refineries are generally in compliance for regulated substances (oil and grease, sulphide, ammonia, total suspended matter, and phenols) and have substantially reduced their daily loadings to coastal waters (1978-1983 data, Day, unpubl. data). However, they are still significant sources of PAHs and occasional spillages of oils.

Chlor-alkali plants (one each in New Brunswick, Nova Scotia, and on the Saguenay River) continue to discharge mercury in their effluents. The federal government has regulated such discharges, and since 1972, concentrations have declined markedly.

The "tar pond" associated with the Sydney Steel Company's plant has contributed major quantities (approximately 3.5 million kg) of PAH compounds to Muggah Creek Estuary and the South Arm of Sydney Harbour (Hildebrand, 1982; Matheson et al., 1983). As a result, DFO closed a lobster fishery in the South Arm. The "tar pond" is now in the process of being removed through incineration.

The ERCO phosphorus plant in Long Harbour (Placentia Bay), Newfoundland, reduced its discharges of phosphorus since the "red herring" pollution crisis of 1969 (Jangard, 1972). Subsequently the plant had a minimum effect on local fisheries (Eaton et al., 1986). The plant has been closed since 1989.

Thermal pollution from power plants is a minor problem regionally, as are discharges (radioactive, chemical, and thermal) from the Point LePreau, N.B., nuclear power generating station. An intergovernmental group has monitored the discharges from the Point LePreau station since the plant opened.

Dredging and Ocean Dumping

In 1987, 101 permits were issued for the Atlantic provinces for ocean dumping under the *Ocean Dumping Control Act*, now Part Six, *Canadian Environmental Protection Act*, or CEPA (Government of Canada, 1988). The disposal of approximately 1.8 million cubic metres of dredge spoils accounted for 63 percent of the permits issued. Since 1976, the annual quantity of dredged material has ranged from 1.8 to 8.2 million cubic metres (Environment Canada, 1989) (see Table 5.1). Permits issued in 1987 in the Atlantic provinces also included the ocean disposal of vessels (5); fish offal (27), firearms and prohibited weapons (1), oil experiments (2), lime sludge (1), and brine water (1) (Environment Canada, 1989). The Quebec Regional Ocean Dumping Advisory Committee (RODAC) issued 20 permits in 1986, all for dredged materials. In addition, other dredging activities occurred in the St. Lawrence Estuary (Trois Rivières to Pointe des Monts) and in areas of the Quebec offshore under federal jurisdiction (Table 5.1). Overall, 40 to 50 federal dredging projects occur annually in Quebec, accounting for approximately 800,000 cubic metres of spoil.

Table 5.1 Average annual quantities of sediments dredged in marine areas of Eastern canada

Areas	Quantity dredged (averaged annually over an 8-year period), m^3
St. Lawrence Estuary	245,000[1]
Gulf of St. Lawrence (area under Quebec provincial jurisdiction)	140,000[1]
ODCA Area - Quebec Region	775,000[2]
ODCA Area - Atlantic Region	4,800,000[2]

Source: 1. R. Rochon, pers. comm., Environment Canada, Quebec.
2. Ocean Dumping Control Act Annual Report, 1984/85, Environment Canada, 1986.

Mining and Associated Industries

There are at least 12 coalfields in the Atlantic provinces with a large number of mines, most of which discharge wastewater and runoff into the ocean (Eaton et al., 1984). The discharges, containing many organic and inorganic substances, may have less impact in the sea than in other aquatic environments. This is due, in part, to the acid-buffering and general metal-complexing capacity of seawater. However, metals accumulate in estuaries, and a wide range of organics occur in coal wastewaters (Atwater et al., 1990). Disposal of waste rock is occasionally achieved by dumping it on the shore to be dispersed by natural wave action and currents (Eaton et al., 1986). A coalfield in Cape Breton (No. 26 Colliery) has routinely dumped an average of 69,000 tonnes of waste rock per year on the shore for the last 60 years (Eaton et al., 1986). This has resulted in modification and loss of intertidal habitat.

Increased production and use of coal in the Atlantic provinces is predicted. Potential quantities of waste rock have been estimated at 400,000 tonnes per year for the next 50 years (Eaton et al., 1986). Waste rock disposal of this magnitude may have cumulative effects on intertidal and subtidal environments close to these mines through habitat destruction and chemical contamination from seepage (e.g., cyanide). Some waste rock also may disperse naturally from the shoreline and form useable habitat for benthic organisms such as lobsters and crabs.

At Baie Verte, Newfoundland, tailings from an asbestos mining operation have entered the bay through runoff and slumping (sliding of the tailings pile due to excessive snow melt and rain) (W. Moores, pers. comm.). The asbestos-containing tailings have smothered the substrate and benthos in a portion of the bay (J.M. Osborne, pers. comm.).

Industries associated with coal production, such as generating stations and coke oven facilities, produce materials that contaminate nearshore environments. Coal ash and its leachates, coal tar, creosote, and PAHs are the main contaminants produced. Problems associated with these materials can be serious, leading to human health effects and closure of valuable fisheries. The PAH situation is discussed below (see *Sydney Harbour* below).

A lead smelter at Belledune, N.B., has contaminated fish species (lobster, mussels) in the past with discharges that contained cadmium and other metals (Environment Canada, unpubl. data; Uthe and Chou, 1985). An improved effluent treatment system led to major improvements in effluent quality and reduced metal (cadmium) levels in local biota (Uthe et al., 1986; Bewers et al., 1987). Heavy metals have contaminated sediments in Bathurst Harbour, downstream from metal mines. The level of contamination exceeds CEPA guidelines and prevents annual dredging (Hildebrand, 1984). Aluminum smelting plants in the Saguenay Fjord have discharged PAHs, fluorides, and metals to the fjord for many years (Environmental Protection, unpubl. data). This has resulted in elevated total PAH levels (up to 4.5 mg/L) in the sediments (Martel et al., 1986; Smith, 1988) and concern for local biota. The smelter operators are apparently starting to upgrade their pollution treatment systems.

There is also increasing interest in extraction of minerals from the coastal seabed, such as construction aggregate, titanium, and gold. Exploration is underway with some pilot-scale operations.

Oil and Hazardous Chemical Spills

From 1978 to 1983, 637 significant spills (volumes greater than 2,275 litres) occurred throughout the Atlantic provinces. In 1984, oil and petroleum products accounted for 88 percent of all spills, and for 89 percent of the 1.6 million litres spilled. Half of the significant spills (324 of 637) between 1979 and 1983 were from ships; most of the remainder came from leaking storage containers, especially in harbours. Chemicals such as sulphuric acid and phosphorus accounted for a small proportion of spills, with only seven being reported between 1981 and 1983. In 1983, the oil most frequently spilled was No. 2 fuel, and the chemicals most frequently spilled were PCBs and the pesticide fenitrothion, in New Brunswick (Environment Canada, 1985). Oil spills occurred most often in harbours.

A recent spill trend analysis (Environment Canada, 1987a), reported 2,284 oil spills (28,679 tonnes) and 336 spills of other hazardous materials (8,053 tonnes) between 1974 and 1984 in the Atlantic provinces. The most frequently spilled oil was No. 2 Fuel, while No. 6 Fuel accounted for the largest volume. The most frequently spilled hazardous materials were industrial chemicals, such as PCBs, while industrial wastes accounted for the largest volume. Sea transport accidents were among the major sources of spills.

Maritime traffic and municipal effluents cause most spills and environmentally-significant accidents in the St. Lawrence Estuary and Gulf. This region is a heavily used shipping corridor (9,334 commercial vessel movements annually through the Gulf, averaged over six years)(J.F. Gravel, pers. comm.). Consequently, it experiences various types of accidents. About 200 oil slicks are reported annually in the St. Lawrence River and Estuary (G. Martin, pers. comm.). An average of 54 spills per year, for the 1980-84 period, were reported between Cornwall and the western tip of Anticosti Island (Environment Canada, 1986b). Ship groundings also occur (about 12 per year), usually with little or no environmental impact (G. Martin, pers. comm.). Occasionally, such accidents do lead to major spills, as at Matane in 1985.

Riverine Inputs

On the Atlantic coast, the St. Lawrence River is the major freshwater source to the Gulf of St. Lawrence. This river drains the most heavily industrialized drainage basin in Canada, and consequently transports substantial quantities of contaminants from inland sources. Table 5.2 summarizes selected contaminant loadings from industrial sectors to the river between Cornwall, Ontario and Montmagny, Quebec.

The St. Lawrence River and Estuary have received a considerable contaminant burden, but the impacts of these discharges are poorly understood. Scientists have conducted a range of studies and monitoring programs which reveal chemicals in water, sediments, and biota along the River and within the estuarine section (e.g., Gagnon et al., 1988; Lucotte, 1988; Lum et al., 1988; Yeats and Loring, 1988). The St. Lawrence River Estuary acts as a sink for toxic substances through natural processes (Allan, 1986, 1990). Some of these chemicals are buried deeply in bottom sediments, particularly between the eastern tip of Ile d'Orleans and Tadoussac, Quebec. However, a portion of the chemical load may move out to the Gulf of St. Lawrence (Allan, 1986).

No one has estimated total contaminant discharges from the St. Lawrence River to the Gulf and the Northwest Atlantic. Pocklington (1988) concluded that "human additions of organic compounds to the Gulf are insignificant quantitatively, being only a fraction of annual primary production. Qualitatively, they may give some cause for concern" (see Table 5.3), as is also shown by data in *Seabirds* below. Background levels of petroleum residues are declining in Gulf waters (Levy, 1988). Lignin concentrations, which indicate terrigenous organic matter, are high near areas of pulp and paper waste input, and low or non-detectable in open areas of the Gulf (Pocklington and Roy, 1975; Pocklington, 1976, 1988) (Table 5.3). Addison's (1984) conclusion that riverine inputs are not major sources of contaminants to the Northwest Atlantic may be true for open offshore waters. However, this conclusion remains largely untested for estuarine and coastal waters downstream of major industrial activity. More recently, it was calculated that riverine inputs of organochlorines to the Gulf of St. Lawrence are similar to those from the atmosphere (R.F. Addison, pers. comm. 1991).

Many other large rivers (Saint John, St. Croix, Restigouche, Miramichi) discharge unknown amounts of contaminants to Atlantic coastal waters. Such discharges need to be quantified.

Non-Point Sources of Pollution

Agricultural runoff consisting of chemicals, pathogens, and soils is a major non-point contaminant of many estuarine and coastal marine areas (Johnston, 1976). This problem afflicts parts of the Atlantic coast. For example, agricultural runoff is the major non-point source affecting shellfish growing in the Atlantic provinces (Menon, 1988). For example, it is currently causing the closure of shellfish areas in Prince Edward Island. Runoff may contain high concentrations of nutrients and pesticides. Fertilizer and pesticide application in the Maritimes increased approximately 120 and 30 percent, respectively, between 1970 and 1980 (Statistics Canada, 1986). In the region, farmers treated approximately 120,000 hectares with fertilizers and 54,000 hectares with pesticides in 1980 (Statistics Canada, 1986). Some studies have detected fenitrothion residues in molluscs in the Northumberland Strait adjacent to forest spraying areas in New Brunswick (Lord et al., 1978; Wells et al., 1979).

Table 5.2 Selected loadings to the St. Lawrence River (Cornwall-Montmagny) by Contaminant or Parameter Industrial Sector (kg/day)

Contaminant or Parameter	Industrial Sector								Total Loading (kg/day)
	Organic Chemical	Metal Plating	Petroleum Refining	Metallurgy	Inorganic Chemical	Textiles	Chlor-Alkali	Wood Pre-serving	
No. of Plants	8	3	7	11	4	11	2	2	
Zinc (Zn)	3.70	41.79	20.59	931.23	565.7	0.99	95.68	0.01	1 659
Suspended Solids (SS)	627	6 931	9 505	272 580	18 094	597	1 308.0	29	309 671
Chemical Oxygen Demand (COD)	18 023	543	32 270	45 892	9 656	1 775	0	24	108 183
Total Kejaldahl Nitrogen (TKN)	272	8	5 299	785	1 330	37	125	0	7 856
Phosphorus (P)	234.5	395.4	85.3	1 526.1	341.5	20.7	7.3	0	2 610
Cadmium (Cd)	0	1.39	0.73	14.86	0.11	0	0	0	17
Chromium (Cr)	14.95	81.95	22.06	511.29	162.53	0.16	2.31	0.08	795
Copper (Cu)	74.04	6.95	13.92	321.63	5.76	0.23	1.88	0.01	424
Iron	21.45	9.18	238.34	19 024.3	22 832.3	1.82	16.53	0.09	42 144
Mercury	0.003	0.0004	0.0877	0.2504	0.0750	0.0020	0.550	0	0.97
Nickel	0.18	37.88	4.58	161.64	80.79	0	0	0	285
Lead	0.32	5.95	4.14	943.03	9.24	0.02	0	0	962

Source: Environment Canada, Conservation and Protection, Quebec Region, 1986.

Table 5.3 Contribution of lignin to sediments from the Gulf of St. Lawrence

Location	Lignin (mg/g dry wt.)	Organic Matter[a] (%)	Lignin (as % of OM)
Upper Saguenay	4.56	5.54	8.2
	9.04	7.13	12.7
Lower Saguenay	0.03	0.64	0.5
St. Lawrence Estuary	0.77	3.61	2.1
Laurentian Channel (inside Gulf)	0	2.60	0
Chaleur Trough	0.71	4.04	1.8
Esquiman Channel	+[b]	4.83	0
Corner Brook Harbour	16.51	17.2	9.6
Humber River	1.46	4.19	3.5
Cabot Strait	0	3.62	0
Laurentian Trough (outside Gulf)	0	3.26	0

[a] Organic carbon converted to organic matter using the empirical multiplier 1.887.

[b] + indicates positive spot test but no quantitative measure.

Source: Pocklington, 1988.

Many weather fronts crossing the Northwest Atlantic have passed over the highly industrialized areas of central and eastern North America. The atmosphere receives emissions with contaminants such as sulphur dioxide, carbon monoxide, nitrogen oxides, ozone, heavy metals, and organics, and deposits them over land and sea (Eaton et al., 1986; Wilson and Addison, 1984; Hilborn and Still, 1990). There is indirect evidence that such atmospheric transport contributes significantly to contaminant input, e.g., PCBs, into the Atlantic offshore (Ware and Addison, 1973; Brandon and Yeats, 1984).

In the St. Lawrence Estuary and Saguenay Fjord regions, scientists believe that atmospheric depositions of PAHs originate locally. They point to industrial activities such as aluminum manufacturing, carbon anode manufacturing, petroleum cracking plants, use of petroleum coke, and the manufacture of carbon silicide as sources of these PAHs (see Pocklington, 1988). PAHs also come from oil and wood burning, transportation, and open air incineration, including forest fires. The total quantities of PAHs entering Canadian Atlantic coastal waters from anthropogenic sources are currently unknown.

Urban runoff results in measurable levels of hydrocarbons, metals, silt, and persistent plastics entering waters near cities, towns and industrial sites. No one has quantified and assessed this problem extensively in Atlantic Canada. However, studies on Sable Island and in Halifax Harbour have now described the extent of persistent plastics and litter along the shore (W.R. Parker and Z. Lucas, pers. comm.; DPA Group, 1989).

Specific Substances

Investigations have detected a number of anthropogenic substances in the waters and sediments at specific sites, and in tissues of Atlantic biota. The presence of metals, organohalogens, polycyclic aromatic hydrocarbons, other petroleum-derived hydrocarbons, and organotins is described below.

Metals

Sources of mercury include, or have included, pulp and paper mills, where use of mercury as a fungicide was banned in the 1970s, chlor-alkali plants, where emissions have dropped 75 percent since 1978, municipal sewage, coal mining, burning of coal, long-range atmospheric transport, and "geological releases" due to surface water acidification (Wilson et al., 1976; Eaton et al., 1986). Presently, the two largest contributors of mercury are municipal sewage and coal combustion for electrical generation. Municipal sewage contributes 19 percent of all loadings of total mercury to coastal waters. Coal combustion for electrical generation, which is the single largest source of atmospheric mercury, contributed between 550 and 1,150 kg/yr in 1982 in New Brunswick and Nova Scotia (Eaton et al., 1986). The plethora of mercury sources results in many harbour sediments containing mercury at levels exceeding CEPA, Section VI limits for "at sea disposal" during dredging operations. This has led to the disposal of dredging spoils on land.

Zinc, lead, copper, and cadmium continue to contaminate sediments at Dalhousie and Belledune, N.B. with elevated concentrations in some benthos (Samant et al., 1990). In Newfoundland, three ore loading and storage sites had total concentrations of zinc, copper and lead in sediments well beyond background levels (Barrie, 1984). Zinc (up to 4,280 ppm) at all three sites (Hawkes Bay, Tilt Cove, Botwood), copper (up to 3,550 ppm) at Tilt Cove and Botwood, and lead (3,705 ppm) at Botwood, were much higher than levels at other contaminated Atlantic areas. Table 5.4 summarizes total metal levels and bioavailable metals in sediments at the sampled sites. Measurements recorded highly variable levels of copper, lead and zinc in biota at these sites (Barrie, 1984). Tissue levels ranged from 0.01 to 600 ppm for zinc, 0.03 to 452 ppm for lead, and 0.01 to 62 ppm for copper. Cadmium levels in sampled tissues were consistently low (less than 1.0 ppm). Metal levels in biota were similar to those found at other contaminated sites.

Estuaries are often sinks for toxic and persistent substances, especially heavy metals (Allan, 1986). A number of studies have confirmed this finding for the St. Lawrence (Loring, 1975; Piuze and Tremblay, 1979; Smith and Loring, 1981; Cossa and Rondeau, 1985; Allan, 1986; Strain, 1988). Sediment data obtained from federal dredging projects in the estuary also support this conclusion (Table 5.5; Environment Canada, Quebec Region, unpubl. data).

Several metals contaminate sediments and biota in the Saguenay Fjord, St. Lawrence Estuary, and Gulf of St. Lawrence, among other locations. In some cases, levels exceed Quebec guidelines for contaminants in sediments, particularly in the Lower St. Lawrence and the Saguenay Fjord. Although metal levels in some subsurface sediments result largely from past natural deposition rates, Loring's (1975) data for the Saguenay Fjord suggested an anthropogenic source, most likely a chlor-alkali plant and several pulp and paper mills (Smith, 1988). Sediments in the Saguenay Fjord have remained contaminated with mercury while bioaccumulation in shellfish has decreased by a factor of 20 since 1970 (Cossa and Desjardins, 1984). Cadmium and lead levels in

Table 5.4 Summary of heavy metal levels* in sediments at Tilt Cove, Hawkes Bay, Botwood and control sites, Newfoundland (November, 1983)

Analysis	Tilt Cove	Hawkes Bay	Botwood	Control Sites
Total Copper (mean)	3350.0	26.5	2966.0	12.2-37.6
Bioavailable **Copper (range)	21.68-96.59	0.29-0.33	3.79-96.57	-
Total Lead (mean)	102.4	35.6	3704.7	29.6-37.6
Bioavailable Lead (range)	6.15-44.29	1.51-13.0	1010-9098	-
Total Zinc (mean)	1890.7	2899.5	4280.0	30.2-79.3
Bioavailable Zinc (range)	29-132	62-956	248-519	-
Total Cadmium (mean)	4.7	66.4	229.0	1.0-1.4
Bioavailable Cadmium (range)	0.05-0.09	0.31-5.02	0.46-2.97	-

* Concentrations in parts per million, dry wt.
** Levels in tissues of local species.

Table 5.5 Sediment contamination by metals in marine waters of Quebec (ppm, dry weight)

	Location				Objectives for Quebec Region	
Metals	Saguenay Fjord	St Lawrence Ile d'Orleans	Estuary Rimouski	Gulf Sept-Iles	Acceptable Level,ppm	Non-acceptable Level,ppm
Chromium	-	127.0(1)	348.0(1)	262.0(1)	70	90
Copper	-	-	289.0(1)	-	-	-
Mercury	$\bar{x}$ =2980(2) ppb	-	14.0(1)	-	0.3	1.0
Lead	-	20.0(1)	60.0(1)	35.0(1)	20.0	60.0
Zinc	-	179.0(1)	112.0(1)	90.0(1)	80.0	175.0

Sources: (1) Data obtained from Federal Dredging Projects, Environment Canada, Conservation and Protection, Quebec Region, 1986.

(2) Loring, 1975.

sediments appear to be below the guideline values used in Quebec. The St. Lawrence and Saguenay Rivers have total dissolved arsenic concentrations similar to the lowest values found in other world rivers, and do not display the effects of air- or water-borne contamination (Tremblay and Gobeil, 1990).

PCBs and Other Organohalogens

The contamination of harbour sediments by PCBs is a relatively common occurrence due to past spills of transformer fluids, and industrial and municipal effluent discharges. Contaminated harbours include Halifax, Charlottetown, Sydney, St. John's, Fortune, Nfld, and Petit-de-Grat, N.S. (Eaton et al., 1986; A. d'Entremont, pers. comm.). The regular disposal of fish offal from fish processing plants may cause PCB contamination in some harbours (Wiltshire, 1978), although this conclusion is controversial (V. Zitko, pers. comm.). Limited water exchange by tides and currents in harbours may prevent the dispersal of contaminating wastes, resulting in accumulation of PCBs in sediments.

Organochlorine contamination is widespread along the Atlantic coast. For example, in the St. Lawrence Estuary and Gulf, PCBs are present in sediments and biota, and in trace concentrations in seawater (Smillie, 1976). Baie Comeau harbour sediments contain PCBs up to 27 ppm (R. Rochon, pers. comm.). Beluga whales (*Delphinapterus leucas*), seals (several species) and herring (*Clupea harengus harengus*) contain PCBs as well as a range of other organohalogens (Sergeant, 1980; Khalil et al., 1984; Martineau et al., 1985; Béland, 1988; Addison, 1989). In particular, PCB concentrations ranged up to several hundred ppm (wet weight) in belugas, with presently unknown consequences (Addison, 1989). *Seabirds* below also describes such contamination.

Hydrocarbons and PAHs

The input of petroleum hydrocarbons to the world's oceans from all sources is estimated at approximately 3.5 million tonnes per year (NAS/NRC, 1985). Transportation contributes approximately one-half of this volume. Since less than one percent of the world tanker traffic passes the east coast of Canada (Eaton et al., 1986), the degree of contamination from shipping, except where major spills occur, is expected to be relatively slight. This is reflected in the level of tar pollution in the Northwest Atlantic, which was "virtually undetectable" during the early 1970s (Levy and Walton, 1976). Today, even after some major spills (e.g., *Arrow*, *Kurdistan*) in the 1970s, levels of dissolved hydrocarbons and floating tar have returned to previous background levels (Levy, 1988). However, some marine sediment and shoreline contamination persists where ship spills have occurred (*Arrow* in Chedabucto Bay, *Kurdistan* in Cabot Strait, *Irving Whale* in Gulf of St. Lawrence, etc.), or where discharges and minor spills occur near refineries (e.g., island shorelines in Halifax Harbour). Frequent coastal oiling from ship discharges along the south coast of Newfoundland and the resulting seabird kills is a major regional wildlife concern (Environment Canada, 1988d; R.G.B. Brown and G. Finney, pers. comm.).

Offshore production of oil and gas on the Grand Banks and Scotian Shelf, may result in contamination due to increased tanker activity, spills from shipping and storage, wellhead accidents, and routine effluent and rig discharges to the sea. Globally, however, offshore production represents a small input of hydrocarbons to the sea (0.05 million metric tonnes/annum), compared to transportation, municipal and industrial wastes, and runoff (NAS/NRC, 1985).

Anthropogenically-derived PAHs are found in a number of locations, and originate from specific industrial emissions, creosoted wharves, urban runoff, and oil spills. PAHs from discharges at SYSCO coke ovens accumulate in the sediments and biota throughout Sydney Harbour (Matheson et al., 1983; Sirota et al., 1984). Accumulation of PAHs in lobsters led to the closure of the lobster fishery in the South Arm of the harbour in 1982 (Uthe and Musial, 1986). Creosoted materials (50 percent PAHs) contaminate most harbours. Studies identified thirteen PAHs in digestive glands from lobsters captured in Halifax Harbour in January 1989, levels reflecting the greater degree of contamination in the inner harbour (Uthe et al., 1989).

In the St. Lawrence Estuary, investigations detected elevated quantities of PAHs in and near Saguenay Fjord (Smith, 1988). Levels in the sediments ranged from 500 and 4,200 ppm (dry weight), decreasing with distance from Chicoutimi (Martel et al., 1986). Background levels in "uncontaminated" sediments were 55 ppb, 9 - 80 times lower (Laflamme and Hites, 1978). A mussel transplantation/monitoring experiment conducted in 1982 showed that all of Saguenay fjord is contaminated with benzo[a]pyrene (Picard-Berubé et al., 1983). The same study did not detect most PAHs in other regions of the St. Lawrence Estuary. Other studies have detected PAHs, benzo[a]pyrene metabolites, in brain tissue of some Beluga whales inhabiting the estuary (Béland, 1988).

Most recently, studies have detected low levels of PAHs in the muscle tissue of ten species of marine mammals from Newfoundland and Labrador waters. The high concentrations (up to 5.51 ppm, petroleum equivalents) measured in some animals from fishing areas suggests the need for more research (Hellou et al., 1990).

Organotins

Until recently, marine paints incorporated organotins (particularly tributyltin compounds) as anti-fouling agents (Thompson et al., 1985; Champ and Lowenstein, 1987). Until 1986, fishermen in the Northumberland Strait used fuel oil containing tributyltin oxide (TBTO) as a protective coating on wooden lobster traps. TBTO bioaccumulates readily, and is very toxic to some marine organisms, especially young life stages of molluscs and crustaceans (Thompson et al., 1985; Champ and Pugh, 1987). There is considerable concern about the overall hazard of TBTO to shallow subtidal communities. Harbours are expected to be particularly contaminated, based on evidence from ports on the Great Lakes (Thompson et al., 1985). This has been confirmed for the California coast (Champ and Pugh, 1987). Recent work demonstrated that butyltins and methyltins are frequently found in harbour sediments throughout the Atlantic provinces, especially in areas of heavy boating and shipping traffic (Maguire et al., 1986). The toxicological effects of such compounds in sediments is unknown at present. Use of paints with organotins on larger naval and commercial vessels continues.

Other Substances and Materials

Atlantic estuarine and coastal waters, sediments, and in some cases biota, contain a host of other chemicals such as chlorophenols, specific aromatic hydrocarbons, pesticides, resin acids, cyanides, and other heavy metals such as lead (Farrington et al., 1983; Wilson and Addison, 1984; Zitko, 1988). Some of the chemicals may contaminate fisheries and aquaculture species (Adam et al., 1987).

Persistent plastics, litter, and lost fishing nets foul shorelines and kill fish and wildlife at sea (DPA Group, 1989; Evans and Nettleship, 1985). Fishing nets set or lost in coastal and offshore areas incidently catch tens of thousands of marine birds and mammals (Piatt and Nettleship, 1987).

Natural toxins are also prominent contaminants. Domoic acid occurred in cultured blue mussels (*Mytilus edulis L.*) in the fall of 1987 in a localized area of eastern Prince Edward Island (Quilliam and Wright, 1988; Wright et al., 1989). The toxin, an amnesic shellfish poison originating in diatom microalgae, joined the list with paralytic shellfish poisons as a continuing problem in local coastal waters (Messieh and El-Sabh, 1990).

Coastal Development and Physical Changes

Dams, wharves, dikes, causeways, and tidal power projects individually or collectively influence the quality of estuaries and coastal waters. Dams on rivers in southern Quebec have reduced the amounts of freshwater entering the St. Lawrence River Estuary and Gulf with negative effects on the salinity regimes and biological production in some river mouths (Drinkwater, 1985). Wharves influence water and sediment flows in many locations, changing the structure of beaches and other shorelines. This is a problem in Prince Edward Island in particular.

The past four hundred years of European settlement have reduced coastal marine habitats. For example, the Acadians diked approximately seventy-five percent of the original salt marshes of the Bay of Fundy for farming (Gordon, 1990). In-filling, "land reclamation", and other coastal developments continue to remove productive and critical habitat from the marine environment, especially areas used by migratory birds. Although not well documented, habitat loss in open waters and from the ocean floor has also occurred (Gordon, 1989) (see *Wildlife* below).

Causeways have been built throughout the Atlantic provinces. Some have disrupted the natural flow and accumulation of sediments (e.g., Petitcodiac River at Moncton, N.B., the Avon River at Windsor, N.S., numerous highways) (Daborn and Dadswell, 1988; P. Lane, pers. comm.). Others have prevented the flow of estuarine waters and the dilution of industrial discharges (l'Etang Inlet, N.B.), or the natural distribution of critical life stages of commercial fish species, such as at Canso Causeway, N.S. (Harding et al., 1979, 1983). The problems with causeways are now well recognized, and some are being removed or modified. The proposed bridge to Prince Edward Island (the so-called Fixed Link Crossing) recently underwent an environmental impact assessment and was rejected due to serious concerns for local fisheries and their habitat.

Harnessing tidal power in the Bay of Fundy has been considered for many decades. Numerous recent studies intensively evaluated its environmental consequences to the Bay's unique ecology (Daborn, 1977; Gordon, 1984; Gordon and Dadswell, 1984; Plant, 1985). Primary concern centred on sediment transport which is so vital to the productive mudflats, the movement of fish, and the food supplies of migratory birds in the upper Bay. The new, pilot-size Annapolis Tidal Power Station on the Annapolis River, N.S., is attributed with killing fish and changing current patterns, causing additional river bank erosion upstream, and changing the deposition of natural muds in the Annapolis Basin (Daborn and Dadswell, 1988; Prouse et al., 1988). Such coastal construction and developments cause cumulative effects along a coastline (Simon, 1978). They can substantially influence its continued natural functioning (water flow, sediment deposition, productivity, condition of habitats) and appearance.

Physical impacts of fishing activity on bottom habitats and their organisms are a subject of recent concern and investigation. Fishing gear can extensively scour and disrupt the sea bottom, with both positive and negative impacts (P. Pocklington, pers. comm.).

Contaminants – Fate and Effects in Biota

Scientists frequently use biota as indicators of marine environmental quality, conducting measures of chemical residues in tissues and a range of ecotoxicological responses, from the individual organism to the whole community. This section focuses on the DDT and PCB groups as they have a long history of contamination in Atlantic waters, and some data sets suitable for trend analysis are available. As a guide, Table 5.6 lists some of the organochlorine compounds detected in marine environments (Harding, 1986). Due to its importance, the threat of oil to seabirds is also described in this section.

Table 5.6 Organochlorine compounds detected in the marine environment

pp-DDT	2,2-bis-(p-chlorophenyl)-1,1,1-trichloroethane
p,p'-DDT	2-(o-chlorophenyl)-2(p-chlorophenyl)-1,1,1-trichloroethane
p,p'-DDE	2,2-bis-(p-chlorophenyl)-1,1-dichloroethylene
p,p'-DDD	2,2-bis-(p-chlorophenyl)-1,1-dichloroethane
Chlordane	Cis- and trans-isomers of 1,2,4,5,6,7,8,8-octachlor-3a,4,7,7a-tetrahydro-4,7-methanoindane
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8a-octahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene
Aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,6,7,8a-hexahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Toxaphene	Chlorinated camphene (mixture, components resemble aldrin)
Heptachlor	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene
Heptachlor epoxide	1,4,5,6,7,8,8-heptachloro-2,3-epoxy-2,3,3a,4,7,7a-hexahydro-4,7-metanoindene
HCH	$\alpha,\beta,\gamma,\delta$-isomers of 1,2,3,4,5,6-hexachlorocyclohexane
Lindane	(gamma)-hexachorocyclohexane
PCBs	mixture of chlorobiphenyls
Hexachloro-benzene	hexachlorobenzene
Nonachlors	trans-Nonachlor(1,2,3,4,5,6,7,8,8-nonachloro-2,3,3a,4,7,7a-hexahydro-4,7-Methane-IH-indene)
PCTs	Polychlorinated terphenyls

Sources: G.C.H. Harding, 1986; V.Zitko, pers. comm., 1989.

Shellfish, Crustaceans and Fish

Many studies (e.g., Sprague and Duffy, 1971; Zitko, 1971, 1978, 1980; Zitko et al., 1974; Hargrave and Phillips, 1976; Sims et al., 1977; Musial et al., 1981; Musial and Uthe, 1983; Freeman et al., 1984; Misra and Uthe, 1987) show that commercially valuable shellfish, crustaceans, and fish in Atlantic Canada can contain a wide range of contaminants (such as DDT residues, PCBs, fenitrothion, nonachlor, chlordane, toxaphenes, chlorobenzenes, and other organochlorines). Evidence of trends in levels of contamination is very limited (Misra et al., 1988). In addition, there presently is limited field evidence to indicate that these contaminants are causing or contributing to direct or indirect biological effects. However, "examples of sick, heavily contaminated fish have been documented" in the region's coastal waters (Scarratt, 1987).

Scientists have expressed concern about cadmium concentrations in sea scallops (*Placopecten magellanicus*) taken in Atlantic Canadian waters (Ray et al., 1984). However, Uthe and Chou (1985, 1987) showed that similar sized scallops taken in the vicinity of Belledune contained cadmium concentrations of 0.257±0.066 mg/kg (wet weight). Scallops taken on Browns Bank, well away from any point source of cadmium, showed levels of 0.338±0.125 mg/kg (wet weight). Uthe and Chou (1987) argued that the Browns Bank concentrations are due to uptake of the bioavailable ambient cadmium due to nutritional conditions, and are not caused by anthropogenic sources of cadmium. Sediment concentrations of cadmium measured on Browns Bank are comparable to other offshore banks and are in the range identified as naturally occurring (Loring, 1984).

PAHs have been detected in mussels (*Mytilus edulis*) in the St. Lawrence Estuary and the northwest Gulf of St. Lawrence (Cossa et al., 1983). Industrial activities on the Saguenay River and Fjord may be responsible for the presence of several unsubstituted PAHs "in appreciable amounts."

Apart from data summarized by Misra and Uthe (1987) and Misra et al. (1988), much of the analysis of metal contamination in commercial species has centred on specific locations. In 1980, DFO closed Belledune Harbour, in Chaleur Bay, to lobster (*Homarus americanus*) fishing due to public health concerns about cadmium concentrations in its edible tissue (Uthe et al., 1986). Improved waste treatment at the lead smelter began late in 1980. This resulted in reduced contamination of water, sediments, and lobster tissue, and a re-opening of a restricted lobster fishery in 1985.

The Department of Fisheries and Oceans closed the South Arm of Sydney Harbour, N.S., to lobster fishing in 1982 due to the presence of PAHs in muscle and digestive gland tissue samples of the commercial catch. Using benzo[a]pyrene as an indicator of the suite of PAHs measured, Uthe and Musial (1986) reported concentrations of 1,430 ng/g wet weight in the digestive gland of lobsters from South Arm areas compared to 2.5 ng/g wet weight for lobsters from a control site near Port Morien. Analysis of data from 1982 and 1984 showed little change in concentrations of higher molecular weight PAHs and suggests, as a health precaution, that the fishery will remain closed until the PAHs are removed or isolated. The closure may also be unaffected by the on-going clean-up of the Sydney "tar pond," due to the levels and persistence of PAHs already in inshore marine sediments (NRCC, 1983; NAS/NRC, 1985).

A survey of dioxins and furans in the digestive gland of lobsters (Clement et al., 1987) in Chaleur Bay, Miramichi Bay, and Sydney Harbour did not find TCDD congeners in any samples. However, the survey found trace levels of TCDF in all sampled lobsters. More recent work on the Miramichi Estuary relates TCDF (specifically 2,3,7,8-T4CDF) contamination in the digestive glands of lobsters to discharges from the REPAP paper mill in Newcastle, N.B. (W.R. Parker, pers. comm.). Levels here are lower than those considered a health threat by Health and Welfare Canada.

Early studies showed PCBs and p,p'-DDE residues in Atlantic herring (*Clupea harengus harengus*) and yellow perch (*Perca flavescens*) (Zitko et al., 1974). Nonachlor and chlordane were present in lobsters, cod, herring, redfish, salmon, and white shark (Zitko, 1978). The studies identified several organochlorine compounds (PCBs, hexachlorobenzene, DDT and its residues, chlordanes, nonachlors, toxaphenes and others) in livers of sharks and bluefin tunas (*Thunnus thynnus*) (Zitko, 1980). Levels of organochlorines in herring may be causing physiological effects (Scarratt, 1987).

Between 1972-73 and 1974-75 PCB levels in cod (*Gadus morhua*) liver may have declined to relatively constant levels of approximately 2.0 μg/g (wet weight) (Freeman et al., 1984). DDT levels in cod followed a similar trend; dieldrin and HCB levels (0.03 μg/g wet weight) may be relatively stable.

A trend analysis of contaminants (arsenic, copper, mercury, zinc, lead, cadmium, selenium, PCB, alpha-HCH, HCB) in cod of the southern Gulf of St. Lawrence was conducted. It showed significant temporal trends, largely decreasing, for various organochlorines, but no clear relationship for metals (Misra and Uthe, 1987). This study concluded that "temporal variations in contaminant levels in Atlantic cod continue to occur" (Misra et al., 1988). Particular concern exists in Prince Edward Island regarding pesticide residues and estuarine and coastal fisheries (Scarratt, 1987).

Seabirds

Oil pollution is a major threat to seabirds. Oil spills and illegal releases of bilge waters from ships continue to affect seabirds along the Atlantic coast, through direct mortality and destruction of feeding and breeding habitats (Brown and Nettleship, 1984; Nettleship, 1977; Brown, 1982; Brown and Johnson, 1980; Brown et al., 1973). The effects of oil on seabirds after serious spills (*Arrow*, Chedabucto Bay, 1970; *Irving Whale*, Gulf of St. Lawrence, 1970; *Kurdistan*, Cabot Strait, 1979) are well-known (NAS/NRC, 1985), with many seabirds and waterfowl being killed. For example, "over 2600 birds are known to have been killed by oil off eastern Nova Scotia in the spring of 1979, most being victims of *Kurdistan* oiling" (Brown and Johnson, 1980). Species most seriously affected are those that dive and spend much time on the water surface, such as alcids, diving ducks, loons, and grebes (Brown and Nettleship, 1984; Peakall et al., 1987). But spill size does not necessarily relate to the numbers of birds killed, and bird counts along the shore seldom include birds affected offshore by oil slicks (R.G.B. Brown, pers. comm.). Small spills continue to occur near refineries, and many illegal discharges of oil off southeastern Newfoundland continue to affect seabird populations (Environment Canada, 1988d; MEQ Advisory Group, 1989). Surveys of beached birds to document seabird oiling and mortality have been conducted in southeastern Newfoundland since 1984; no reduction of the problem is evident yet. Similar surveys are conducted on Sable Island (A. Gaston, pers. comm.). There are concerns for seabirds in the areas of impending oil production (Sable Island, Hibernia oil field) and from continued oil releases (Bunker C at the *Irving Whale* site) and shipping.

For two decades, seabirds have been used to monitor the presence and effects of other marine contaminants in the Northwest Atlantic (see Zitko et al., 1972; Gilbertson and Reynolds, 1974; Zitko, 1976; Chapdelaine et al., 1987; Nettleship, 1975, 1976; Noble and Elliott, 1986; Gilbertson et al., 1986; Pearce et al., 1989; Elliott et al., 1988b). A wide range of chemicals, including PCBs, DDT, DDE, DDD, mirex, dieldrin, heptachlor epoxide, HCB, HCH, oxychlordane, and chlordane metabolites, are present in many populations (Noble and Elliott, 1986). Canadian Atlantic coast seabird populations are ranked from most, to least contaminated: (1) the St. Lawrence Estuary, (2) the Gulf of St. Lawrence, (3) Bay of Fundy, (4) Atlantic coast of Newfoundland, and (5) Lancaster Sound. In general, contamination in the Gulf of St. Lawrence is about three times lower than in populations in the Great Lakes, but of a similar magnitude to levels on the northeastern coast of the United States. There is a distinct gradient for PCB contamination in seabirds. The Great Lakes record greater contamination than the nearshore marine area, while the offshore is lower than both (Norstrom, 1988).

Scientists have established trends of OC contamination for four species of Northwest Atlantic seabirds (Chapdelaine et al., 1987; Norstrom, 1988; Pearce et al., 1989). Gannet eggs from Bonaventure Island have shown significant declines in DDT, HCB, PCBs, and dieldrin residues (Table 5.7). For cormorants, puffins, and storm-petrels, "the general picture over the period monitored is of declining levels of most chemicals in the Bay of Fundy colonies, slower rates of decline or no change at colonies on the outer continental shelf, and no change or increases in the St. Lawrence Estuary" (Pearce et al., 1989) (Figure 5.2). Contamination by oxychlordane, however, has declined only in Atlantic Puffins (*Fratercula arctica*), and HCH contamination is either stable or increasing in most species.

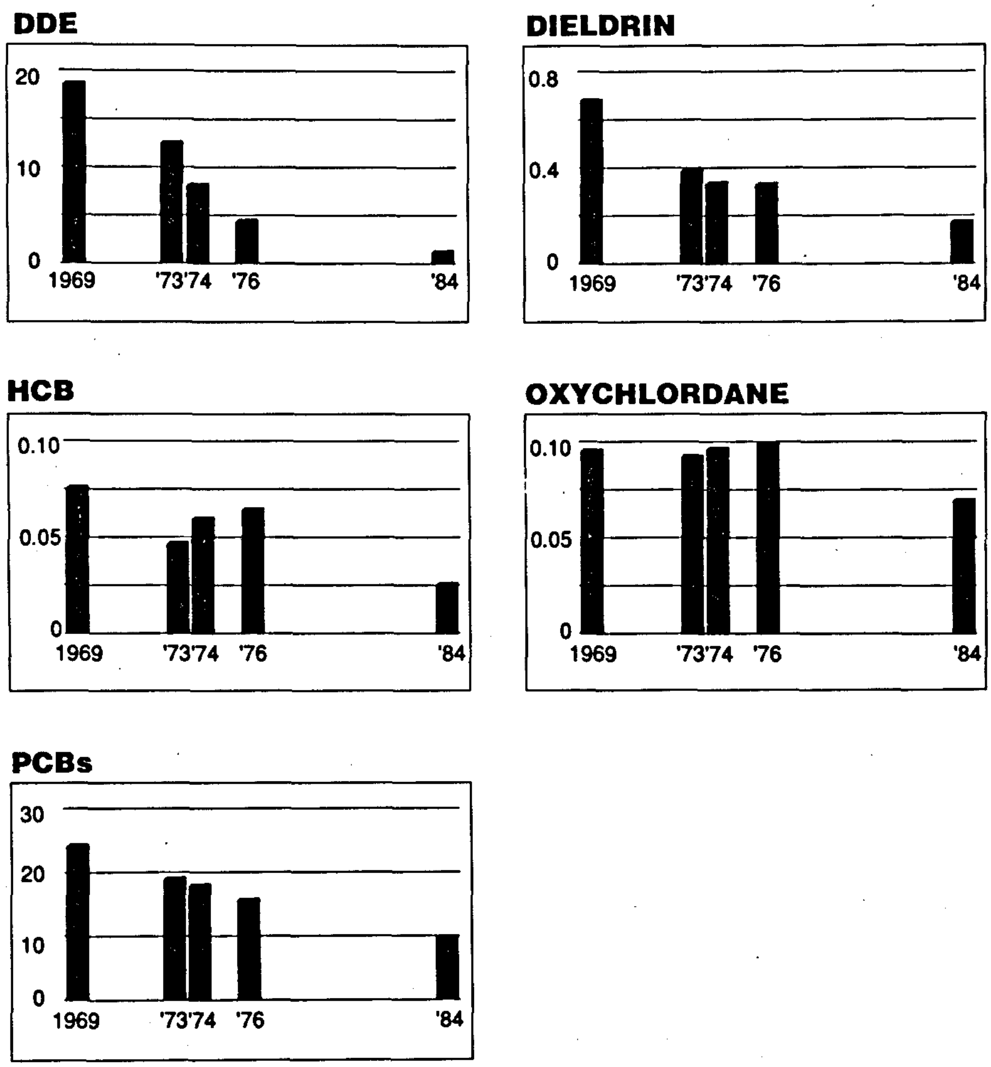
Contamination of Atlantic seabirds by OCs has caused sublethal rather than lethal effects. Eggshell thinning and other forms of reproductive failure have occurred at several colonies, resulting in reduced populations (Elliott et al., 1988b). During the late 1960s, eggs taken from Northern Gannets (*Sula bassanus*) on Bonaventure Island, Quebec, contained mean DDE levels of 18.5 ppm (fresh live eggs) and 30.6 ppm (unhatched dead eggs), and exhibited significant shell thinning. Hatching success was reduced to 45 percent of the normal rates, and the population was declining (Chapdelaine et al., 1987). PCBs, dieldrin, HCB, and chlordane-related compounds may also have contributed to the decline of gannets. Restrictions on the use of DDT was accompanied by increased breeding success and population numbers. The evidence "strongly suggests DDE-induced shell thinning as a main factor in reducing productivity" (Elliott et al., 1988b).

In the early 1970s, twenty percent of the Double-crested Cormorant (*Phalacrocorax auritus*) eggs sampled on the Atlantic coast contained DDE residues sufficient to cause significant eggshell thinning. Sampling recorded similar conditions for the Leach's Storm Petrel (*Oceanodroma leucorhoa*) nesting on Kent Island, New Brunswick. DDE, the main metabolite of DDT, has declined in the affected populations (Figure 5.2). Reproduction is now normal, and populations are increasing, although these changes cannot be attributed solely to reductions in organochlorine concentrations.

Mercury may have caused deaths of some seabirds on the Atlantic coast. Mercury contamination in Chaleur Bay's cormorants (*Phalacrocorax auritus*) compared to levels resulting in deaths elsewhere (Noble and Elliott, 1986).

More recent studies have focused on contaminants in the food of shorebirds, especially migrating seabirds. For example, studies did not detect DDT and its derivatives and PCBs in lipid extracts of *Corophium volutator*, an amphipod crustacean inhabiting the intertidal mudflats of the Bay of Fundy (Napolitano and Ackman, 1989). This crustacean is an important food for migratory birds such as Semipalmated Sandpipers (*Ereunetes pusillus*). Oiling of mudflats probably remains the greatest threat to such seabirds (R.G.B. Brown, pers. comm.).

Table 5.7 Organochlorine residues (geometric mean, μg/g, wet weight) in Gannet eggs from Bonaventure Island, Quebec, 1969-1984
Sample size N = 6 eggs for each year

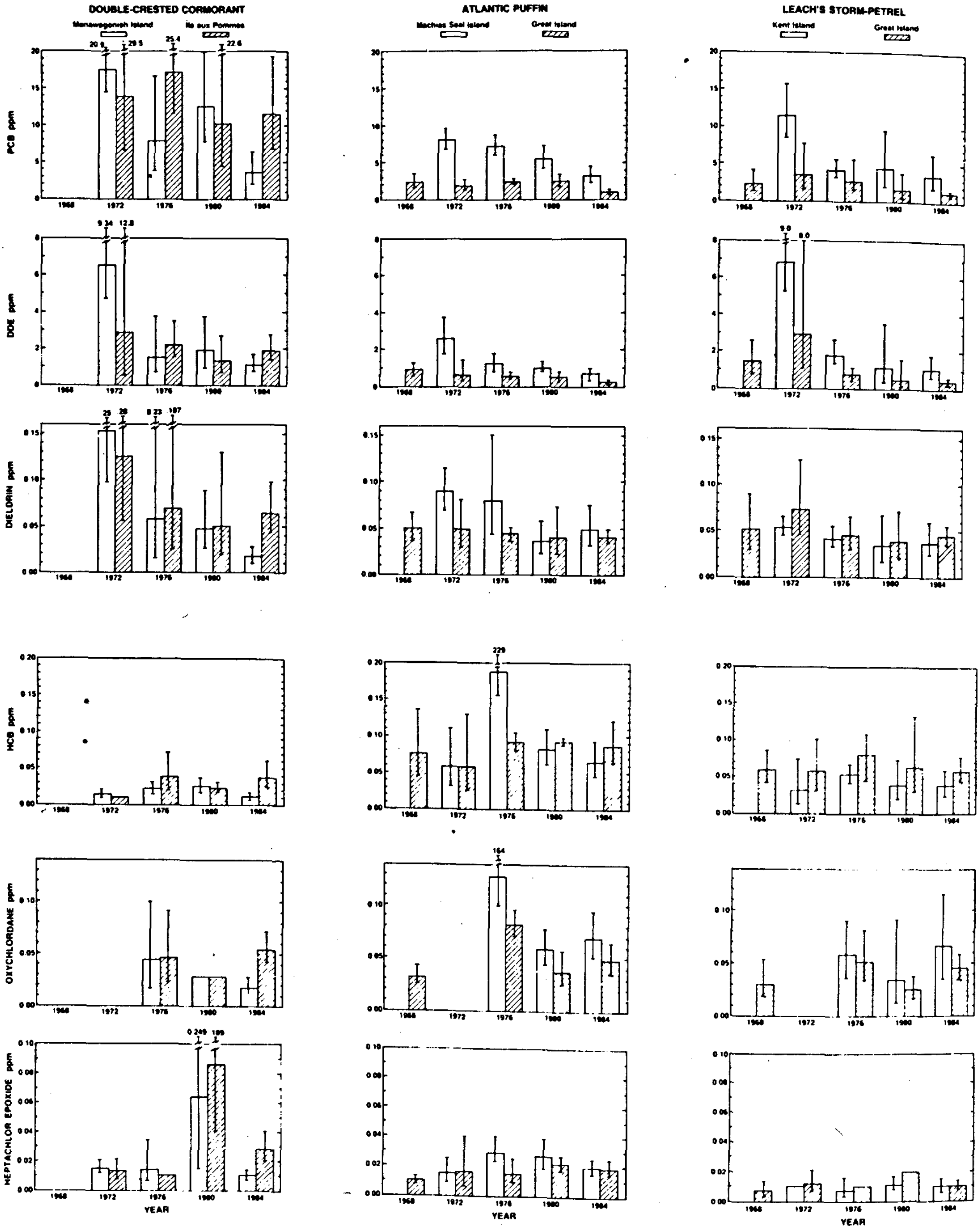


Annual percentage decrease in residue level

	DDE	DIELDRIN	HCB	OXYCHLORDANE	PCBs
Average	19%	9.4%	6%	2%	6%

Source: After Elliott et al., 1986.

Figure 5.2 Levels of PCBs, DDE, dieldrin, HCB, oxychlordane and heptachlor epoxide (mg/kg, wet weight) in eggs of Double-crested Cormorants, Atlantic Puffins and Leach's Storm Petrel in Atlantic Canada, 1968-1984



Marine Mammals

Numerous studies document the contamination of Atlantic Canadian seals (Addison et al., 1973; Frank et al., 1973; Gaskin et al., 1973; Addison and Brodie, 1977; Roswell et al., 1979; Addison et al., 1984; Addison et al., 1986b; Ronald et al., 1984). Significant declines in DDT contamination in Atlantic Grey Seals (*Halichorerus grypus*) and Harp Seals (*Phoca groenlandicus*) occurred over approximately a decade (Addison et al., 1984). However, PCB levels showed no decline (Addison et al., 1984; Addison et al., 1986a).

Many other studies document the types and concentrations of contaminants in pinnipeds and cetaceans living in Northwest Atlantic waters (Pearce et al., 1973; Frank et al., 1973; Saschenbrecher, 1973; Aquilar and Jouer, 1982; Gaskin et al., 1983; Massé et al., 1986; Hellou et al., 1990). However, these studies do not permit trend analysis due to variations in sampling and measurement techniques. The studies do demonstrate that levels of contaminants in harbour porpoises in the lower Bay of Fundy (Passamaquoddy Bay) are high. They record DDT levels greater than 500 ppm, PCB levels greater than 200 ppm, and mercury levels of 90 ppm in liver tissue and 8 ppm in brain tissue (Gaskin's recent studies, from Thurston, 1990). There is, unfortunately, little knowledge of the effects of this suite of contaminants acting in concert on these animals, although such levels may be high enough alone to elicit clinical signs of poisoning.

The St. Lawrence Beluga Whale

The population of the St. Lawrence beluga or white whale (*Delphinapterus leucas*), estimated at approximately 5,000 individuals in the late nineteenth century, has declined to between 350 (Pippard, 1985) and 500 individuals (Sergeant, 1986). Hunting, harassment, loss of critical habitat, and contamination by chemical compounds are believed to have contributed to this decline. The St. Lawrence beluga is designated an endangered species by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Burnett et al., 1989).

Hunting by humans was a significant threat to belugas earlier in the century, but has progressively decreased over the past thirty years (Reeves and Mitchell, 1984). The government has prohibited hunting since 1979. However, the population has failed to recover despite the cessation of hunting (Massé et al., 1986).

Beluga habitat has been reduced in size and quality. Studies conducted in the 1940s revealed summering groups of belugas at, among other places, the mouths of the Manicouagan and Outardes Rivers (Vladykov, 1944). Subsequent work in 1974-75 revealed that belugas had disappeared from these areas, presumably due to reduced or fluctuating temperatures unsuitable for calving, caused by upstream dam construction (Sergeant and Brodie, 1975; H. Neu, unpubl. observ.). Another theory is that these dams had an adverse effect on fish and invertebrate reproduction, reducing the number of prey species available to the whales (Pippard, 1985).

Various organochlorine compounds (such as PCBs, DDT, mirex, HCB), PAHs, and metals (mercury and cadmium) have been measured in the blubber and organs of stranded dead belugas, often at very high levels (Massé et al., 1986; Béland, 1988). The levels of PCBs are comparable to those found in populations of other marine mammals which have experienced reproductive dysfunction and population declines (Wagemann and Muir, 1984). Levels of PAHs are similar to those leading to pathological lesions, and physical and reproductive disorders in other mammals (Martineau et al., 1985, 1988). The reproductive rate of the St. Lawrence belugas is currently about one-third below that in the Canadian Arctic population (Sergeant, 1986). However, scientists have not established an unequivocal cause-effect relationship between OC and/or PAH contamination and reproductive failure for these animals (Béland, 1988; Addison, 1989). Nonetheless, the presence of the various residues at high concentrations is cause for grave concern and continued investigation (P. Béland, pers. comm.). Numerous commentators have suggested that the St. Lawrence beluga may be the most contaminated mammal on earth.

Geographic Concerns

The environmental health of a wide range of Atlantic geographic regions and sites is of concern (Wells, et al., 1986; Wells and Côté, 1988; Government of Canada, 1990; see Table 5.8). Some of these are discussed below.

Halifax Harbour

The harbour receives many types of wastes, of which untreated municipal wastewater (i.e., sewage) from most of the surrounding municipalities is the primary concern. Recent studies (ASA, 1986) have shown reduced water quality due to elevated faecal coliforms, high BOD loadings, and persistent flotables. Recent surveys recorded coliform concentrations of 100 to 10^5 CPU/100 ml, depending upon location of sampling. In the inner harbour, values are often 10^4 CPU/100 ml or higher, while in the outer harbour, beyond Georges Island, values drop to 100 CPU/100 ml or lower (A. Menon, pers. comm.). Other studies have shown that many contaminants exist in harbour waters and sediments (e.g., Michalik and Gordon, 1971, for oil residues; Ward, 1990, for metals in mussels; Mudroch and MacKnight, pers. comm., for various organics; Buckley and Hargrave, 1989 and LeBlanc et al., 1991, for metals). Many organisms, ranging from plankton to fish, marine mammals (seals, whales), and seabirds, live in the harbour and inlet for all or part of the year. The benthos is diverse, with a biomass similar to other coastal embayments and no obvious areas of impoverishment (Hargrave et al., 1989b). Lobsters and finfish support small but valuable commercial fisheries (Ducharme, 1990). The potential exists for adverse, acute and chronic effects of contaminants on the harbour's natural ecosystem and for serious impairment of some traditional uses such as swimming, boating, commercial and sport fishing, and aesthetic enjoyment (ASA, 1986; Fournier, 1990).

Some industries, such as the oil refineries, have treatment facilities for their wastewater. Most do not, and they discharge wastewater through the sewer systems or directly into the harbour (Environmental Protection, unpubl. data). Hence, as in any industrialized harbour, there are many waste inputs, all but the diffuse sources (i.e., urban runoff, atmospheric deposition) being amenable to prevention or treatment.

A three-phase study of Halifax Inlet water quality was conducted recently (ASA, 1986). The final product was a numerical water quality model which allows simulation of processes affecting the fate of sewage effluents in these waters and predicts the impact of effluents on water quality (Hurlbut, 1990; P. Klaamas, pers. comm.). In June 1988, three levels of government approved and funded a programme to construct a sewage treatment plant or plants in Halifax Inlet. A number of studies in support of the programme have started, e.g., measuring and mapping contaminant levels in the Inlet's water, sediment and biota (Nicholls, 1989), assembling a comprehensive bibliography (Hargrave and Lawrence, 1988); and conducting an environmental impact assessment

Table 5.8 Some Atlantic coast geographic concerns for MEQ

Location	Examples of Concerns
Various Harbours* (Halifax, Saint John, Pictou, Sydney, St. John's, etc.)	• municipal and industrial pollution • shoreline development • conflicting uses
Gulf of Maine	• coastal development • industrial discharges
Lower Bay of Fundy* St. Croix Estuary L'Etang Estuary Annapolis Basin	• shellfish, fish passage • shellfish/pulp mill conflict • tidal power plant/fish conflict
Upper Bay of Fundy*	• contaminants, spills • sedimentation at causeways • power projects
Shubenacadie - Stewiacke Basin, NS	• multiple use conflicts
Bras D'Or Lakes, Cape Breton	• conflicts between aquaculture and other uses
N.B., N.S., P.E.I. coasts	• bacterial contaminants/PSP in shellfish
Northumberland Strait/ P.E.I. coastal waters +	• pesticides • nutrients/sediments • natural toxins • PEI "Fixed Link" Crossing
Miramichi River Estuary +	• pulp and paper contaminants • wood treatment chemical residues • dredging • metals in sediments
Restigouche Estuary + Chaleur Bay	• industrial contaminants • ocean dumping • fisheries habitat - salmon
Chaleur Bay*, + (Baie des Chaleurs)	• multiple industrial inputs • ocean disposal and dumping • metals in sediments
St. Lawrence River* **Estuary**	• multiple industrial inputs • contaminated fisheries species • cetaceans and organochlorines
SE Coast of Newfoundland*	• Grand Banks oil and gas • coastal shipping, oil spillages, bilge dumping

* Also see text
\+ Also considered together as Southern Gulf of St. Lawrence (Messieh and El-Sabh, 1988)

review on the harbour (Fournier, 1990; S. Conover, pers. comm.). In 1989-90, a Halifax Harbour Task Force made a number of recommendations regarding the siting and type of sewage treatment plant and overall harbour environmental management needs (Fournier, 1990). Two Halifax Inlet Research Workshops have been held to discuss research results and plans pertaining to the harbour, covering seafloor geology, physical oceanography, geochemistry, water chemistry, biological oceanography, fisheries, monitoring, and harbour management (DFO, 1990).

Sydney Harbour

In the past, Sydney Harbour has supported commercial lobster and shellfish fisheries. Presently, it serves a number of industries, including the Sydney Steel Corporation (SYSCO, Nova Scotia's only steel manufacturing plant) and coal beneficiation facilities (Eaton et al., 1986). Sources of contaminants to the harbour include effluents and air emissions from the SYSCO plant, effluents from coal beneficiation operations, runoff containing contaminants deposited on land by SYSCO and coal mining operations, and untreated sewage from Sydney and other municipalities around the harbour. The primary contaminants, PAHs and heavy metals (cadmium, mercury, lead, and zinc), are widespread in harbour sediments and biota (Vandermeulen, 1989).

The PAHs originate largely from the "tar pond" at the mouth of Muggah Creek on the harbour's South Arm (Matheson et al., 1983; Vandermeulen, 1989). The "tar pond" has received coke oven effluents and other waste streams from the SYSCO Steel Works for over 80 years. The pond covers an area of approximately 338,000 m^2 of shoreline and adjacent land. A coal tar deposit of up to one percent measured PAHs highly contaminates the top 1.5 m of sediments (Hildebrand, 1982). The PAHs from SYSCO effluents and the "tar pond" are migrating from Muggah Creek into Sydney Harbour at an estimated rate of 100 kg/year. An investigation in 1981 (Matheson et al., 1983) revealed elevated concentrations (range: 130 - 10^4 ng/g dry weight) of PAHs in sediments throughout the harbour which decreased with distance from Muggah Creek. In addition, PAHs contaminated intertidal and benthic biota in the harbour (Matheson et al., 1983). Mussels contained 40 times the level of benzo[a]pyrene compared to mussels taken from non-contaminated areas. Analysis of two species of mussels (*Mytilus edulis, Modiolus modiolus*) suggested a direct relationship between total PAH sediment concentration and tissue contamination. Lobsters were contaminated at 26 times the levels of total PAHs and 572 times the levels of benzo[a]pyrene from non-contaminated areas (Uthe and Musial, 1986). This led to the closure of lobstering in the South Arm of Sydney Harbour in 1982 (Eaton et al., 1986), a ban still in effect.

Federal and provincial authorities agreed in 1987 to clean-up the SYSCO "tar pond". The recommended remedial action involves excavation and incineration of the sediments. A clean-up program is currently underway (I. Travers, pers. comm.), supported by a monitoring survey of the harbour waters, sediments, and biota.

St. John's Harbour

St. John's Harbour receives untreated municipal sewage, effluents from some combined sewers, untreated industrial waste discharges, stormwaters, discharges from ships, and urban runoff. In 1981, a study assessed water quality in the harbour, the impact of discharges from the harbour mouth to the open ocean, and the effect of proposed relocations of sewage outfalls on water quality in the harbour and open ocean (Newfoundland Design Assoc. Ltd., 1982). The initial water quality survey of the harbour showed that geometric mean faecal coliform contamination exceeded 1100 CFU/100 ml at some locations. An 80 percent reduction in coliform levels in some areas of the harbour would be required to reach an objective of 200 CFU/100 ml. Dissolved oxygen deficits generally ranged between 9 and 20 percent except for one site with a deficit of up to 55 percent at low tide.

The study also measured elevated levels of coliform bacteria in the coastal waters beyond the mouth of the harbour (Newfoundland Design Assoc. Ltd., 1982). Dilution of coliforms is slow in surface streaks or plumes originating from the harbour mouth. The study estimated that faecal coliform levels at the harbour mouth would have to be decreased 30 to 46 percent to achieve coliform levels of less than 200 CFU/100 ml in surface streaks one kilometre from the mouth of the harbour.

Relocating some sewage outfalls within the harbour and constructing an open ocean outfall beyond the entrance, as proposed in 1988, should improve harbour water quality. This should also reduce coliform levels in ocean plumes caused by surface streaking phenomena.

The Bay of Fundy

Sustaining the environmental quality of the Bay of Fundy ecosystem is of concern to many parties because of the Bay's economic and scientific value, the uniqueness of its diverse habitats and wildlife, and the nature of both short- and long-term threats to the Bay's health (Thomas, 1983; Gordon and 1984; Daborn and Dadswell, 1988; Plant, 1985; Gordon, 1990; Thurston, 1990). The Bay has been threatened by industrial effluents, oil spills, power-plant discharges, municipal sewage, tidal power development, ocean dumping, salt marsh reclamation, causeways, and aquaculture projects. These have caused contamination, pollution, habitat and species loss, and interfered with migratory and endangered species, i.e., seabirds and whales. A full survey of these threats and the present condition of the Bay is needed to guide future science and management action, following the example of the Bay of Fundy Program of the 1980s (Gordon, 1990).

Work on Saint John Harbour should be considered within the context of the whole Bay and its unique oceanography and protection needs. Local fishermen and others considered that extensive dredging required to maintain the harbour and channel at Saint John was having a detrimental impact on the fishery in the area, and was affecting the marine fauna and flora along the coastline. A workshop brought together concerned parties and jurisdictions in 1981 (Lindsay et al., 1983). Analysis of sediment distribution and dredging-related activity indicated that harbour dredging was not the major, or perhaps even a significant, source of pollution. Natural siltation processes accelerated by onshore development, and growth of Saint John due to the pulp and paper, fishing, and other industries (refineries, for example), were more likely sources of environmental degradation or change. Disposal of largely untreated sewage and modifications resulting from causeway and wharf construction were also seen as contributing contaminants and changing the flow pattern and flushing action in the harbour. A rigorous assessment of the harbour's condition will begin in 1991 (T. Hennigar, pers. comm.).

The Gulf of Maine

The states and provinces bordering the Gulf of Maine have recently focused on the Gulf in order to undertake cooperative conservation and protection measures to ensure its long-term sustainability and health. A number of studies describe the many threats (toxic chemicals, effluents, habitat loss, natural toxin outbreaks, closed shellfish beds, contaminated seafood and restricted swimming waters) to the Gulf (VanDusen and Hayden, 1989; Konrad et al., 1990; Waterman, 1990). The provinces and states bordering the Gulf signed an *Agreement on the Conservation of the Marine Environment of the Gulf of Maine* in December 1989. The signatories have developed an Action Plan and identified monitoring and scientific priorities. The Gulf of Maine Program forms a key part of a network of coastal protection, conservation, and remedial programs in the Northwest Atlantic, some spanning both the U.S. and Canada, all of them addressing marine environmental quality.

Chaleur Bay

Both sides of this bay in the western Gulf of St. Lawrence receive effluents from a number of industries including five pulp and paper mills, an alum chemical plant, a chlor-alkali plant, a lead smelter, a fertilizer plant, and base metal mining discharges. Effluents enter either directly or indirectly through rivers draining into the Bay (Hildebrand, 1984). Almost 50 fish processing plants operate around the Bay contributing process effluents and offal. A thermal generating station releases various atmospheric contaminants including heavy metals and PAHs, some of which probably fall in the Chaleur Bay area. Finally, numerous communities discharge municipal wastewaters into the Bay.

Since the early 1970s, the communities and industries surrounding Chaleur Bay have taken steps to alleviate pollution problems. The pulp mills, lead smelter, chlor-alkali plant, and some mining operations have implemented effluent quality controls. For example, DFO reopened a restricted lobster fishery in Belledune Harbour in 1985 as a consequence of major (97 percent) reductions in cadmium releases from the smelter.

Most communities around the Bay have installed or upgraded their wastewater treatment facilities. This has reduced bacterial contamination; however, the upgrading of the wastewater treatment plant in Caraquet has had no significant ameliorative effect on the contamination of Caraquet Bay oysters. This fishery, currently worth about $500,000 per year, could be worth approximately $2,000,000 per year if all production areas currently closed due to bacterial contamination were opened.

Overall, Chaleur Bay has low levels of contamination, but local problems persist around the periphery of the bay. Such problems are or have been severe along the New Brunswick side of the bay where heavy industrialization and urbanization are most intense. In general, the Bay faces the same pressures (physical modification, pollution, fishing) as do other parts of the southern Gulf of St. Lawrence (Messieh and El-Sabh, 1988), and indeed, the whole Gulf system (Dickie and Trites, 1983).

St. Lawrence Estuary

The St. Lawrence Estuary receives freshwater draining from a land basin of over 1.4 million square km, one of the most populated and industrialized areas in North America. Overall, quantitative inputs from the St. Lawrence River to the estuary have not been calculated. Chemical and pollutant sources of concern include municipal effluents, waste dump and landfill sites, industrial effluents, agricultural runoff, oil spills, and air emissions. Together, these sources contribute a variety of organic and inorganic compounds (organohalogens, agricultural chemicals, petroleum products, heavy metals, and PAHs), and oxygen depleting materials to the river system. In general, the impacts of these materials are thought to decrease as one moves from the River, through the estuary, and out to the open Gulf. Also of concern to the overall physical stability and biological integrity of the estuary is the influence of dams on the volume and pattern of water flow into it. Dams influence seasonal cycles of temperature, nutrients, and flow volumes in downstream waters, affecting small and large estuaries along the St. Lawrence (Dickie and Trites, 1983).

Signs of anthropogenic stress include contaminated sediments (heavy metals, organic compounds), decreased water quality (BOD, COD, organic compounds), and contaminated biota (heavy metals, organic compounds) in varying degrees along the St. Lawrence River. In the case of the St. Lawrence beluga, high mortality and disease rates, possibly associated with high levels of contamination by organochlorines and PAHs, has led to critical questions about the whales' continued survival in the estuary (Luoma, 1989; P. Béland, pers. comm.; also see *St. Lawrence Beluga Whale* above). Based on contaminant levels in seabird eggs, the estuary is one of the most contaminated marine environments in Canada (Noble and Burns, 1990).

However, increased efforts in pollution abatement are the result of better information on the state of the St. Lawrence ecosystem and the threats to it. At present, remedial initiatives are underway as far upstream as the Great Lakes. These efforts, in conjunction with pollution control efforts targeted at municipal and industrial effluents in Quebec through the St. Lawrence River Action Plan (Environment Canada, 1988c), should improve the environmental quality of the estuary.

St. Lawrence Coastline

Shellfish

The distribution of benthic organisms such as bivalve molluscs often reflects human pressures exerted on the St. Lawrence corridor. There are 401 shellfishing areas in Quebec, based on a geographic breakdown of the St. Lawrence system, including the Saguenay. Of these, 164 are presently closed to shellfishing because of real or potential contamination by industrial or domestic sewage discharges, or by toxins usually present during favourable harvesting seasons. The Saguenay shoreline is contaminated along 64 percent of its length (197 of its 310 km of shore). The south shore of the St. Lawrence Estuary and the Gaspé Peninsula, which comprises 803 and 835 km of shoreline respectively, are also heavily affected. Respectively, 61 percent and 43 percent of the coast are closed to shellfishing. Overall, approximately 30 percent of the coast in southern Quebec is closed to shellfishing because of contamination from human activities. This is a minimum figure since more than half of the shellfishing areas where fishing operations or harvesting are permitted have not yet undergone bacteriological analysis (P. Laramée, pers. comm., 1988).

Wildlife

The St. Lawrence Estuary and the northern Gulf of St. Lawrence are part of a vital migration corridor for waterfowl in eastern Canada. Extensive wetlands provide a wide variety of plants and animals with critical habitat that is necessary for the survival of rare, threatened, or endangered wildlife species (Environment Canada, 1986c; Burnett et al., 1989). This area harbours the entire Greater Snow Goose (*Chen caerulescens*) population and nearly all of the Barrow's Goldeneyes (*Bucephala islandica*) wintering in eastern North America. At given points in their annual cycles, between 15 and 80 percent of the populations of 12 species (Brant, Canada Goose, American Black Duck, Canvasback, Common Eider, King Eider, Oldsquaw, Black Scoter, Surf Scoter, Common Goldeneye, Gadwall and Redhead) are found here (Lehoux et al., 1985).

Since 1945, various encroachments along the St. Lawrence have destroyed or rendered unusable nearly 4,000 hectares of riparian habitats (Table 5.9). Marine transportation has encroached upon slightly more than 44 km of shoreline (approximately 100 harbour facilities), representing 1.1 percent of its total length (Goudreau, 1981). The diet of Snow Geese comprises 66 percent saltwater sedge (*Scirpus* sp.) tubers and 19 percent cordgrass (*Spartina* spp.) roots. The American Black Duck (*Anas rubripes*) nests in salt marsh grasses, and 85 percent of its diet comes from areas of emergent *Spartina*. The disappearance of these habitats threatens these two species and the existence of several others. In the past 40 years, encroachment by agriculture has reduced the number of *Spartina* salt marshes along the St. Lawrence by 47.7 percent (Goudreau, 1981). Further loss during the 1980s needs to be documented.

A dozen migratory bird sanctuaries protect nearly 88 km of shoreline from all human activity. Bird rest areas protect 11 km of shoreline, while three national wildlife areas protect a further 45 km. Forillon National Park protects 25.4 km of shoreline (Goudreau, 1981). The protected area (169 km) represents only four percent of the total length of St. Lawrence River and Gulf shorelines, notwithstanding the wide distribution of wildlife populations along the shore.

Despite low human population densities (Table 5.9), the coastline's condition has been reduced considerably throughout the St. Lawrence Estuary and northern Gulf of St. Lawrence. Such habitat loss has to be slowed or reversed if the quality of the estuary and northern Gulf is to be sustained for shellfish and wildlife.

The Newfoundland and Labrador Coastlines

This coastline is an important area for breeding seabirds. Their continued success is a measure of the health of this long, productive, and rugged coastline (Brown et al., 1975; Brown and Nettleship, 1984; R.G.B. Brown, pers. comm.). The breeding population along this coast is at least one million pairs, compared to 742,000, 365,000, and 615,000 in Baffin Bay and Davis and Hudson Straits respectively, and only 93,000 in the rest of Atlantic Canada. This is the breeding centre for Leach's Storm-Petrels, Razorbills, Common Murres, and Atlantic Puffins in the western Atlantic. Funk Island alone has 500,000 pairs of Common Murres; Baccalieu, Cape St. Mary's, and the Witless Bay Island, also in eastern Newfoundland, and the Gannet Islands in Labrador, are the other principal breeding sites. Oil and chemical pollution along this coastline and

Table 5.9 Descriptive elements of the St. Lawrence coastline, Quebec

	Length of Shoreline (km)	Total Area of Littoral (ha)	Area of Wetlands (ha)	Area of Intertidal Marshes/km (ha)	Human Population density/km^2 bordering shore
Brackish Estuary					
Beaupré to Baie St. Paul (N) Berthier to Point Ouelle (S)	255	4565	2743 *Scirpus* Grasses 1373 *Carex* Grasses	17.9	27
Salinity: 0.3 to 17%					
Marine Estuary					
Baie St. Paul to Pte des Monts (N) Point Ouelle to Matane (S)	803	4417	2707 *Spartina* Grasses 1710 Salt Marshes	5.4	22.4
Salinity: 17%					
Gulf					
Pte des Monts and Matane to Restigouche, including the Magdalen Islands to Blanc Sablon	2781*	4167	415 *Spartina* Grasses 3752 Salt Marshes	1.5	5.2

* The shoreline for the most part comprises rocky substrates and various types of beaches (cobble to sand) and headlands.

Source: Environment Canada, Conservation and Protection, Quebec Region, Montreal.

offshore literally could have a global impact on some of these species (R.G.B. Brown, pers. comm.).

Atlantic Offshore

The Atlantic offshore is the area beyond the immediate influence of land-based sources of contamination but within the limits of Canadian jurisdiction. The fishing banks of the Atlantic offshore from the Grand Banks to Georges Bank support a major commercial fishery, valued at approximately $1.5 billion in 1984 (DFO, 1985). In addition, the Banks are of major importance as a habitat for millions of non-breeding seabirds. This area is now a focus of hydrocarbon development and future seabed mining.

Point source contamination in the offshore is transitory in nature, consisting of discharges or spills from ships and petroleum exploration rigs. Major shipping lanes transect the offshore. In 1984, the Canadian Coast Guard issued 8,359 vessel clearances for ships greater than 500 tonnes carrying dangerous cargoes, travelling through Canadian waters (Canadian Coast Guard, Ship Safety Division, pers. comm.). As a result of exploration activities conducted since 1964, gas and oil deposits off Sable Island on the Scotian Shelf and an oil deposit on the northeastern Grand Banks were proposed for development (COGLA, 1985; Sheppard, 1988). Development started in both locations in 1990. There is currently a moratorium on drilling on the Canadian side of Georges Bank due to concerns about oil spill impacts on its fisheries resources (Gordon, 1988). Nonetheless, oceanographic and biological studies continue there due to the value of the resource and the need to accurately predict chemical and oil impacts.

The most probable contaminants in the offshore in the 1990s will be petroleum hydrocarbons and related chemicals. Oil exploration drilling involves the discharge of various fluids, "muds", production waters and other wastes. The reported levels for BOD, COD, and TOC for drilling mud are: BOD_5 - 1,373 - 2,743 mg/kg; COD - 8,000 - 41,200 mg/kg; and TOC - 3,040 - 15,000 mg/kg (U.S. EPA, J. Osborne, pers. comm.). The reported levels for cuttings are: BOD_5 - 8,000 mg/kg; COD - 90,000 - 270,000 mg/kg; and TOC - 23,000 - 51,000 mg/kg. At present, levels of petroleum hydrocarbons in offshore surface waters are low. Concentrations of petroleum residues above background levels such as the southern Grand Banks and the Laurentian Channel, can be correlated currently with oil tanker and shipping activity (Levy, 1984). Accidental spills and operational discharges from drilling platforms may cause higher concentrations of contaminants in offshore waters and sediments, with some biological impacts.

Non-point source contamination of the offshore comes from atmospheric transport and deposition of contaminants originating from central and eastern North America (Harvey and Steinhauer, 1974).

Generally, very low levels of chemicals from human activity contaminate the Atlantic offshore. Levels of naturally occurring elements are at or near natural levels. Studies have recorded a wide range of organochlorine compounds in livers of sharks and tunas (Zitko, 1980) and PCBs in Flemish Cap cod livers (J.F. Uthe, pers. comm.). However, few data for fish are available. Early studies by Zitko and Choi (1971) and Sims et al. (1977) noted that levels of organochlorines in tuna varied with species and location, and that bluefin tunas had generally elevated levels of PCBs and DDT compounds.

As stated above, the Atlantic offshore and especially its fishing banks are a major and important habitat for non-breeding seabirds, many of which are migratory. Among others, the world population of Greater Shearwaters (*Puffinus gravis*) from the sub-Antarctic winter here in the summer. Most of the world's Dovekies (*Plautus alle*), from northwest Greenland, are here in the winter, along with about 3.8 million Thick-billed Murres (*Uria lomvia*) from the Arctic – mainly from Hudson Strait, but also from Baffin Bay, Lancaster Sound and Iceland (Gaston, 1980). There are Kittiwakes (*Rissa tridactyla*) and other species from the northeast Atlantic as well. The tide-rips in the outer Bay of Fundy are stopovers in the fall for large numbers of migrant phalaropes (*Phalaropus fulicarius, Lobipes lobatus*). The tide-rips are as important to them as the mudflats at the head of the Bay are to more orthodox shorebirds (Mercier, 1985).

With increasing pressure to develop mineral and petroleum reserves on and beneath the ocean floor, industries and government need to develop new technologies and effective management techniques to avoid significant environmental degradation and damage to fisheries resources. There is a need for hazard assessments of potential industrial impacts, such as for Georges Bank (Howarth, 1987; Neff, 1987; Gordon, 1988). The source, transport, fate, and effects of aerially-transported contaminants to the offshore also requires further research.

Assessment

The Atlantic coastal region supports many uses – valuable fisheries, aquaculture, many industries, recreation, tourism, and abundant wildlife and habitats. As a consequence, there has been much effort over the decades to ameliorate use conflicts, especially the impacts of industrialization and coastal development along the coasts. There have been successes in water pollution control, toxic chemicals management, and habitat protection and conservation, and these have collectively contributed to slowing marine environmental decline and losses.

However, the situation remains that water, sediments and biota are contaminated in many areas; natural habitats and wildlife are diminishing; fish stocks are seriously depleted; and threats to human health sometimes occur. Marine environmental quality is clearly threatened by a host of stresses, some of which have been ameliorated but many of which require remedial action and future prevention. At this time, what can be stated about Atlantic marine environmental quality and what trends are apparent?

There is a wide range of contamination and pollution sources. Many of them have received regulatory attention over the past twenty years, with a number of successes. Much remains to be done. Many municipal effluents are not treated; they are the direct cause of approximately 20 percent of all shellfish closures in the Maritimes and cause widespread contamination in the St. Lawrence Estuary. Shellfish closures are increasing in number. Many industrial effluents discharged in the Atlantic provinces and Quebec enter the Atlantic coastal waters. Pulp and paper effluents, although often improved in quality since the early 1970s, still disrupt fish habitat and contaminate biota, and consequently are a focus of much attention. Food processing wastes cause water quality problems in some harbours. Refineries are generally in compliance for regulated substances, and chlor-alkali plants have controlled their mercury discharges. The Sydney "tar pond" led to massive harbour contamination, and is now being cleaned up. Other industries such as power plants are closely monitored.

Ocean dumping, primarily of harbour sediments, is regulated and some dumpsites are monitored. Local problems sometimes occur from contaminants and the dumping of fish offal. Mining and associated industries can cause loss of intertidal habitat through the disposal of waste rock and local chemical contamination. Coal production industries cause chemical, particularly PAH contamination, and the closure of valuable fisheries such as at Sydney. The smelter at Belledune has improved effluent quality and causes less cadmium contamination of local biota than in the 1970s. Mining industries upstream have contaminated some estuarine sediments. Aluminum smelters in the upper Saguenay Fjord led to its widespread contamination and are now starting to treat their effluents.

Riverine inputs of contaminants can be substantial but the impacts are often poorly understood. The St. Lawrence River Estuary acts as a sink for toxic substances, but some materials may be transported to the open sea. Such discharges need to be quantified. Spills of oil and hazardous chemicals occur periodically; oil and petroleum products are most frequently spilled and in the greatest volumes. The most frequently spilled hazardous materials are industrial chemicals.

There are many non-point sources of pollution along the Atlantic coast. Agricultural runoff affects shellfish growing areas in the Atlantic provinces, and fertilizer and pesticide use grew in the Maritimes during the 1970s, increasing the potential for coastal contamination. There is indirect evidence that atmospheric transport contributes significantly to contaminant input such as PCBs into the Atlantic offshore, and PAH depositions may occur locally in some estuaries. Urban runoff is largely unassessed. Persistent plastics and litter may be on the increase; some monitoring has occurred in both the nearshore and offshore, and should be continued.

A large number of specific anthropogenic substances have been detected in the waters, sediments, and biota of Atlantic coastal and offshore waters, and some trends are apparent from the limited data. Mercury has decreased in some industrial emissions (pulp and paper mills, chlor-alkali plants) but is in substantial amounts in sewage and found in many harbour sediments. Sediments in the Saguenay remain contaminated with mercury while bioaccumulation in shellfish has decreased by a factor of 20 since 1970. Sediments near ore loading and storage sites reflect heavy metal contamination. A range of heavy metals contaminate sediments and biota in the Saguenay Fjord and St. Lawrence Estuary, and sediments in northern New Brunswick, as well as in a number of harbours.

Organochlorines are widespread along the Atlantic coast. PCBs are commonly found in harbour sediments, and often in fish and mammals. Levels of dissolved hydrocarbons and floating tar in surface waters are generally low or undetectable, and near the background levels of the early 1970s. Some marine sediment and shoreline contamination persists near oil spill sites. Frequent coastal oiling on the south coast of Newfoundland is a major wildlife concern. PAHs from industry, wharves, urban runoff and oil spills are found in sediments and biota in a number of locations, and have led to fisheries closures. Creosoted materials contaminate most harbours, and some fisheries species. Benzo[a]pyrene is present throughout the Saguenay fjord, and their metabolites contaminate belugas, but most PAHs are not detected in other parts of the St. Lawrence Estuary. No trend information is available.

Organotins (butyltins and methyltins) are frequently found in harbour sediments throughout the Atlantic Provinces, especially in areas of heavy boating and shipping traffic, but TBTO use as an anti-foulant by fishermen has ceased. A host of other chemicals are present in estuarine and coastal waters, sediments, and biota, and some of them contaminate fisheries and aquaculture species. Few water quality guidelines are available to assist in interpreting such occurrences. In addition, persistent plastics, litter, and lost fishing gear are a growing problem, fouling shorelines and killing fish and wildlife at sea. Natural toxins are also prominent contaminants in local coastal waters, the incidence of new ones being intensively studied and monitored.

Coastal development and physical changes are widespread, and increasing in extent and number. Dams, wharves, dikes, causeways, and tidal power projects individually or collectively influence the quality of many estuaries and nearshore waters. In-filling, land reclamation, and other coastal developments continue to remove productive and critical habitat, especially from areas used by migratory birds and as nursery grounds by fish. Salt marshes have declined by at least 75 percent in the Bay of Fundy since settlement and require continual conservation efforts. Some causeways, having created sedimentation problems and water flow disruptions in the past, are now being modified or removed, a very positive trend if continued. Potential impacts of proposed power projects on the Bay of Fundy and the road linkage to PEI have been appraised carefully so as to avoid damage to fisheries and inshore habitats. Physical impacts of extensive fishing activity on bottom habitats and organisms are a subject of recent investigation. The value of the coastlines is being recognized, and efforts are continuing to slow its loss or modification.

Knowledge from research and monitoring on the fate and effects of contaminants in biota provides a sensitive measure of marine environmental quality along the Atlantic coast. Commercially valuable fish, shellfish, and crustaceans in the Atlantic Provinces contain a wide range of contaminants, but evidence of trends in levels is limited. These contaminants may be causing or contributing to direct or indirect biological effects, but information is again limited. Some compounds, often considered contaminants, occur naturally, i.e., cadmium in offshore scallops. Unnatural cadmium levels in water, sediments, and lobster tissue dropped near Belledune, N.B., and a restricted lobster fishery reopened, showing positive effects of the waste treatment of the smelter effluents. PAHs are bioaccumulated in mussels in the St. Lawrence Estuary and in lobsters in Sydney harbour, reflecting industrial activity. Furans are found in lobsters in three harbours and estuaries, again likely reflecting industrial activity. A wide range of organochlorines are found in fish and may be causing effects in some species. PCBs and DDT may have declined in cod to constant levels; other contaminants vary temporally and trends are uncertain. No systematic formal monitoring program is in place measuring residues and effects of contaminants in commercial fish species. As a result, this important measure of marine environmental quality is severely limited by data availability.

Contaminants effects on seabirds are a proven sensitive indicator of MEQ. For two decades, seabirds have served as monitors for the presence and effects of persistent chemicals, especially organochlorines, and provide the best available trend information. The St. Lawrence Estuary and Gulf ranks most contaminated of all sites along the Atlantic coast. However, gannets in the northwestern Gulf have shown declines in several chemicals, and populations have recovered from DDT effects. Other bird colonies show declining levels of most monitored chemicals in the Bay of Fundy, together with increasing populations, and no change or increases in concentrations in the St. Lawrence. Restrictions on DDT use have been beneficial, by all signs, an encouraging result of effective regulations.

Oil pollution continues as a major threat to seabirds, especially in offshore waters and at spills. Losses occur frequently. They will only be reduced through continued monitoring to discourage violations and to document the impacts, and through public information.

Contaminant levels in mammals are well documented for pinnipeds and cetaceans, but rarely permit trend analysis. Levels of contaminants in Harbor porpoises in the Bay of Fundy are high, as are levels in the St. Lawrence belugas which may be declining in numbers as a result. The belugas contain organochlorines, metals and PAHs often at very high levels (100 ppm) that are known to cause toxicity. Such contamination may be a major signal of declining marine environmental quality, in that a large estuarine ecosystem is being affected by a wide range of chemicals, with as yet unclear consequences.

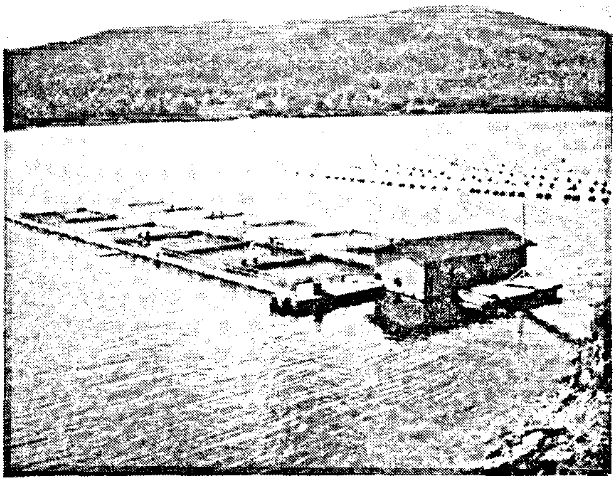
Geographic concerns along the Atlantic coast include harbours, bays, gulfs and estuaries, whole coastlines, and the offshore. Many of these areas continue to be under cumulative chemical and physical pressures. The primary harbour issues (e.g., Halifax, Sydney, Saint John, St. John's) are sewage, specific effluents and chemicals, and conflicting uses. There are recent initiatives to start harbour assessment, management and clean-up programs. The bays and gulfs (e.g., Gulf of Maine, Fundy, Annapolis Basin, Chaleur Bay, St. Lawrence Estuary) require detailed assessments, monitoring programs, and pragmatic action plans; they are facing cumulative stresses and require comprehensive, future-oriented approaches to ensure continued ecosystem health. The coastlines (e.g., St. Lawrence, Newfoundland and Labrador) are critical for wildlife and need further conservation measures. The Atlantic offshore is invaluable for its fisheries and its seabirds, and requires constant monitoring and detailed hazard assessments to minimize industrial and shipping impacts. The opportunity now exists for a full Atlantic network of nearshore, coastal, and offshore programs to sustain a high level of marine environmental quality. The recently initiated Atlantic Coastal Action Plan and the ongoing Estuaries Joint Venture Program are key steps in this process.

Summary – Marine Environmental Quality on the Atlantic Coast

Marine environmental quality along the Atlantic coast faces many stresses due to conflicting uses and the combined pressures of a rural and an urban society dependent largely upon the region's natural resources. Many of these stresses and pressures are well recognized, and environmental protection and conservation efforts over the past three decades have ameliorated many of them or are now doing so. A number of indicators and some trend information show that marine environmental quality is degraded in many places. Other indicators (such as still abundant marine wildlife, largely undisturbed beaches, aquatic life even in heavily used harbours and inlets) are signs that most of the natural systems are still functioning and can recover from many abuses if they stop. The decline that has been detected can only be reversed and prevented in the future through having continued strong programs of conservation and protection, guidelines and objectives for MEQ, status and trends monitoring, comprehensive coastal management programs and supportive research.

Chapter Six

Assessment of Canadian Marine Environmental Quality



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Introduction

In recent years, concerns about the health of marine ecosystems have been voiced with increasing frequency in Canada and many other countries. This report has evaluated these concerns in a Canadian context, largely from a pollution perspective.

Canadian seas and coastlines, and their multiple uses, are threatened or have had their quality impaired in many locations by contaminants, wastes, and disturbance from human activities (Figure 6.1). Many of these threats to marine environmental quality (MEQ) originate on land, and are referred to as land-based sources of marine pollution (LBSMP). They are a major threat to coastal seas. However, marine-based discharges, such as from vessels, cargo spills and offshore drilling wastes can have serious local effects, such as with oil spillages impacting offshore seabird populations. Most of the major threats to the marine environment are now well recognized, even if their total impacts are only partially or even poorly understood. The evidence shows that over the years, there have been many impaired or curtailed uses of marine waters due to declines in environmental quality (Table 6.1).

Table 6.1 Examples of curtailed or impaired uses of estuaries and coastal waters in Canada

Curtailed or Impaired Uses	Causes
Losses of natural biota (plants, invertebrates, fish, wildlife)	Toxic chemicals Habitat loss due to coastal development Overfishing of commercial species
Reduced fish habitat	Acid rain Coastal development
Reduced aquaculture sites	Ocean dumping Coastal development
Reduced saleability of fish species	Toxic chemicals Oil spills
Closures of shellfish and other fisheries	Toxic chemicals Municipal and/or industrial effluents Oil spills Natural toxins

Source: P.G. Wells (MS in preparation); A. McIver, pers. comm.; W. Barchard, pers. comm.

Figure 6.1 Threats to marine environmental quality in Canada

LOCATION AND TYPE OF ENVIRONMENT

	PACIFIC				ARCTIC			ATLANTIC			
	Wetlands	Estuaries/Fjords	Coastal (1)	Open Ocean (2)	Estuaries	Coastal	Open Ocean	Wetlands	Estuaries/Fjords	Coastal	Open Ocean
Land-based Sources											
- industrial	High	Severe	Moderate	Low	None	Moderate	None	Moderate	Severe	Moderate	No information
- municipal	Moderate	High	Moderate	Low	None	Low	None	Moderate	High	High	No information
- river discharges	High	High	Low	No information	Low	None	None	Low	High	No information	No information
Coastal Development											
- construction	High	NA	High	NA	NA	Low	NA	Moderate	NA	High	NA
- modification (habitat loss)	Moderate	Low	No information	NA	No information	Moderate	None	Severe	Moderate	Moderate	None
Toxic Chemicals (4)											
- effluents	No information	Severe	High	No information	No information	Low	Low	Moderate	Severe	High	No information
- agriculture	Moderate	Low	No information	No information	NA	NA	NA	None	Moderate	No information	No information
Oil and Gas Industry											
- spills	High	High	Moderate	None	None	None	None	High	High	Moderate	Low
- offshore exploration and development	NA	NA	Moderate	None	NA	High	Low	NA	NA	Moderate	Low
Transportation (shipping)	Moderate	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	High
Waste Disposal (dredging and dumping)	Moderate	Moderate	Moderate	None	NA	Moderate	None	Moderate	Moderate	Moderate	None
Natural Toxins	NA	High	Moderate	NA	No information	No information	No information	NA	High	High	NA
Fishing Activity (3)	NA	None	None	NA	No information	No information	NA	NA	Moderate	High	High
Hydroelectric Power											
- dams	NA	NA	NA	NA	No information	No information	NA	No information	High	High	None
- tidal	NA	NA	NA	NA	NA	NA	NA	No information	Moderate	None	None
Long-Range Transport of Atmospheric Pollutants (LRTAP)	NA	NA	NA	NA	No information	Moderate	Moderate	No information	No information	No information	Low
Acid Rain and Drainage	NA	NA	NA	NA	NA	NA	NA	NA	High	High	NA
Aquaculture	NA	Moderate	Moderate	None	NA	NA	NA	NA	No information	No information	None

● SEVERE
◕ HIGH
◑ MODERATE
◔ LOW
○ NONE
⊖ NO INFORMATION TO BASE ASSESSMENT ON
(NA) NOT APPLICABLE

(1) Coastal = Nearshore including habitats.
(2) Open Ocean = Offshore, including shelf areas.
(3) Loss of habitat, reduction of populations, impact on seabirds.
(4) Also see LRTAP column.

Most of the public, scientific, and regulatory concern is directed at the more frequently seen or measured chemical contamination (e.g. the appearance of tumours in flatfish in Vancouver Harbour, the high levels of contaminants in beluga whales in the St. Lawrence Estuary), or physical disruption, often on large scales (e.g. coastal salinity regimes changed by dams, the presence of plastic debris along coastlines, and offshore oil exploration and development, with its harbours, pipelines and associated infrastructures and transportation modes). However, of equal concern are problems that may be occurring due to long-term, low-level, cumulative discharges and emissions of persistent, bioaccumulative, and toxic chemicals and their metabolites (Howells et al. 1990). Similarly, small physical changes can have cumulative effects on habitats and whole ecosystems. These problems are not as visible, and though they may be studied scientifically, less attention is paid to them by the public and the decision makers.

Clearly, the threats to the quality of our seas may be short- or long-term, chemical or physical, overt or subtle. The threats in Canadian marine areas are described in the previous chapters. Their detection, assessment, and resolution require, among other considerations, an advanced capability to measure marine environmental quality and to conduct marine status and trends analysis for periodic "state of environment" evaluations.

Marine Environmental Quality

What is meant by marine environmental quality or marine ecosystem health? As described in Chapter One, the formal definition is that marine environmental quality is the condition of a particular marine environment measured in relation to each of its intended uses and functions (Wells and Côté, 1988). It can be described subjectively, especially if stresses impinging on the system are large and if the ecosystem or habitat are obviously degraded. However, MEQ is usually assessed quantitatively for each environmental compartment, on temporal and spatial scales. It is measured using sensitive indicators of natural condition and change. Such measures are interpreted using objectives and limits set by environmental, health and resource agencies.

Measures of marine environmental quality can be said to show the deviation from the pre-industrial, pre-settlement condition. In contrast, measures of marine ecosystem health describe functioning of the existing ecosystem, and the degree to which it is actively improving or degrading (A. Gaston, pers. comm.). Hence, quality denotes historical change in the condition, whereas health is the present condition and the direction of change. The terms are, however, often used synonymously in popular usage, and are considered equivalent for the present report.

There are many compelling reasons to understand the quality of marine ecosystems. They include the protection of human health; maintaining the integrity of marine ecosystems; advancing understanding of the functioning of undisturbed and disturbed ecosystems; identifying appropriate monitoring variables for describing the status and trends of ocean health at selected sites. This knowledge also guides remedial actions and control measures for improving environmental quality; maximizing economic returns from the sea by minimizing resource-use conflicts; and informing the public and other sectors of the ocean's condition and prospects for the future. In short, we must have our finger on the pulse of the sea in order to safeguard it from abuse and over-exploitation.

Being successful at measuring ocean health requires ongoing measurements of reliable, sensitive, and interpretable indicators of condition or change for the particular part of the sea under consideration. The indicators should relate directly to characteristics, uses and/or sustainability of the particular marine system. Examples of indicators include: trends in fisheries closures due to chemical contamination, loss of productivity of an area, reduced quality of resource species or their habitat, numbers of spills of noxious chemicals, and direct measures of the condition of individual organisms, populations and their communities. Scientific studies and assessments of the past decade suggest an optimum approach – it is best to measure a number of indicators together (from cellular processes to community properties, from fisheries closures to quantity of litter per kilometre of beach). As much as possible, some of the indicators should measure the ecological integrity of the system. Data on MEQ should be regularly collected and validated through formal research and monitoring programs. Further, it should be readily accessible for analysis and interpretation. As a first step, guidelines, objectives, and limits defining acceptable and unacceptable conditions must be established. This facilitates data interpretation, and allow conclusions to be reached about condition and trends. Finally, marine ecotoxicology research is essential to support and enhance MEQ monitoring and guideline development.

Current Status

How successful has Canada been to date at measuring marine ecosystem health for specific coastal areas? What can be concluded from the Pacific, Arctic, and Atlantic assessments presented in the previous chapters? Are conditions getting better or worse?

It is clear that many physical, chemical, and biological threats to MEQ in Canada have been identified (Figure 6.1). Both habitats and living resource populations are affected, especially in estuarine and nearshore environments. Ecosystem level effects have been measured in several locations (see Table 6.2). It is apparent that the most prominent ecosystem health effects measured to date, include:

- widespread distribution and elevated levels of contaminants, especially in sediments and biota;
- sublethal effects of persistent chemicals and effluents;
- occurrence of fish and mammalian diseases, with possible chemical causes; and
- habitat (intertidal and subtidal) modifications and loss, with special impacts on wildlife.

There is little question that an alarming number of estuaries and nearshore regions of Canada, particularly near urban centres and major industrial operations, have been and are being degraded by physical disruption and chemical contamination (Figure 6.1 and Table 6.1). As a consequence, important uses of such areas, e.g., shellfisheries and public amenities, are being impaired or lost.

Continued habitat loss is evident in many places, e.g., Fraser River Delta, and chemical effects on individual species are suspected (cod), strongly suspected (flounders, Great Blue Herons, whales), or demonstrated (oysters, seabirds). Areas of chemical contamination are numerous and geographically widespread, indicating that pollution may be occurring at several coastal locations and increasing in severity. World-wide, there is sufficient published evidence of cause-effect linkages to warrant immediate preventive action.

Considerable information is available on contaminant levels at waste discharge sites. However, interpretation has been difficult due to the lack of commonly accepted

Table 6.2 Some ecosystem level effects demonstrated in Canadian seas

Cause	Effect
Pacific Coast	
Coastal Mines	• smothering of benthic communities • habitat changes • community changes
Pulp Mills	• loss of benthos • loss of bottom habitat • fish kills, fish avoidance
Organochlorines [suspected]	• Great Blue Heron reproductive failures
Effluents/Mixtures [suspected]	• diseases in bottom fish
Arctic Coast	
Dredging/dumping	• localized bottom habitat disruption
Toxic chemical residues	• ecosystem-wide contamination
Oil spills	• long-term contamination of intertidal zones
Atlantic Coast	
Coastal Mines	• habitat smothering
Coastal Development	• loss or modification of critical fish, waterfowl, and seabird habitats
Pulp Mills	• loss of intertidal, subtidal habitats
Industrial Contaminants [suspected]	• pathology and decline in whales in St. Lawrence Estuary
Toxic chemicals	• contamination of sediments, seabirds, fisheries species
Commercial fishing	• declines in invertebrate and fish populations • habitat disruption due to gear • competition with seabirds

Source: This report, chapters 3, 4, and 5.

biological and human effects thresholds for most marine contaminants. Ideally, such thresholds should also consider "whole ecosystem effects." The process for achieving such toxicological thresholds as MEQ guidelines has started in Canada, as elsewhere. We are, however, a long way from using them to evaluate marine ecosystem health.

In addition, there is a general paucity of monitoring information for areas outside the obvious urban and industrial sites of contamination. There are some exceptions where monitoring has been consistently conducted for years (e.g. seabirds, seals in offshore waters), or in remote areas (e.g., trace contaminants in high Arctic wildlife).

We now have a description of the major problems due to the many studies and data assessments over the past three to four decades using a combination of techniques. There seems to be a new consensus about the most useful indicators of MEQ, e.g., the techniques used in the Group of Experts on Environmental Pollution Workshops, Intergovernmental Oceanographic Commission, and identified by the Environment Canada State of the Environment (SOE) Indicator Workshops. Practical techniques are evolving rapidly, driven by a world-wide demand for marine environmental information.

In Canada, as in many countries, the lack of a range of complementary, formally planned, long-term monitoring programs in most marine areas has resulted in a severe shortage of reliable and consistent data. An additional serious shortfall is the lack of cohesive procedures for effectively managing and interpreting the data already in hand. This combined situation limits or prevents analysis of the status and trends in MEQ for most Canadian coastal and offshore waters. A network of existing monitoring programs should be established and expanded, especially with the aim of providing suitable data for the government-wide initiatives on SOE reporting.

There already have been economic impacts due to the deterioration of marine environmental quality in Canada. These impacts have occurred even after the problems have been detected by such crude indicators as the presence or absence of toxic chemicals, or numbers of bacteria. Impacts include fish kills due to effluents, closure of fishing areas due to dioxin contamination in crustaceans, and closure of bivalve shellfish growing areas and recreational areas due to coliform bacteria. This raises the question of the economic implications of having more sensitive measures to apply to coastal areas known or suspected to be under chemical or physical stress. We may only have detected the tip of the pollution iceberg in southern Canadian seas. Clearly this has been recently shown with the demonstration of widespread contamination in high Arctic areas (Twitchell, 1991). This clearly is the time to act.

What Should Canada Do Next?

The measurement and maintenance of marine environmental quality is an important and urgent task in Canada. What are some of Canada's immediate tasks?

First, it is important to consider the global conclusions of the latest Joint Group of Experts on the Scientific Aspects of Marine Pollution *State of the Marine Environment* report (GESAMP, 1990), regarding ecological effects of contaminants in the sea, and the recovery of damaged ecosystems and species. The GESAMP report makes it clear that long-term effects of contaminant exposure to populations or communities are difficult to distinguish from natural changes. There is greatest concern with exposure over the long-term, and with delayed or subtle effects of contaminants. The difficulty of separating incremental environmental degradation from natural change is not easily resolved. The careful analysis of natural phenomena , or of changes in biological communities following accidents, or along a gradient from the pollutant source, seem to offer the best direct evidence of population responses to natural events or anthropogenic activities. The GESAMP review also states that the time-scale of recovery and the degree to which population changes can be reversed and species or communities restored are uncertain since they are critically dependent on the specific conditions at the damaged site, as well as on the potential for replacement. Hence, we may not be detecting all of the subtle effects that are occurring in Canadian seas even now. Heavily stressed areas that we have detected and subsequently protected may take many years to recover. We may also discover that some systems rebound from abuse, such as Chedabucto Bay after the 1970 Bunker C oil spill (J. Vandermeulen, pers. comm.). We need more monitoring and a clearer understanding of the functioning and recovery potential of both pristine and perturbed areas of Canada's seas.

Second, among the main threats to MEQ on a global basis are coastal development and the attendant destruction of habitats, eutrophication, microbial contamination of seafood and beaches, fouling by plastic litter, build-up of chlorohydrocarbons, and accumulation of tar on beaches (GESAMP, 1990). Coastal habitat destruction and the sublethal effects of low-level chemical contamination over long periods with significant damage to ecosystems require immediate attention and resolution. Canada suffers from many of the same coastal problems. Thoroughly assessing and remedying them, has now started through the Atlantic Coastal Action Plans under the "Green Plan". This should continue to be a top priority of all levels of government.

Third, a practical national marine environmental framework is needed to guide the evaluation and management of MEQ in Canada. Essential elements of the conceptual MEQ framework presented in Chapter One could be combined with elements of scientifically-based management frameworks such as the Environmental Protection Framework of the UNEP Montreal Guidelines (UNEP, 1985; Wells and Gratwick, 1988). This would satisfy both evaluation and management needs. Such a National Framework would incorporate the Environment Canada MEQ Action Plan (1989-94). Relevant elements of the Action Plan include monitoring, guidelines/objectives, SOE reporting, coastal management plans, research, and communications. The new federal MEQ Framework (Environment Canada, 1990b) will also contribute to the National Framework. All of these activities contribute to Canada's commitment to the UNEP Montreal Guidelines principles and strategies, and our other international marine environmental quality commitments such as UNCLOS and the Brundtland Commission's recommendations. Canada's ongoing task is implement the Action Plan. This has started under the federal "Green Plan" of December 1990. In addition, Canada must implement a federal MEQ Action Plan cooperatively among federal agencies.

Finally, there is a continued need for Canada to contribute to and benefit from global actions to protect and enhance marine environmental quality. There is an especially urgent need to reduce the impacts of land-based marine pollutants in coastal waters. With this in mind, Canada is hosting a United Nations Intergovernmental Experts Meeting on Land-Based Sources of Marine Pollution (LBSMP), in May 1991. It is planned as a major step towards more comprehensive and global attention to land-based threats to marine environmental quality, perhaps leading to a global convention on LBSMP in the near future.

Conclusions

Continued and concerted action by Canadians on the health of our oceans will ensure that its invaluable resources, wildlife, and ecosystems will be sustained for the future. Actions should include contributing to the national marine environmental quality framework, supporting enhanced monitoring, data assessments, and public information on our oceans, and deriving guidelines and objectives for interpreting and protecting MEQ. In addition, we must establish further partnership programs for coastal environmental conservation, protection and management and conduct interdisciplinary research in support of all the above actions.

By world standards, large areas of the Canadian marine environment are relatively uncontaminated and undisturbed by humans, and support a diverse and flourishing biota and many commercial uses. But as shown by this report, we do have some serious problems – especially in harbours, estuaries, and nearshore waters, and even distant offshore waters are threatened by humankind's activities. Remote parts of the Arctic are also beginning to experience effects similar to those along the other coasts. There are early warning signs that show a decline in marine environmental quality in many areas. Fortunately, research and regulatory agencies have been working together since the 1970s on both the problems and their long-term resolution. Progress has been made to reverse some of the trends and prevent future degradation.

Within this context, this report forms a small contribution towards current Canadian understanding of the extent of local marine pollution, and further actions needed to reduce and prevent it.

References Cited

PERSONAL COMMUNICATIONS

R.F. Addison, Fisheries and Oceans, Dartmouth, N.S.

P. Béland, National Ecotoxicology Institute, Rimouski, P.Q.

M. Bigg, Fisheries and Oceans Biological Station, Nanaimo, B.C.

R.G.B. Brown, Canadian Wildlife Service, Dartmouth, N.S.

Canadian Coast Guard, Ship Safety Division, Dartmouth, N.S.

A. Colodey, Environment Canada, Vancouver, B.C.

S. Conover, Dalhousie University, Halifax, N.S.

S. Day, Environment Canada, Dartmouth, N.S.

A. d'Entremont, Environment Canada, Yellowknife, N.W.T.

Environment Canada, Pacific and Yukon Region, Vancouver, B.C.

Environment Canada, Quebec Region, Montreal, P.Q.

G. Finney, Canadian Wildlife Service, DOE, Sackville, N.B.

C. Garrett, Environment Canada, Vancouver, B.C.

D. Goyette, Environment Canada, Vancouver, B.C.

J.F. Gravel, Environment Canada, Montreal, P.Q.

G. Harding, Fisheries and Oceans, Dartmouth, N.S.

S. Heinze-Milne, Yellowknife, N.W.T.

T. Hennigar, Environment Canada, Dartmouth, N.S.

B.H. Kay, Environment Canada, Vancouver, B.C.

P. Klaamas, Environment Canada, Dartmouth, N.S.

B. Kooi, Fisheries and Oceans, Vancouver, B.C.

P. Laramée, Environment Canada, Montreal, P.Q.

P.A. Lane, P.A. Lane Associates, Halifax, N.S.

Z. Lucas, Halifax, N.S.

G. Martin, Environment Canada, Montreal, P.Q.

A. Menon, Environment Canada, Dartmouth, N.S.

W. Moores, Environment Canada, St. John's, Nfld.

E. Norrena, Environment Canada, Dartmouth, N.S.

S. McKnight, Dartmouth, N.S.

P. Mudroch, Environment Canada, Hull, P.Q.

H. Neu, Halifax, N.S.

J. Osborne, Environment Canada, St. John's, Nfld.

W.R. Parker, Environment Canada, Dartmouth, N.S.

R. Rochon, Environment Canada, Montreal, P.Q.

I. Travers, Environment Canada, Halifax, N.S.

J.F. Uthe, Fisheries and Oceans, Halifax, N.S.

V. Zitko, Fisheries and Oceans, St. Andrews, N.B.

Adam, M., W.D. McKone and H. Shear. 1987. *Report from a Workshop on Chemical Hazards to Fish and Fisheries, Burlington, Ontario, September 1985*. Can. Tech. Rep. Fish. Aquat. Sci. 1525. 105p.

Addison, R.F. 1984. River input of pollutants to the Western North Atlantic. In: *Health of the Northwest Atlantic: A Report to the Interdepartmental Committee on Environmental Issues*. R.C.H. Wilson and R.F. Addison (eds.). Environment Canada, Department of Fisheries and Oceans, and Department of Energy, Mines and Resources, Ottawa. pp. 42-43.

Addison, R.F. 1989. Organochlorines and marine mammal reproduction. *Can. J. Fish. Aquat. Sci.* 46: 360-68.

Addison, R.F. and T.G. Smith. 1974. Organochlorine residue levels in Arctic ringed seals: variation with age and sex. *Oikos* 25: 335-37.

Addison, R.F. and P.F. Brodie. 1977. Organochlorine residues in maternal blubber, milk and pup blubber from Grey seals (*Halicerus gyrpus*) from Sable Island, Nova Scotia. *J. Fish. Res. Bd. Can.* 34: 937-41.

Addison, R.F., S.R. Kerr, J. Dale and D.E. Sergeant. 1973. Variation of organochlorine residue levels with age in Gulf of St. Lawrence Harp seals (*Pagophilus groenlandicus*). *J. Fish. Res. Bd. Can.* 30: 595-600.

Addison, R.F., P.F. Brodie, M.E. Zinck and D.E. Sergeant. 1984. DDT has declined more than PCB's in Eastern Canadian seals during the 1970's. *Environ. Sci. Tech.* 18: 935-37.

Addison, R.F., M.E. Zinck and T.G. Smith. 1986a. PCBs have declined more than DDT-group residues in Arctic Ringed seals (*Phoca hispida*) between 1972 and 1981. *Environ. Sci. Tech.* 20: 253-56.

Addison, R.F., P.F. Brodie, A. Edwards and M.C. Saddler. 1986b. Mixed function oxidase activity in the Harbor seal (*Phoca virtulina*) from Sable Island, N.S. *Comp. Biochem. Physicol.* 85C: 121-24.

Agriculture Canada. 1990. Antifouling Paints for Ship Hulls. Agriculture Canada, Food Protection and Inspection Branch, Pesticides Directorate, Ottawa, CAPCO Note 90-08.

Alexander, V. 1986. Arctic ocean pollution. *Oceanus* 29(1): 31-5.

Allan, R.J. 1986. The limnological units of the lower Great Lakes – St. Lawrence River corridor and their role in the source and aquatic fate of toxic contaminants. *Water Poll. Res. J. Can.* 21(2): 168.

Allan, R.J. 1990. Estuarine and coastal water contamination, an issue for the 1990's. *Sci. Total Environ.* 97/98 (1990): 1-5.

Aquilar, A. and L. Jouer. 1982. DDT and PCB residues in the Fin whale, *Balaenoptera physalus*, of the North Atlantic. *Rep. Int. Whal. Comm.* 32: 299-301.

Arctic Laboratories Limited. 1986. *Cadmium, Lead and Zinc Particulate Fluxes and Seawater Concentrations, Strathcona Sound, N.W.T.: Winter-Spring Studies, 1984-85*. Report prepared for Indian and Northern Affairs Canada, Northern Affairs Program, Yellowknife, N.W.T.

ASA Consulting Ltd. 1986. *The Halifax Inlet Water Quality Study: Phase 2*. Report prepared for Metropolitan Area Planning Commission, Dartmouth, N.S.

Atwater, J.W., S.E. Jasper, P.D. Parkinson and D.S. Mavinic. 1990. Organic contaminants in Canadian coal wastewaters and associated sediments. *Water Poll. Res. J. Can.* 25(2): 187-200.

Ayers, R.C., T.C. Sauer, D.O. Stuebner and R.P. Meek. 1980. An environmental study to assess the effect of drilling fluids on water quality parameters during high rate, high volume discharges to the ocean. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings Proceedings: Volume 1.* Lake Buena Vista, Florida, January 1980. pp. 351-79.

Baird, R.W., K.M. Langelier and P.J. Stacey. 1988. Stranded whale and dolphin program of B.C. – 1987 Report. *Wildlife Veterinary Report* 1(1): 9-12.

Baird, R.W., K.M. Langelier and P.J. Stacey. 1989. First records of False Killer whales (*Psuedorca crassidens*) in Canada. *Can. Field Nat.* 103(3): 368-371.

Barrie, J.D. 1984. *Heavy metals in marine sediments and biota at three ore loading sites in Newfoundland.* Report prepared by LGL Ltd. for Environment Canada, Environmental Protection Service, Newfoundland and District Office, St. John's, Nfld.

Béland, P. 1988. Witness for the prosecution. *Nature Canada* 17(4): 28-36.

Bewers, J.M., D.H. Loring, K. Kranck, G.H. Seibert, R.L. Charron, J.F. Uthe, C.L. Chou, and D.G. Robinson. 1987. Cadmium pollution associated with a coastal lead-smelting plant. In: *Oceanic Processes in Marine Pollution, Volume 2. Physicochemical Processes and Wastes in the Ocean.* T.P. O'Connor, W.V. Burt and I.W. Duedall (eds.). R.E. Krieger Publishing Co., Malabar, Florida. pp. 117-132.

Bidleman, T.F., G.W. Patton, M.D. Walla, B.T. Hargrave, W.P. Vass, P. Erickson, B. Fowler, V. Scott and D.J. Gregor. 1989. Toxaphene and other organochlorines in Arctic Ocean fauna: evidence for atmospheric delivery. *Arctic* 42(4): 307-313.

Bird, P.M. and D.J. Rapport. 1986. *State of the Environment Report for Canada.* Supply and Services Canada, Canadian Government Publishing Center, Ottawa. 263p.

Borgese, E.M. 1986. *The Future of the Oceans. A Report to the Club of Rome.* Harvest House, Montreal. 144p.

Brander-Smith, D., D. Therrien and S. Tobin. 1990. *Protecting our waters.* Report of the Public Review Panel on Tanker Safety and Marine Spills Response Capability. Supply and Services Canada, Ottawa. 263p.

Brandon, E.W. and P.A. Yeats. 1984. Contaminant transport through the marine environment. In: *Health of the Northwest Atlantic: A Report to the Interdepartmental Committee on Environmental Issues.* R.C.H. Wilson and R.F. Addison (eds.). Environment Canada, Department of Fisheries and Oceans, Department of Energy, Mines and Resources, Ottawa. pp. 44-55.

Braune, B.M., R.J. Norstrom, M.P. Wong, B.T. Collins and J. Lee. 1990. Geographical distribution of metals in livers of polar bears from the Northwest Territories, Canada. *Sci. Total Environ.* (in press).

Brothers, D.E. and D.L. Sullivan. 1984. *False Creek Benthic Sediment Summary 1982/83.* Environment Canada, Environmental Protection Service, Pacific and Yukon Region, Vancouver, Regional Program Report 84-08.

Brown, R.G.B. 1982. Birds, oil and the Canadian environment. In: *Oil and Dispersants in Canadian Seas – Research Appraisal and Recommendations.* J.H. Vandermeulen (ed.). Environment Canada, Economic and Technical Review Report EPS 3-EC-82-2. pp. 105-112.

Brown, R.G.B. and B.C. Johnson. 1980. The effects of *Kurdistan* oil on seabirds. In: *Scientific Studies During the Kurdistan Tanker Incident: Proceedings of a Workshop*. J.H. Vandermeulen (ed.). Bedford Institute of Oceanography, Dartmouth, N.S., Report Series BI-R-80-3. pp. 203-207.

Brown, R.G.B. and D.N. Nettleship. 1984. The seabirds of northeastern North America: their present status and conservation requirements. In: *Seabirds of the World: their Status and Conservation*. J. Croxall, P.G.H. Evans, and R.S. Schreiber (eds.). International Council for Bird Preservation, Cambridge, England. pp. 85-100.

Brown, R.G.B., D.I. Gillespie, A.R. Lock, P.A. Pearce and G.H. Watson. 1973. Bird mortality from oil slicks off eastern Canada, February-April 1970. *Can. Field. Nat.* 87: 225-234.

Brown, R.G.B., D.N. Nettleship, P. Germain, C.E. Tull and T. Davis. 1975. *Atlas of Eastern Canadian Seabirds*. Environment Canada, Canadian Wildlife Service, Ottawa. 220 p.

Brown, D.A., K.A. Thompson, W.A. Heath, P.E. Erickson, W.J. Cretney and C.S. Wong. 1983. Histopathological evaluation of bivalves from Kitimat Arm – Douglas Channel and Alberni Inlet, British Columbia. In: *Proceedings of a Workshop on the Kitimat Marine Environment. Sidney, British Columbia*. R.W. Macdonald (ed.). Can. Tech. Rep. Hydrog. Ocean Sci. 18.

Buckley, D.E. and B.T. Hargrave. 1989. Chapter 1. Geochemical characteristics of surface sediments. In: *Investigations of Marine Environmental Quality in Halifax Harbour*. H.B. Nicholls (ed.). Can. Tech. Rep. Fish. Aquat. Sci. 1693. pp. 9-36.

Burd B.J., D.Moore and R.O. Brinkhurst. 1987. *Distribution and Abundance of Macrobenthic Infauna from Boundary and Mud Bays near the British Columbia/U.S. Border*. Can. Tech. Rep. Hydrog. and Ocean Sci. 84. 90p.

Burling, R.W., J.E. McInerney and W.K. Oldham. 1983. *A Continuing Technical Assessment of the Amax/Kitsault Molybdenum Mine Tailings Discharge to Alice Arm, British Columbia*. Report prepared for the Hon. P. de Bané, M.P., Minister of Fisheries and Oceans, Ottawa, 31 July 1983.

Burnett, J.A., C.T. Dauphine, Jr., S.H. McCrindle, and T. Mosquin. 1989. *On the Brink. Endangered Species in Canada*. Western Producer Prairie Books, Saskatoon, Saskatchewan. 192p.

Calambokidis, J., J. Peard, G.H. Steiger, J.C. Cribbage and R.L. Delong. 1984. *Chemical Contamination in Marine Mammals from Washington State*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Washington, D.C., NOAA Tech. Memo NOS OMS 6.

Cameron, J.J., J. Dusseault and B. Elkin. 1982a. *Community Water and Sanitation Services – 1982: Kitikmeot Region, Northwest Territories*. Report prepared by EPEC Consulting Western Ltd. under authorization and direction of Government of the Northwest Territories, Yellowknife, N.W.T.

Cameron, J.J., J. Dusseault and B. Elkin. 1982b. *Community Water and Sanitation Services – 1982: Kitikmeot Region, Northwest Territories*. Report prepared by EPEC Consulting Western Ltd. under authorization and direction of Government of the Northwest Territories, Yellowknife, N.W.T.

Canada Oil and Gas Lands Administration (COGLA). 1985. *Annual Report for 1984*. Ottawa.

Carey, J.H. and D.C.C. Lam. 1990. Pathways of chlorophenols in the Fraser River estuary, British Columbia. Abstract of paper presented at *International Symposium on the Fate and Effects of Toxic Chemicals in Large Rivers and their Estuaries*, Quebec City, P.Q., October 1988. Canada Centre for Inland Waters, Burlington, Ontario (unpublished).

Champ, M.A. and F.L. Lowenstein. 1987. TBT: The dilemma of high technology anti-fouling paints. *Oceanus* 30(3): 69-77.

Champ, M.A. and W.L. Pugh. 1987. Tributyltin antifouling paints: introduction and overview. In: *Oceans 87: The Ocean "An International Workplace." Proceedings. Volume 4*. Marine Technology Society and IEEE Ocean Engineering Society, Halifax, N.S., 28 September - 1 October 1987. pp. 1296-1308.

Chapdelaine, G., P. Laporte and D.N. Nettleship. 1987. Population, productivity and DDT contamination trends of Northern Gannets (*Sula bassanus*) at Bonaventure Island, Quebec, 1967-1984. *Can. J. Zool.* 65: 2922-2926.

Clement, R.E., H.M. Tosine, V. Taguchi, C.J. Musial and J.F. Uthe. 1987. Investigation of american lobster, *Homarus americanus*, for the presence of chlorinated dibenzo-*p*-dioxins and dibenzofurans. *Bull. Environ. Contam. Toxicol.* 39: 1069-1075.

Coastline Environmental Services Ltd. 1984. *Preliminary Assessment of the Toxicity of Sewage Effluent to Eggs and Larvae of Pacific Herring*. Report prepared for Fisheries and Oceans Canada, Ottawa.

Colodey, A.G. 1985. *Impact of a Pentachlorophenol/Tetrachlorophenol Spill on Freshwater and Marine Environments*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report (unpublished).

Colodey, A.G. 1986. *Investigations in Boundary Bay and Georgia Strait following a Chlorophenate Spill*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 86-18.

Colodey, A.G. 1989. *Environmental Impact of Pulp and Paper Mill Effluents in Sweden, Finland and Norway: Implications to the Canadian Environment*. Environment Canada, Ottawa. Environment Canada Discussion Paper 1P-99.

Colodey, A.G. and M. Pomeroy. 1985. *Low Dissolved Oxygen in Neroutsos Inlet, British Columbia: Observed Impacts of Sulphite Pulpmill Effluent, July - October 1985*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report (unpublished).

Colodey, A.G., L. Harding, M. Pomeroy, T. Lorenzetti and M. Saunders. 1988. *Retrospective Summary of Dissolved Oxygen Conditions within Alberni Harbour (1978-1988) and Evaluation of Critical BOD Loading*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report (unpublished).

Colodey, A.G., L.E. Harding, P.G. Wells and W.R. Parker. 1990. *Effects of pulp and paper mill effluents and their constituents on estuarine and marine environments in Canada: a brief review*. Environment Canada, Conservation and Protection, Pacific and Yukon Region, and Atlantic Regions. Regional Program Report 90-08. 44p.

Cominco Limited – Polaris Operations. *Annual Reports, 1981 to 1988.*

Cossa, D. and C. Desjardins. 1984. *Evolution de la concentration en mercure dans les crevettes du fjord du Saguenay (Quebec) au cours de la periode 1979-1983.* Rapp. Tech. Can. Hydrog. Sci. Ocean 32. 8p.

Cossa, D. and J.G. Rondeau. 1985. Seasonal, geographical and size-induced variability in mercury content of *Mutilus edulis* in an estuarine environment: a reassessment of mercury pollution level in the Estuary and Gulf of St. Lawrence. *Marine Biology* 88: 43-49.

Cossa, D., M. Picard-Berubé and J.-P. Gouygov. 1983. Polynuclear aromatic hydrocarbons in mussels from the estuary and Northwestern Gulf of St. Lawrence. *Bull. Environ. Contam. Toxicol.* 31: 41-47.

Cretney, W.J., C.S. Wong, R.W. MacDonald, P.E. Erikson and B.R. Fowler. 1983. Polycyclic aromatic hydrocarbons in surface sediments and age-dated cores from Kitimat Arm, Douglas Channel and Adjoining Waterways. In: *Proceedings of a Workshop on the Kitimat Marine Environment. Sidney, British Columbia.* R.W. Macdonald (ed.). Can. Tech. Rep. Hydrog. Ocean Sci. 18.

Crippen, S.W., S.L. Hodd and G. Greene. 1980. Metal levels in sediments and benthos resulting from a drilling fluid discharge into the Beaufort Sea. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings Proceedings: Volume 1.* Lake Buena Vista, Florida, January 1980. pp. 636-69.

Daborn, G.R. (ed.) 1977. *Fundy Tidal Power and the Environment.* The Acadia University Institute, Wolfville, N.S.

Daborn, G.R. and M.J. Dadswell. 1988. Natural and anthropogenic changes in the Bay of Fundy – Gulf of Maine – Georges Bank System. In: *Natural and Man-made Hazards.* M.I. El-Sabh and T.S. Murty (eds.). D. Reidel Publishing Company, Dordrecht. pp. 547-560.

D. McLeay and Associates Limited. 1987. *Aquatic Toxicity of Pulp and Paper Mill Effluent: A Review.* Environment Canada, Conservation and Protection, Environmental Protection, Ottawa. EPS 4/PF/1. 243p.

Davis, J.C. 1975. *Waterborne Dissolved Oxygen Requirements and Criteria with Particular Emphasis on the Canadian Environment.* National Research Council of Canada, Associate Committee on Scientific Criteria for Environmental Quality. Report No. 13.

Davis, J.C., I.G. Shand and B.J. Mason. 1976. *Biological and Oceanographic Studies at a Kraft Pulp and Paper Mill Outfall at Crofton, B.C., 1974.* Fish. Mar. Serv. Tech. Rep. 652.

Department of Fisheries and Oceans (DFO). 1985. *Report from a Workshop on Chemical Hazards to Fish and Fisheries. Volume II: Regional Fisheries Resources Zonal Overviews.* Burlington, Ontario, 10-12 September 1985.

Department of Fisheries and Oceans (DFO). 1986a. *The Oceans Sector: An Overview.* Department of Fisheries and Oceans, Economic and Commercial Analysis Directorate, Ottawa. 55p.

Department of Fisheries and Oceans (DFO). 1986b. *Oceans Forum, Issues and Opportunities on the Oceans Frontier.* September 1986, Victoria, British Columbia. Department of Fisheries and Oceans, Ottawa. 67p.

Department of Fisheries and Oceans (DFO). 1986c. *Oceans Inventory.* June 1986. Department of Fisheries and Oceans, Ottawa. 19p. + Appendices.

Department of Fisheries and Oceans (DFO). 1986d. *The Department of Fisheries and Oceans Policy for the Management of Fish Habitat*. Department of Fisheries and Oceans, Ottawa. October 1986. 30p.

Department of Fisheries and Oceans (DFO). 1987a. *Oceans Policy for Canada. A Strategy to Meet the Challenges and Opportunities on the Oceans Frontier*. Department of Fisheries and Oceans, Ottawa. 15p.

Department of Fisheries and Oceans (DFO). 1987b. *Canada's Oceans. An Economic Overview and a Guide to Federal Government Activities*. Department of Fisheries and Oceans, Ottawa. 56p.

Department of Fisheries and Oceans (DFO). 1988. *Multi-Year Marine Science Plan: Executive Summary*. Prepared under the direction of the Federal Interdepartmental Committee on Oceans. Supply and Services Canada, Ottawa. 20p.

Department of Fisheries and Oceans (DFO). 1990. *Proceedings. First Halifax Inlet Research Workshop, Bedford Institute of Oceanography*, 9 November 1989, Dartmouth, N.S. Department of Fisheries and Oceans, Dartmouth, N.S. 33p.

Dickie, L.M. and R.W. Trites. 1983. The Gulf of St. Lawrence. In: *Estuaries and Enclosed Seas*. B.H. Ketchum (ed.). Elsevier Scientific Publishing Co., New York. pp. 403-425.

Dobrocky Seatech Limited. 1985. *1982-83 Beaufort Sea Shorebase Monitoring Program, Statistical Analysis and Recommendations for Future Programs*. Report prepared for Indian and Northern Affairs Canada, Northern Affairs Program, Yellowknife, N.W.T.

DPA Group Inc. 1989. *Plastics Debris in the Aquatic Environment—Halifax Workshop Report*. Report of a Workshop held in Halifax, N.S., 16-18 May 1989. Report prepared for Department of Fisheries and Oceans, Ottawa. 46p.

Drinkwater, K. 1985. *Effects of River Runoff on the Marine Environment off Eastern Canada: A Submission to the Inquiry on Federal Water Policy*. Bedford Institute of Oceanography, Dartmouth, N.S.

Ducharme, A. 1990. The fisheries of the Halifax Inlet. In: *Proceedings, First Halifax Inlet Research Workshop*, Bedford Institute of Oceanography, November 1, 1989. Fisheries and Oceans Canada, Dartmouth, N.S.

Duncan, M.J. 1984. *Levels of Contaminants in Bivalve Molluscs of British Columbia*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report No. 83-19.

Dunn, B.P. and H.F. Stitch. 1976. Release of the carcinogen benzo[*a*]pyrene from environmentally contaminated mussels. *Bull. Environ. Contam. Toxicol.* 15(4): 398-401.

Dusseault, J. and B. Elkin. 1983a. *Community Water and Sanitation Services, 1983. Keewatin Region, Northwest Territories*. Government of the Northwest Territories, Yellowknife, N.W.T.

Dusseault, J. and B. Elkin. 1983b. *Community Water and Sanitation Services, 1983. Baffin Region, Northwest Territories*. Government of the Northwest Territories, Yellowknife, N.W.T.

Eaton, P.B., J.F. Uthe and G.R. Sirota. 1984. Coal and coal-based products. In: *Health of the Northwest Atlantic: A Report to the Interdepartmental Committee on Environmental Issues*. R.C.H. Wilson and R.F. Addison (eds.). Environment Canada, Department of Fisheries and Oceans, Department of Energy, Mines and Resources, Ottawa. pp. 109-120.

Eaton, P.B., L.P. Hildebrand and A.A. d'Entremont. 1986. *Environmental Quality in the Atlantic Region 1985*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S. 241p.

Elliott, J.E., R.W. Butler, R.J. Norstrom and P.E. Whitehead. 1988a. *Levels of Polychlorinated Dibenzodioxins and Polychlorinated Dibenzofurans in Eggs of Great Blue Herons (Ardea Herodias) in British Columbia, 1983-87: Possible Impacts on Reproductive Success*. Environment Canada, Canadian Wildlife Service, Ottawa. Canadian Wildlife Service Progress Note No. 176.

Elliott, J.E., R.J. Norstrom and J.A. Keith. 1988b. Organochlorines and eggshell thinning in Northern Gannets (*Sula bassanus*) from Eastern Canada, 1968-1984. *Environ. Poll.* 52: 81-102.

Elliott, J.E., P.E. Whitehead, R.J. Norstrom and D.G. Noble. 1989a. Organochlorine contaminants in sea bird eggs from the Pacific coast of Canada, 1971-1986. *Environ. Monitor. Assess.* 12: 67-82.

Elliott, J.E., R.W. Butler, R.J. Norstrom and P.E. Whitehead. 1989b. Environmental contaminants and reproductive success of Great Blue Herons *Ardea Herodias* in British Columbia, 1986-87. *Env. Poll.* 59: 91-114.

Ellis, D.V. 1984. *Problems of Metal Bioaccumulations Arising from Mining Industry Disposal of Tailings to the Sea*. Proccedings Eleventh Annual Toxicity Workshop, Vancouver, British Columbia, 13-15 November 1984.

Englehardt, F.R. (ed.). 1985. *Petroleum Effects in the Arctic Environment*. Elsevier Applied Science Publishers, Essex, United Kingdom. 281p.

Environment Canada. 1979. *Monitoring Environmental Contamination from Chlorophenol Contaminated Wastes Generated in the Wood Preservation Industry*. Environment Canada, Environmental Protection Service, Pacific and Yukon Region, Vancouver, Regional Program Report 79-24.

Environment Canada. 1985. *A Summary of Trends Relating to Spills of Oil and Hazardous Materials in the Atlantic Region*. Environment Canada, Environmental Protection Service. EPS-5-AR-85-6. 76p.

Environment Canada. 1986a. *Canada's Environment. An Overview*. Environment Canada, Ottawa. 20p.

Environment Canada. 1986b. *Regional Data Base on Discharges to the St. Lawrence River from Industry and Tributaries*. Environment Canada, Conservation and Protection, Quebec Region.

Environment Canada. 1986c. *Stratégie mondiale de la Conservation – Canada: Rapport sur les réalisations dans le domaine de la Conservation*. Environment Canada, Ottawa. 72p.

Environment Canada. 1986d. *National Inventory of Municipal Waterworks and Wastewater Systems in Canada*. Environment Canada, Ottawa.

Environment Canada. 1987a. *A Summary of Trends Relating to Spills of Oil and Hazardous Materials in the Atlantic Region. 1984*. Environment Canada, Environmental Protection, Atlantic Region, Dartmouth, N.S. Surveillance Report EPS-5-AR-87-3. 60p.

Environment Canada. 1987b. *Marine Environmental Quality Management Framework.* Environment Canada, Conservation and Protection, Ottawa. 21 September 1987. 4p. Internal Document.

Environment Canada. 1988d. *Mitigation of Effects of Oil Pollution on Seabird Populations: Prevention and Prosecution in Newfoundland and Labrador Waters.* Proceedings of a Workshop, 7-8 November 1988, St. John's, Nfld. Environment Canada, St. John's, Nfld.

Environment Canada. MS. 1988a. Draft Five. *Action Plan on Marine Environmental Quality.* Environment Canada, Conservation and Protection, Marine Environmental Quality Advisory Group, Ottawa. 21p.

Environment Canada. 1988b. *A Framework for the Management of Environment Canada's Responsibilities in the Marine Environment.* Environment Canada, Ottawa (unpublished). 4p.

Environment Canada. 1988c. *The St. Lawrence River Action Plan.* Environment Canada, Ottawa and Quebec City, P.Q.

Environment Canada. 1989. *Keeping the Ocean Clean. Ocean Dumping Control Act: 1987-88 Annual Report.* Supply and Services Canada, Ottawa. 32p.

Environment Canada, Department of Fisheries and Oceans, and Indian and Northern Affairs Canada. 1989. *Proceedings of a Workshop on Arctic Marine Environmental Quality.* 1-2 June 1988, Yellowknife, N.W.T. Environment Canada, Western and Northern Region, Department of Fisheries and Oceans, Pacific and Freshwater Fisheries, and Indian and Northern Affairs Canada, N.W.T.

Environment Canada. 1990a. *Guidelines for Environmental Effects Monitoring at Pulp and Paper Mills.* Environment Canada, Ottawa (unpublished). 13p.

Environment Canada. 1990b. *A Proposed Framework for the Management of Marine Environmental Quality within the Federal Government.* Prepared for the Interdepartmental Committee on Oceans Working Group on Marine Environmental Quality. Environment Canada, Ottawa, 1 March 1990. 10p.

ESL Environmental Sciences Limited. 1982. *The Biological Effects of Hydrocarbon Exploration and Production Related Activities, Disturbances and Wastes on Marine Flora and Fauna of the Beaufort Sea Region.* Report prepared for Dome Petroleum Limited, Calgary.

Evans, P.G.H. and D.N. Nettleship. 1985. Chapter 10. Conservation of the Atlantic Alcidae. In: *The Atlantic Alcidae.* D.N. Nettleship and T.R. Birkhead (eds.). Academic Press, Orlando. pp. 427-488.

Fallis, B.W. 1982. *Trace Metals in Sediments and Biota from Strathcona Sound, Northwest Territories: Nanisivik Marine Monitoring Program, 1974-1979.* Can. Tech. Rep. Fish. Aquat. Sci. 1082.

Farrington, J.W., J.H. Vandermeulen and D.G. Cook (eds.). 1983. Proceedings of the Conference on Pollution in the North Atlantic Ocean. *Can. J. Fish. Aquat. Sci.* 40(Suppl. 2): 1-362.

Federal Environmental Assessment Review Office (FEARO). 1980. *Arctic Pilot Project (Northern Component). Report of the Environmental Assessment Panel.* FEARO, Ottawa. Federal Environmental Assessment and Review Process, 14.

Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. 1984. *Responses of narwhals (Monodon monoceras) and belugas (Delphinapterus leucas) to ice-breaking ships in Lancaster Sound – 1983.* Report prepared for Department of Indian and Northern Affairs, Ottawa, by LGL Limited, King City, Ontario.

Fournier, R.O. 1990. *Halifax Harbour Task Force Final Report.* Report prepared for The Honourable John Leefe, Minister of the Environment, Government of Nova Scotia. 84p.

Fowler, B.K. and D. Hope. 1984. *Detailed Organic Analysis of Surficial Sediments from Abandoned Arctic Artificial Islands in the Beaufort Sea.* Report prepared by Arctic Laboratories Limited for Environment Canada, Environmental Protection Service, Yellowknife, N.W.T.

Frank, R., K. Ronald and H.E. Braun. 1973. Organochlorine residues in Harp seals (*Pagophilus groenlandicus*) caught in Eastern Canadian waters. *J. Fish. Res. Bd. Can.* 30: 1053-63.

Freeman, H.C., J.F. Uthe and P.J. Silk. 1984. Polychlorinated biphenyls, organochlorine pesticides and chlorobenzenes content of livers from Atlantic cod (*Gadus morhua*) caught off Halifax, Nova Scotia. *Environ. Monitor. Assess.* 4: 389-94.

Futer, P. and M. Nassichuk. 1983. *Metals in Eulachons from the Nass River and Crabs from Alice Arm, British Columbia.* Department of Fisheries and Oceans, Ottawa. Can. Man. Rep. Fish. Aquat. Sci. 1699.

Gagnon, M., J.J. Dodson, M.E. Comba and K.L.E. Kaiser. 1988. Congener specific distribution of polychlorinated biphenyls in the aquatic food-chain of the upper St. Lawrence River estuary. *Sci. Total Environ.* 97/98: 739-759.

Garrett, C.L. 1982. *Pacific and Yukon Region Toxic Chemicals Profile.* Report prepared for Environment Canada, Pacific and Yukon Region, Vancouver, Toxic Chemicals Committee. DOE Internal Working Document.

Garrett, C.L. 1985. *Chemicals in the Environment, Pacific and Yukon Region Report No. III: Polychlorinated Biphenyls (PCBs).* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Summary Report. 32p.

Garrett, C.L. and J.A. Shrimpton. 1988. *Chemicals in the Environment, Pacific and Yukon Region. Report No. V: Chlorophenols.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Summary Report.

Gaskin, D.E., R. Frank, M. Holdrinet, K. Ishida, C.J. Walton and M. Smith. 1973. Mercury, DDT and PCB in harbor seals (*Phoca virtulina*) from the Bay of Fundy and Gulf of Maine. *J. Fish. Res. Board Can.* 30: 471-475.

Gaskin, D.E., R. Frank and M. Holdrinet. 1983. Polychlorinated biphenyls in Harbor porpoises *Phocoena phocoena* (L.) from the Bay of Fundy, Canada and adjacent waters, with some information on chlordane and hexachlorobenzene levels. *Arch. Environ. Contam. Toxicol.* 12: 211-219.

Gaston, A.J. 1980. *Populations, movements and wintering areas of Thick-billed Murres (Uria lomvia) in eastern Canada.* Environment Canada, Canadian Wildlife Service, Ottawa. Canadian Wildlife Service Progress Note No. 110. 10p.

Gilbertson, M. and L. Reynolds. 1974. *A Summary of DDE and PCB Determinations in Canadian Birds, 1969 to 1972*. Environment Canada, Canadian Wildlife Service, Ottawa. Canadian Wildlife Service Occasional Papers Series No. 19.

Gilbertson, M., J.E. Elliott and D.B. Peakall. 1986. Seabirds as indicators of marine pollution. Paper presented at *Workshop on Birds as Bio-Indicators of Environmental Conditions*, ICBP, 19th World Conference, 14-21 June 1986, Kingston, Ontario.

Gillespie, D. 1986. *An Inquiry into Finfish Aquaculture in British Columbia: Report and Recommendations*. B.C. Finfish Aquaculture Enquiry and B.C. Ministry of Forests and Lands, Victoria, B.C. 50p.

Gordon, D.C., Jr. 1984. Integration of ecological and engineering aspects in planning large scale tidal power development in the Bay of Fundy, Canada. *Wat. Sci. Tech.* 16: 281-295.

Gordon, D.C., Jr., and M.J. Dadswell. 1984. *Update on the Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy*. Can. Tech. Rep. Fish. Aquat. Sci. 1256.

Gordon, D.C., Jr. (ed.). 1988. *An Assessment of the Possible Environmental Impacts of Exploratory Drilling on Georges Bank Fishery Resources*. Can. Tech. Rep. Fish. Aquat. Sci. 1633. 31p.

Gordon, D.C., Jr. 1989. Habitat loss in the Gulf of Maine. *Proceedings of the Conference The Gulf of Maine: Sustaining Our Common Heritage*, 10-12 December 1989, Portland, Maine. Maine State Planning Office, Augusta, Maine.

Gordon, D.C., Jr. 1990. Experience form Bay of Fundy and recommendations for Gulf Region. In: *Proceedings of Gulf Habitat Science Workshop*. E.M.P. Chadwick (ed.). Can. Industry Rep. Fish. Aquat. Sci. No. 206. pp. 45-48.

Goudreau, M. and B. Gauthier. 1981. *Étude sommaire des empiètements sur le littoral québécois*. Conseil Consultatif de l'Environnement, Government of Quebec. 113p.

Government of Canada. 1988. *Canadian Environmental Protection Act*. 35-36-37 Elizabeth II. Chapter 22. June 1988.

Government of Canada. 1990. *Canada's Green Plan: Canada's Green Plan for a healthy environment*. Minister of Supply and Services Canada, Ottawa. 174p.

Goyette, D. and M. Thomas. In preparation. *Environmental Studies in Alice Arm and Hastings Arm, British Columbia. Part VIa. Tissue Trace Metal Levels in the Bivalve Yoldia spp. Exposed to Molybdenum Mine Tailings*. Environment Canada, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report.

Goyette, D. and P. Christie. 1982. *Environmental Studies in Alice Arm and Hastings Arm, British Columbia. Part III: Initial Production Period—Amax/Kitsault Mine—Sediment and Tissue Trace Metals—May-June and October 1981*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 82-14.

Goyette, D. and K. Ferguson. 1985. *Environmental Assessment of the Britannia Mine, Howe Sound*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report (unpublished).

Goyette, D. and M. Thomas. 1987. *Vancouver Harbour Benthic Environmental Studies. May 1985 to September 1986: Relative Species Abundance and Distribution of Trawl Catches*. Environment Canada, Environmental Protection Regional Data Report 87-03.

Goyette, D., D. Brand and M. Thomas. 1988. *Prevalence of Idiopathic Liver Lesions in English Sole and Epidermal Abnormalities in Flatfish from Vancouver Harbour, British Columbia, 1986.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 87-09.

Goyette, D. and J. Boyd. 1989. *Distribution and environmental impact of selected benthic contaminants in Vancouver Harbour, British Columbia, 1985 to 1987.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 89-02.

Grooms, L.L. 1986. *Pulp and Paper Mills of B.C.: Intertidal Report.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report.

Guthrie, D.R. 1985. *Bioaccumulation from Amax/Kitsault Mine Tailings.* Environment Canada, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Manuscript Report 85-02.

Hall, K.J. 1985. A review of toxic substances in the Fraser River Estuary. In: *Toxic Chemicals Research Needs in the Lower Fraser River, Workshop Proceedings.* University of British Columbia, Vancouver, 19 June 1985. Environment Canada, Pacific and Yukon Region, Toxic Chemicals Committee. Environment Canada, Ottawa. 114p.

Harding, G.C.H., P.G. Wells and K.F. Drinkwater. 1979. The distribution and abundance of lobster larvae (*Homarus americanus*) in St. George's Bay, Nova Scotia, in 1975 and 1976 and the possible effect that the Canso causeway has had on the Chedabucto Bay lobster fishery. In: *Canso Marine Environment Workshop. Part 3 of 4 Parts. Fishery Impacts.* F.D. McCracken (ed.). Fisheries and Marine Service, Ottawa. Technical Report No. 834 (January 1979). pp. 101-111.

Harding, G.C.H. 1986. Organochlorine dynamics between zooplankton and their environment, a re-assessment. *Mar. Ecol.—Prog. Ser.* 33: 167-191.

Harding, G.C.H., K.F. Drinkwater and W.P. Vass. 1983. Factors influencing the size of american lobsters (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. *Can. J. Fish. Aquat. Sci.* 40(2): 168-184.

Harding, L. 1983. Use of fjords for disposal of mine tailings. *Proceedings of the Third Symposium on Coastal and Ocean Management.* American Society of Coastal Engineers, San Diego, California, 1-4 June 1983.

Harding, L. and M. Thomas. 1987. *Baseline Sediment and Tissue Trace Metals in Barkley Sound, Quatsino Sound, Surf Inlet and Laredo Sound, British Columbia.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 87-06.

Harding, L. and B. Kay. 1988. *Levels of Organotins in Water, Sediments and Oysters (Crassostrea gigas) from Nanoose Bay, British Columbia.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, File Report.

Harding, L., M. Pomeroy, A. Colodey and L.L. Grooms. 1988. *Fraser River Estuary Marine Environmental Monitoring Results 1984-86.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 87-18.

Harding, L. and J.R. Englar. 1989. *The Nestucca Oil Spill: fate and effects to May 31 1989.* Environment Canada, Protection and Conservation, Pacific and Yukon Region, Vancouver, Regional Progress Report 89-01.

Hargrave, B.T. and G.A. Phillips. 1976. DDT residues in benthic invertebrates and demersal fish in St. Margaret's Bay, Nova Scotia. *J. Fish. Res. Bd. Can.* 33: 1692-1698.

Hargrave, B.T. and D.J. Lawrence. 1988. *Bibliography of Halifax Harbour and Bedford Basin.* Manuscript Report, Department of Fisheries and Oceans, Bedford Institute of Oceanography, Dartmouth, N.S. 16 p.

Hargrave, B.T., W.P. Vass, P.E. Erickson and B.R. Fowler. 1988. Atmospheric transport of organochlorines to the Arctic Ocean. *Tellus* (40B): 480-493.

Hargrave, B.T., W.P. Vass, P.E. Erickson and B.R. Fowler. 1989a. *Distribution of Chlorinated Hydrocarbon Pesticides and PCBs in the Arctic Ocean*. Can. Tech. Rep. Fish. Aquat. Sci. 1644. 224p.

Hargrave, B.T., D. Peer, and H. Wiele. 1989b. Benthic biological observations. Chapter 2. In: *Investigations of Marine Environmental Quality in Halifax Harbour.* H.B. Nicholls (ed.). Can. Tech. Fish. Aquat. Sci. 1693: 37-45.

Harvey, G.R. and W.G. Steinhauer. 1974. Atmospheric transport of polychlorinated biphenyls to the North Atlantic. *Atmos. Environ.* 8: 777-782.

Hellou, J., G. Stenson, I-H. Ni and J.F. Payne. 1990. Polycyclic aromatic hydrocarbons in muscle tissue of marine mammals from the Northwest Atlantic. *J. Mar. Pollut. Bull.* 21(10): 469-473.

Hilborn, J. and M. Still. 1990. *Canadian Perspectives on Air Pollution. A State of the Environment Report.* Environment Canada, Ottawa. SOE Report No. 90-1. 81p.

Hildebrand, L.P. 1982. *Environmental Quality in Sydney and Northeast Industrial Cape Breton.* Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S. Report EPS-5-AR-82-3. 89p.

Hildebrand, L.P. 1984. *An assessment of environmental quality in the Baie des Chaleurs.* Environment Canada, Environmental Protection Service, Surveillance Report EPS-5-AR-84-8. 191p.

Howarth, R.W. 1987. Chapter 53. The potential effects of petroleum on marine organisms on Georges Bank. In: *Georges Bank.* R.H. Backus and D.W. Bourne (eds.). Massachusetts Institute of Technology, Boston. pp. 540-551.

Howells, G., D. Calamari, J.S. Gray, H. Naeve and P.G. Wells. 1990. Long-term consequences of low-level marine contamination. An analytical approach. *Mar. Poll. Bull.* (in press).

Hurlbut, S. 1990. Water quality modelling in Halifax Inlet. [Abstract] In: *Proceedings*, First Halifax Inlet Research Workshop. Bedford Institute of Oceanography, Dartmouth, N.S., 9 November 1989. Department of Fisheries and Oceans, Dartmouth, N.S.

IEC Beak Consultants Ltd. 1983. *Mercury analysis of Dungeness Crab Tissue.* Report prepared for FMC of Canada Ltd., February, 1983.

Indian and Northern Affairs Canada, Water Resources Division. 1983. *Intervention Submission to the Nanisivik Mines Limited Public Hearing.* 2 March 1983.

Indian and Northern Affairs Canada and Environment Canada. 1985. *Beaufort Environmental Monitoring Project 1984-85: Final Report.* Unpublished report by ESL

Environmental Sciences Limited, LGL Limited, Essa Limited, Arctic Laboratories Limited and Arctic Sciences Limited. 162p.

Indian and Northern Affairs Canada. 1986. *Summary Report: Drilling and Fluid Use and Wastes Discharge in Arctic Marine Waters North of 60° for 1983*. Indian and Northern Affairs Canada, Northern Affairs Program, Water Resources Division, Arctic Waters Section, Yellowknife, N.W.T. 44p.

International Union for the Conservation of Natural Resources. 1980. *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. With the support of the United Nations Environment Programme and the World Wildlife Fund, Gland, Switzerland.

Jangaard, P.M. (ed.). 1972. *Effects of Elemental Phosphorus on Marine Life*. Fisheries Research Board of Canada, Atlantic Regional Office, Halifax, N.S. Circ. No. 2, Nov. 1972. 313p.

Johnston, R. (ed.) 1976. *Marine Pollution*. Academic Press, London.

Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) – IMO/FAO/UNESCO/WMO/IAEA/UN/UNEP. 1987. *Land/Sea Boundary Flux of Contaminants: Contributions from Rivers*. Rep. Stud. GESAMP No. 32. 172p.

Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). 1990. *The State of the Marine Environment*. Joint Group of Experts on the Scientific Aspects of Marine Pollution Reports and Studies No. 39. United Nations Environment Program, Nairobi. 111p.

Kaiser, K.L.E., K.R. Lum, M.E. Comba and V.S. Palabrica. 1990. Organic trace contaminants in St. Lawrence River water and suspended sediments, 1985-1987. *Sci. Total Environ.* 97/98: 23-40.

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. *Benthic Studies in Alice Arm, British Columbia following Cessation of Mine Tailings Disposal*. Can. Tech. Rep. Hydrog. Ocean Sci. 37.

Kay, B.H. 1986a. *West Coast Marine Environmental Quality: Summary Report*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 86-04.

Kay, B.H. 1986b. *West Coast Marine Environmental Quality: Technical Reviews*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 86-01.

Kay, B.H., D. Nuttal, L. MacLeod, R. Moody, A. Moody and D. Meakins. 1986. *West Coast Marine Environmental Quality: Annotated Bibliography. Volumes 1 & 2*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Program Report 86-02.

Kay, B.H. 1989a. *Pollutants in British Columbia's Marine Environment. A Status Report*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, SOE Report No. 89-1. 59p.

Kay, B.H. 1989b. *Pollutants in British Columbia's Marine Environment*. Environment Canada, Conservation and Protection, Ottawa. SOE Fact Sheet No. 89-2. 12p.

Khalil, M.F., J. Labbe, S. Lantagne, A.C. Horth and M. Arnac. 1984. Les organochlores dans l'estuaire du Saint-Laurent. *Sciences et Techniques de l'eau* 17(1): 73-79.

Kinlock, D. and H.V. Kuhnlein. 1986. *Assessment of PCBs in Arctic Foods and Diets – A Sentinel Study in Broughton Island, Northwest Territories.*

Konrad, V., S. Ballard, R. Erb and A. Morin. 1990. *The Gulf of Maine: Sustaining Our Common Heritage.* Proceedings of an International Conference, Portland, Maine, 10-12 December 1989. Maine State Planning Office and the Canadian-American Center of the University of Maine, Augusta, Maine. 270p.

Laflamme, R.E. and R.A. Hites. 1978. The global distribution of polycyclic aromatic hydrocarbons in recent sediments. *Geochim. Cosmochim. Acta* 42: 289-303.

Langford, R.W., S. Reid and L. Harding. 1988. Marine environmental quality in Canada: status and issues. The Pacific Coast of Canada. In: *Canadian Conference on Marine Environmental Quality: Proceedings.* Halifax, N.S., 29 February - 3 March 1988. P.G. Wells and J. Gratwick (eds.). International Institute for Transportation and Ocean Policy Studies, Halifax. pp. 209-228.

Leach, J.M. and A.M. Thackore. 1977. Compounds toxic to fish in pulpmill waste streams. *Prog. Water Tech.* 9: 787-98.

LeBlanc, K.W.G., R.A. Fitzgerald, G.V. Winters, D.E. Buckley and R.E. Cranston. 1991. *Geochemical data from analyses of sediments and pore waters obtained from cores collected in Halifax Inlet.* Geological Survey of Canada, Open File Report 2345. 116p.

Lehoux, D., A. Bourget, P. Dupuis and J. Rosa. 1985. *La Sauvagine dans le système du Saint-Laurent.* Environment Canada, Environmental Protection Service, Quebec Region. 76p.

Levings, C.D., E.P. Anderson and G.W. O'Connel. 1985. Biological effects of dredged material disposal in Alberni Inlet. In: *Wastes in the Ocean, Volume 6.* B. Ketchum, J. Capuzzo, W. Burt, I. Duedall, P. Park and D. Kester (eds.). Wiley Inter-Science, New York. pp. 131-55.

Levy, E.M. and A. Walton. 1976. High seas oil pollution: particulate petroleum residues in the North Atlantic. *J. Fish. Res. Bd. Can.* 33: 2781-2791.

Levy, E.M. 1984. Incidence and distribution of petroleum and petroleum products. In: *Health of the Northwest Atlantic: A Report to the Interdepartmental Committee on Environmental Issues.* R.C.H. Wilson and R.F. Addison (eds.). Environment Canada, Department of Fisheries and Oceans, Department of Energy, Mines and Resources, Ottawa. pp. 70-76.

Levy, E.M. 1988. Chapter IX. Petroleum residues in the waters of the Gulf of St. Lawrence. In: *Chemical Oceanography of the Gulf of St. Lawrence.* P.M. Strain (ed.). Department of Fisheries and Oceans, Ottawa. *Can. Bull. Fish. Aquat. Sci.* 220: 139-57.

LGL Limited. 1986. *A Workshop on Selected Environmental Impacts of Ship Traffic in Lancaster Sound and Northern Baffin Bay.* Report prepared for Department of Indian and Northern Affairs, Ottawa.

Lindsay, G., A. McIver and S. Mahon. 1983. *Report on the Saint John Harbour Environs.* Environment Canada, Environmental Protection Service, Surveillance Report EPS-5-AR-83-8. 177p.

Lord, D.A., R.A.F. Matheson, L. Stuart, J.J. Swiss and P.G. Wells. 1978. *Environmental monitoring of the 1976 spruce budworm spray program in New Brunswick, Canada.* Environment Canada, Environmental Protection Service, Surveillance Report EPS-5-AR-78-3. 161p.

Lorimer, G. 1984. *Review of Selected Marine Municipal Outfalls in British Columbia.* Environment Canada, Conservation and Protection, Environmental Protection Service, Pacific and Yukon Region, Vancouver, Regional Program Report 84-11.

Loring, D.H. 1975. Mercury in the sediments of the Gulf of St. Lawrence. *Can. J. Earth Sci.* 12: 1219-37.

Loring, D.H. 1984. Potential bioavailability of metals in Eastern Canadian estuarine and coastal sediments. *Rapp. P.-v. Reun. Cons. Int. Explor. Mer* 181: 93-101.

Lucotte, M. 1988. Temporary storage and geochemical transformations of contaminants on the marshes of the St. Lawrence Upper Estuary. Abstract of paper presented at *International Symposium on the Fate and Effects of Toxic Chemicals in Large Rivers and their Estuaries*, Quebec City, P.Q., October 1988. Canada Centre for Inland Waters, Burlington, Ontario (unpublished).

Lum, K.R., C. Jaskot and P.R. Youakin. 1988. Mobilization and removal of metals in the upper estuary of the St. Lawrence River. Abstract of paper presented at *International Symposium on the Fate and Effects of Toxic Chemicals in Large Rivers and their Estuaries*, Quebec City, P.Q., October 1988. Canada Centre for Inland Waters, Burlington, Ontario (unpublished).

Luoma, J.R. 1989. Doomed canaries of Tadoussac. *Audubon* March 1989: 92-97.

Machell, J.R. and A.S. Menon. 1989. *Maritime Shellfish Classification Inventory 1989.* Environment Canada, Conservation and Protection, Atlantic Region, Dartmouth, N.S., Manuscript Report. 13p.

Maguire, R.J., R.J. Tkacz, Y.K. Chou, G.A. Bengert and P.T.S. Wong. 1986. Occurrence of organotin compounds in water and sediment in Canada. *Chemosphere* 15(3): 253-274.

Mariani, G.M., L.V. Sick and C.C. Johnson. 1980. An environmental monitoring study to assess the impact of drilling discharges in the Mid-Atlantic. III. Chemical and physical alterations in the benthic environment. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings Proceedings: Volume 1.* Lake Buena Vista, Florida, January 1980. pp. 438-95.

Marine Environmental Quality Advisory Group. 1989. *Health of Our Oceans. The Marine Environmental Quality Issue. Progress Report 1987-1989.* Environment Canada, Conservation and Protection, Ottawa. 32p.

Marsh, J.H. (ed.). 1988. *The Canadian Encyclopedia.* Second Edition. Hurtig Publishers Ltd., Edmonton.

Martel, L.M., J. Gagnon, R. Massé, A. Leclerc and L. Tremblay. 1986. Polycyclic aromatic hydrocarbons in sediments from the Saguenay Fjord, Canada. *Bull. Environ. Contam. Toxicol.* 37: 133-140.

Martin, L.C., W.S. Duval and D.J. Thomas. 1986. *A Process for Assessing the Impact of Dredging Projects on the Biological Resources of the Beaufort Sea.* Report prepared by ESL Environmental Services Ltd. and Arctic Laboratories Ltd. for Environment Canada, Conservation and Protection, Environmental Protection, Yellowknife, N.W.T.

Martineau, D., P. Béland, C. Desjardins and A. Vezina. 1985. *Pathology, Toxicology and Effects of Contaminants on the Population of St. Lawrence Beluga (Delphinapterus leucas), Quebec, Canada.* International Council for the Exploration of the Sea, Copenhagen. C.M. 1985/N: 13.

Martineau, D., A. Lagace, P. Béland, R. Higgins, D. Armstrong and L.R. Stugart. 1988. Pathology of stranded Beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Quebec, Canada. *J. Comp. Path.* 98: 287-311.

Massé, R., D. Martineau, L. Tremblay and P. Béland. 1986. Concentrations and chromatographic profile of DDT residues in stranded Beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary. *Can. Arch. Environ. Contam. Toxicol.* 15: 567-79.

Matheson, R.A.F., G.L. Trider, W.R. Ernst, K.G. Hamilton and P.A. Hennigar. 1983. *Investigation of polynuclear aromatic hydrocarbon contamination of Sydney Harbour, Nova Scotia*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S. EPS-5-AR-83-6. 86p.

McCracken, F.D. (ed.). 1979. *Canso Marine Environment Workshop. Part 3 of 4 Parts. Fishery Impacts*. Fisheries and Marine Service, Ottawa. Technical Report No. 834 (January 1979).

McGreer, E.R. and G.A. Vigers. 1979. *Assessment of the Impact of Sulfite Mill Effluent on Fish Avoidance Behaviour in Neroutsos Inlet. Environmental Improvement at Neroutsos Inlet, British Columbia, Volume 7*. Report prepared for Rayonier, Inc.

McGreer, E.R. and D.R. Munday. 1982. *Effects of Soiled and Contaminated Sediment on Eggs and Larvae of Pacific Cod (Gadus macrocephalus)*. Report on Ocean Dumping R and D, Department of Fisheries and Oceans, Pacific Region, 1980-81. Can. Contract Rep. Hydrog. Ocean Sci. 3.

McGreer, E.R. 1984. *Analysis of Marine Benthic Invertebrate Data from British Columbia Coastal Pulp Mills*. Report prepared for Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, March 1984.

McLeay, D., D. Munday, H. Lanz and D. Konasewich. 1984. *Bioaccumulation Studies with Bivalves Exposed to Alice Arm Sediments Contaminated with Amax/Kitsault Mine Tailings*. Report prepared for Department of Fisheries and Oceans by D. McLeay and Associates Ltd.

Menon, A.S. 1988. Molluscan shellfish and water quality problems in Atlantic Canada. *Toxicity Assessment* 3: 679-686.

Menzie, C.A., P. Mauer and W.A. Leathem. 1980. An environmental monitoring study to assess the impact of drilling discharges in the Mid-Atlantic. IV. The effects of drilling discharges on the benthic community. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings Proceedings: Volume 1*. Lake Buena Vista, Florida, January 1980. pp. 499-536.

Mercier, F.M. 1985. Fat reserves and migration of Red-necked Phalaropes (*Phalaropus lobatus*) in the Quoddy region, New Brunswick, Canada. *Can. J. Zoo.* 63: 2810-2816.

Messieh, S.N. and M.I. El-Sabh. 1988. Man-made environmental changes in the Southern Gulf of St. Lawrence, and their possible impact on inshore fisheries. In: *Natural and Man-made Hazards*. M.I. El-Sabh and T.S. Murty (eds.). D. Reidel Publishing Company, Dordrecht. pp. 499-523.

Messieh, S.N. and M.I. El-Sabh. 1990. The marine killers: dinoflagellates in estuarine and coastal waters. *Natural Hazards* 3:69-86.

Michalik, P.A. and D.C. Gordon. 1971. *Concentration and Distribution of Oil Pollutants in Halifax Harbour 10 June to 20 August, 1971*. Fish. Res. Bd. Can. Tech. Rep. 284.

Miller, G.W. and R.A. Davis. 1984. *Distribution and Movements of Narwhals and Beluga Whales in Response to Ship Traffic at the Lancaster Sound Ice Edge – 1984.* Report prepared for Department of Indian and Northern Affairs, Ottawa, by LGL Limited, King City, Ontario.

Milne, A.R. 1967. Sound propagation and ambient noise under sea ice. In: *Underwater Acoustics, Volume 2.* V.M. Alberts (ed.). pp. 103-37.

Misra, R.K. and J.F. Uthe. 1987. Methods of Time Trends Analysis Applied to Contaminant Levels in Canadian cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* 44: 859-865.

Misra, R.K., J.F. Uthe, C.J. Musial and C.L. Chou. 1988. *The analysis of time trends in contaminant levels in Canadian Atlantic cod (Gadus morhua). 5. Time trends, 1977-1985, employing a multivariate linear model.* International Council for the Exploration of the Sea, Copenhagen. C.M. 1988/E: 4.

Moody, A.I. and R. Moody. 1985. *An Assessment of Mercury Levels in Sediments and Vascular Plants within the Squamish Estuary.* Environment Canada, Conservation and Protection, Environmental Protection, Vancouver, Manuscript Report 85-05.

Moore, J.W. and S. Ramamoorthy. 1984. *Heavy Metals in Natural Waters: Applied Monitoring and Impact Assessment.* Springer-Verlag, New York. 268p.

Mowat, F. 1984. *Sea of Slaughter.* McClelland and Stewart Ltd., Toronto. 438p.

Mudroch, P. 1987. *Distribution of Metals and Hydrocarbons in the Nearshore Zone of the Southern Beaufort Sea.* Environment Canada, Conservation and Protection, Environmental Protection, Western and Northern Region, Yellowknife, N.W.T. 86/87-CP(EP)-9.

Muir, D.C.G., R.J. Norstrom and M. Simon. 1988. Organochlorine contaminants in Arctic marine food chains: accumulation of specific polychlorinated biphenyls and chlordane-related compounds. *Environ. Sci. Tech.* 22: 1071-78.

Musial, C.J., J.F. Uthe, G.R. Sirota, B.G. Burns, M.W. Gilligan, V. Zitko and R.A. Matheson. 1981. Di-n-hexyl phthalate (DHP), a newly identified contaminant in Atlantic hHerring (*Clupea harengus harenguss*) and Atlantic mackerel (*Scomber scombrus*). *Can. J. Fish. Aquat. Sci.* 38: 856-59.

Musial, C.J. and J.F. Uthe. 1983. Widespread occurrence of the pesticide toxaphene in Canadian East Coast marine fish. *Int. J. Environ. Anal. Chem.* 14: 117-26.

Napolitano, G.E. and R.G. Ackman. 1989. Lipids and hydrocarbons in *Corophium volutator* from Minas Basin, Nova Scotia. *Marine Biology* 100: 333-338.

Nassichuk, M.D. 1985. *Pacific Fisheries Resources Final Overview.* Fisheries and Oceans Canada Chemical Hazards Workshop. Burlington, Ontario, 10-12 September 1985. Department of Fisheries and Oceans, Ottawa.

National Research Council of Canada (NRCC). 1983. *Polycyclic aromatic hydrocarbons in the aquatic environment: formation, sources, fate and effects on aquatic biota.* Ass. Comm. Sci. Crit. for Environ. Qual., Ottawa. NRCC No. 18981. 209p.

National Research Council (NAS/NRC). Steering Committee for the Petroleum in the Marine Environment Update, Board on Ocean Science and Policy, Ocean Sciences Board, Commission on Physical Sciences, Mathematics and Resources. 1985. *Oil in the Sea: Inputs, Fates and Effects.* National Academy Press, Washington, D.C. 608p.

Neff, J.M. 1982. *Fate and Effects of Oil Well Drilling Fluids in the Marine Environment: A Literature Review.* Report prepared by Batelle New England Research Laboratory for Environmental Research Laboratory. U.S. Environmental Protection Agency, Gulf Breeze, Florida.

Neff, J.M. 1987. Chapter 52. The potential effects of drilling effluents on marine organisms on Georges Bank. In: *Chapter 52. Georges Bank.* R.H. Backus and D.W. Bourne (eds.). Massachusetts Institute of Technology, Boston. pp. 531-539.

Nettleship, D.N. 1975. A recent decline of gannets, *Morus bassanus*, on Bonaventure Island, Quebec. *Can. Field Nat.* 89: 125-133.

Nettleship, D.N. 1976. Gannets in North America: present numbers and recent population changes. *Wilson Bull.* 88(2): 300-313.

Nettleship, D.N. 1977. Seabird resources of Eastern Canada: status, problems and prospects. In: *Canada's Threatened Species and Habitats.* T. Mosquin and C. Suchal (eds.). Canadian Nature Federation, Ottawa. pp. 96-108.

Nettleship, D.N. and T.R. Birkhead (eds.). 1985. *The Atlantic Alcidae.* Academic Press, London. 574 p.

Nettleship, D.N. and D.B. Peakall. 1987. Organochlorine residue levels in three high Arctic species of colonially-breeding seabirds from Prince Leopold Islands. *Mar. Poll. Bull.* 18(8): 434-38.

Newfoundland Design Associates Limited and Gore Storrie Limited. 1982. *St. John's Sewage Disposal Study. Volume III: St. John's Harbour Assimilative Capacity and Ocean Diffusion.* Report to the Government of Newfoundland and Labrador, Department of Municipal Affairs, St. John's, Nfld.

Nicholls, H.B. (ed.). 1989. *Investigations of Marine Environmental Quality in Halifax Harbour.* Can. Tech. Rep. Fish. Aquat. Sci. 1693. 83p.

Noble, D.G. and J.E. Elliott. 1986. *Environmental Contaminants in Canadian Seabirds, 1968-1984: Trends and Effects.* Environment Canada, Canadian Wildlife Service, Ottawa. Canadian Wildlife Service Tech. Report Series No. 13. 275p.

Noble, D.G. and S.P. Burns. 1990. *Contaminants in Canadian Seabirds.* Environment Canada, Conservation and Protection, Ottawa. State of the Environment Fact Sheet No. 90-1. 12p.

Norstrom, R.J. 1988. Bioaccumulation of polychlorinated biphenyls in Canadian wildlife. In: *Hazards, Decontamination and Replacement of PCBs.* J.-P. Crine (ed.). Plenum Publ. Corp. pp. 85-100.

Norstrom, R.J. 1990. Are polar bears threatened by PCBs? *Comite Artique International Commentary* No. 2: 13-17.

Norstrom, R.J. and D.C.G. Muir. 1988. Long-range transport of organochlorines in the Arctic and sub-Arctic: evidence from analysis of marine mammals and fish. In: *Toxic Contamination in Large Lakes: Vol. 1 Chronic Effects of Toxic Contamination In Large Lakes.* N.W. Schmidtke (ed.). Lewis Publishers, Chelsea, MI. pp. 83-112.

Norstrom, R.J., D.C.G. Muir and R.E. Schweinsburg. 1985. *Organochlorine and heavy metal contaminants in Polar bears.* Interim Report to Department of Indian and Northern Affairs, Ottawa, 25 June 1985.

Norstrom, R.J., M. Simon, D.C.G. Muir and R.E. Schweinsburg. 1988a. Arctic marine food chains: identification, geographical distribution and temporal trends in polar bears. *Environ. Sci. Tech.* 22: 1063-70.

Norstrom, R., M. Simon, C. Garrett, J. Shrimpton and P. Whitehead. 1988b. Bleached kraft mills and chlorophenols identified as major sources of PCDDs and PCDFs in marine environments in British Columbia, Canada. Paper presented at *Dioxin '88, The 8th International Symposium on Chlorinated Dioxins and Related Compounds*, Umea, Sweden, 21-26 August 1988.

Norstrom, R.J., M. Simon, and D.C.G. Muir. 1990. Polychlorinated dibenzo-*p*-dioxins and dibenzofurans in marine mammals in the Canadian North. *Environ. Poll.* 65: (in press).

Northern Spill Reporting Service. *Spill Reports, 1972 to 1988.*

Packman, G.A., R.G. Shearer and W.W. Fenton. 1986. *Progress towards Standardized Programs to Monitor Site Specific Impacts in the Beaufort Sea Benthic Environment.* Environment Canada, Conservation and Protection, Environmental Protection, Yellowknife, N.W.T. (unpublished).

Packman, G.A. and R.G. Shearer. 1988. An overview of marine environmental quality in the Canadian Arctic. In: *Canadian Conference on Marine Environmental Quality: Proceedings*. Halifax, N.S., 29 February - 3 March 1988. P.G. Wells and J. Gratwick (eds.). International Institute for Transportation and Ocean Policy Studies, Halifax. pp. 229-42.

Patton, G.W., D.A. Hinckley, M.D. Walla, T.F. Bidleman and B.T. Hargrave. 1989. Airborne organochlorines in the Canadian high Arctic. *Tellus* 41B: 243-255.

Payne, J.F. and A. Rahimtula. 1984. A perspective on potential environmental problems associated with chlorine usage. In: *Health of the Northwest Atlantic. A report to the interdepartmental committee on environmental issues*. R.C.H. Wilson and R.F. Addison (eds.). Environment Canada and Department of Fisheries and Oceans, Dartmouth, N.S. pp. 94-108.

Peakall, D.B., P.G. Wells and D. Mackay. 1987. A hazard assessment of chemically dispersed oil spills and seabirds. *Mar. Environ. Res.* 22: 91-106.

Pearce, P.A., I.M. Gruchy and J.A. Keith. 1973. *Toxic Chemicals in Living Things in the Gulf of St. Lawrence.* Environment Canada, Canadian Wildlife Service, Pesticide Section, Ottawa. Canadian Wildlife Service Manuscript Report No. 24.

Pearce, P.A., J.E. Elliott, D.B. Peakall and R.J. Norstrom. 1989. Organochlorine contaminants in eggs of seabirds in the Northwest Atlantic, 1968-1984. *Environ. Poll.* 56: 217-35.

Pearse, P.N. 1982. *Turning the Tide: A New Policy for Canada's Pacific Fisheries. Commission on Pacific Fisheries Policy Final Report.* Vancouver, B.C.

Percy, J.A. and P.G. Wells. 1984. Effects of petroleum in polar marine environments. *Marine Technology Society J.* 18: 51-61.

Piatt, J.F. and D.N. Nettleship. 1987. Incidental catch of marine birds and mammals in fishing nets off Newfoundland, Canada. *Mar. Poll. Bull.* 18(68): 344-349.

Picard-Berubé, M., D. Cossa and J. Piuze. 1983. Teneurs en Benzo 3,4, Pyrene chez *Mytilus edulis* L. de l'Estuaire et du Golfe du Saint-Laurent. *Mar. Environ. Res.* 10: 63-71.

Pippard, L. 1985. Status of the St. Lawrence River population of beluga (*Delphinapterus leucas*). *Canadian Field Naturalist* 99(3): 438-50.

Piuze, J. and M. Tremblay. 1979. *Mercury in the Waters of the St. Lawrence Estuary*. International Council for the Exploration of the Sea, Copenhagen. C.M. 1979/E: 49.

Plant, S. 1985. *Bay of Fundy Environmental and Tidal Power Bibliography*. Second Edition. Can. Tech. Rep. Fish. Aquat. Sci. 1339.

Pocklington, R. 1976. Terrigenous organic matter in surface sediments from the Gulf of St. Lawrence. *J. Fish. Res. Bd. Can.* 33: 93-97.

Pocklington, R. 1988. Chapter IV. Organic matter in the Gulf of St. Lawrence. In: *Chemical Oceanography of the Gulf of St. Lawrence*. P.M. Strain (ed.). Department of Fisheries and Oceans, Ottawa. *Can. Bull. Fish. Aquat. Sci.* 220: 49-58.

Pocklington, R. and S. Roy. 1975. *Utilisations de composés organiques comme traceurs de material d'origine terrestre dans l'océan*. International Council for Exploration of the Sea, Copenhagen. Hydrography Committee CM 1975/C: 10.

Pomeroy, W.M. 1983. Fibre deposits: the appearance and difficulty in monitoring. In: *Pulp Mill Effluent Monitoring: An Information Development Program*. Environment Canada, Environmental Protection Service, Vancouver (unpublished).

Porter, E. 1990. *Arctic Marine Environmental Quality (MEQ): prospectus for future research*. Environment Canada, Conservation and Protection, Western and Northern Region, Yellowknife, N.W.T. (unpublished).

Prouse, N.J., T.W. Rowell, P. Woo, J.F. Uthe, R.F. Addison, D.H. Loring, R.T.T. Rantala, M.E. Zinck and D. Peer. 1988. *Annapolis Basin soft-shell clam (Mya arenaria) mortality study: a summary of field and laboratory investigations*. Can. Man. Rep. Fish. Aquat. Sci. 1987. 19p.

Quilliam, M.A. and J.L.C. Wright. 1988. The amnesic shellfish poisoning mystery. *Analyt. Chem.* 61(18):1053A-1060A.

Ray, S., M. Woodside, V.E. Jerome and H.A. Kagi. 1984. Copper, zinc, cadmium and lead in scallops (*Plecopecten magellanicus*) from Georges and Brown's Banks. *Chemosphere* 13: 1247-54.

Reeves, R.R. and E. Mitchell. 1984. Catch history and initial population of white whales (*Delphinapterus leucas*) in the River and Gulf of St. Lawrence, Eastern Canada. *Le Naturaliste Canadien* 3: 63-121.

Reid, B.J. and J. Baumann. 1974. *Preliminary Laboratory Study of the Effects of Burial by Amax-Kitsault Mine Tailings on Marine Invertebrates*. Department of Fisheries and Oceans, Ottawa. Can. Man. Rep. Fish. Aquat. Sci. 1781.

Renzoni, A. and R.J. Norstrom. 1990. Mercury in the hairs of polar bears *Ursus maritimus*. *Polar Record* (in press).

Rescan Environmental Services Ltd. 1990. *Rankin Inlet Nickel Mine: evaluation of reclamation options*. Prepared for Department of Municipal and Community Affairs, Government of the Northwest Territories.

Reynard, S. 1986. *A Planned Strategy for Developing Burrard Inlet's Shorebased Sport Fisheries*. M.Sc. Thesis, University of British Columbia.

Richardson, W.J., R.S. Wells and B. Wursig. 1983. Disturbance responses of bowhead, 1982. In: *Behaviour, disturbance responses and distribution of bowhead whales (Balaena* *mysticetus) in the eastern Beaufort Sea, 1982.* W.J. Richardson (ed.). Report by LGL Ecological Research Associates, Inc., Bryan, Texas for U.S. Minerals Management Service, Reston, Virginia.

Richardson, W.J., M.A. Fraker, B. Wursig and R. Wells. 1985. Behaviour of bowhead whales (*Balaena mysticetus*) summering in the Beaufort Sea: reactions to industrial activities. *Biol. Conserv.* 32: 195-230.

Rogers, I.H., H.W. Mahood, I.K. Birthwell and G.M. Kruzynski. 1984. Organic chemicals in sewage from the Iona Island treatment plant. In: *Proceedings, Workshop on Municipal Marine Discharge*. Environment Canada, Environmental Protection Service, Pacific and Yukon Region, Vancouver, British Columbia, 14-15 February 1984.

Ronald, K., R.J. Frank and J.L. Dougan. 1984. Pollutants in harp seal (*Phoca groenlandicus*). I. Organochlorines. *Sci. Total Environ.* 38: 133-152.

Roswell, K.T., D.C.G. Muir and B.E. Baker. 1979. Organochlorine residues in the harp seal (*Pagophilus groenlandicus*) tissues, Gulf of St. Lawrence 1971-1973. *Pesticides Monitoring J.* 12(4): 189-92.

Sackmann, T., R. Shearer and S. Lundvall. In preparation. *Present Status of Arctic Marine Environmental Quality*. Environment Canada, Conservation and Protection, Environmental Protection, Western and Northern Region, Northwest Territories District Office, Yellowknife, N.W.T.

Sackmann, T. and B.D. Smiley. 1985. *Arctic Industrial Activities Compilation. Volume 2: Sverdrup Basin: Hydrocarbon Exploration 1974 to 1984.* Can. Data Rep. Hydrog. Ocean Sci. 32.

Sackmann, T., J.W. McDonald, P. Brouwer and L. Turney. 1986. *Compilation of 1982-85 Dredging Activities in the Canadian Beaufort Sea: A Supplementary Report.* Report prepared for Environment Canada, Conservation and Protection, Environmental Protection, Yellowknife, N.W.T. by ESL Environmental Sciences Limited, Sidney, British Columbia.

Samant, H.S., K.G. Doe and D.C. Vaidya. 1990. An integrated chemical and biological study of bioavailability of metals in sediments from two contaminated harbours in New Brunswick, Canada. *Sci. Total Environ.* 96: 253-268.

Saschenbrecker, P.W. 1973. Levels of DDT and PCB compounds in North Atlantic fin-back whales. *Can. J. Comp. Med.* 37: 203-206.

Scarratt, D.J. 1987. Fisheries resources zonal overview. In: *Report from a Workshop on Chemical Hazards to Fish and Fisheries*. M. Adam, W.D. McKone and H. Shear (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 1525. pp. 26-35.

Sergeant, D.E. and P.F. Brodie. 1975. Identity, abundance and present status of populations of white whales, *Delphinapterus leucas*, in North America. *J. Fish. Res. Bd. Can.* 32(7): 1047-54.

Sergeant, D.E. 1980. *Levels of Mercury and Organochlorine Residues in Tissues of Sea Mammals from the St. Lawrence Estuary.* International council for the Exploration of the Sea, Copenhagen. C.M. 1970/E: 55.

Sergeant, D.E. 1986. Present status of white whales (*Delphinapterus leucas*) in the St. Lawrence Estuary. *Le Naturaliste Canadien* 113: 61-81.

Sergy, G.A. 1986. *The Baffin Island Oil Spill Project.* Environment Canada, Conservation and Protection, Environmental Protection, Edmonton. 28p.

Sergy, G.A. 1987a. *Recommendation on Aquatic Biological Tests and Procedures for Environmental Protection, Conservation and Protection,* Environment Canada. Environment Canada, Ottawa. 102p.

Sergy, G.A. (ed.). 1987b. *Arctic: Journal of the Arctic Institute of North America* 40(Supp. 1): 1-276 (Special Issue on Baffin Island Oil Spill Project).

Shearer, R.G., R. Haggett and M. Bourque. 1985. *Beaufort Sea 1984 Shoreline Drift Waste Survey.* Environment Canada, Environmental Protection Service, N.W.T. District Office, Yellowknife, N.W.T.

Shearer, R.G. and M. Bourque. 1987. *Beaufort Sea 1985 Shoreline Drift Waste Survey.* Environment Canada, Environmental Protection Service, N.W.T. District Office, Yellowknife, N.W.T.

Sheppard, E.P. 1988. Production of Hibernia oil. An environmental analysis. *Newfoundland Lifestyle* 6(5): 23-30.

Simms, G.G., J.R. Campbell, F. Zemlyak and J.M. Graham. 1977. Organochlorine residues in fish and fishery products from the Northwest Atlantic. *Bull. Environ. Contam. Toxicol.* 18: 697-705.

Simon, A.W. 1978. *The Thin Edge.* Harper and Row/Avon Books, New York. 191p.

Sims, G.G., J.R. Campbell, F. Zemlyak, J.M. Graham. 1977. Organochlorine residues in fish and fishery products from the Northwest Atlantic. *Bull. Environ. Contam. Toxicol.* 18: 697-705.

Sirota, G.R., J.F. Uthe, D.G. Robinson and C.J. Musial. 1984. *Polycyclic aromatic hydrocarbons in american lobster (Homarus americanus) and blue mussels (Mytilus edulis) collected in the area of Sydney, Nova Scotia.* Can. MS Rep. Fish. Aquat. Sci. 1758. 22p.

Smillie, R.D. 1976. *Trace Concentrations of Organochlorines from Waters of the Gulf of St. Lawrence.* Bedford Institute of Oceanography, Dartmouth, N.S. Report BI-R-76-18. 6 p.

Smith, J.N. and D.H. Loring. 1981. Geochronology for mercury pollution in the sediments of the Saguenay Fjord, Quebec. *Environ. Sci. Tech.* 15(8): 944-951.

Smith, J.N. 1988. Chapter VIII. Pollution history and paleoclimate signals in sediments of the Saguenay Fjord. In: *Chemical Oceanography of the Gulf of St. Lawrence.* P.M. Strain (ed.). Department of Fisheries and Oceans, Ottawa. *Can. Bull. Fish. Aquat. Sci.* 220: 123-38.

Sprague, J.B. and J.R. Duffy. 1971. DDT residues in Canadian Atlantic fishes and shellfishes in 1967. *J. Fish. Res. Bd. Can.* 28: 59-64.

Sprague, J.B. and A.G. Colodey. 1989. *Toxicity to Aquatic Organisms of Organochlorine Substances in Kraft Mill Effluents.* Background report for Environment Canada, Ottawa, IP-100.

Standing Committee on the Fraser River Estuary Water Quality Plan. 1987. *Status Report on Water Quality in the Fraser River Estuary – 1987.* Fraser River Estuary Management Program, Government of Canada and Province of British Columbia, Vancouver.

Stanley and Associates and Dobrocky Seatech Limited. 1987. *Sewage Discharges into the Arctic Marine Environment.* Report prepared for Indian and Northern Affairs Canada, Yellowknife, N.W.T.

Statistics Canada. 1986. *Human Activity and the Environment: a statistical compendium*. 2nd Edition. Statistics Canada, Structural Analysis Division, Analytical Studies Branch, Ottawa. 374p.

Strain, P.M. (ed.). 1988. *Chemical Oceanography of the Gulf of St. Lawrence*. Department of Fisheries and Oceans, Ottawa. Can. Bull. Fish. Aquat. Sci. 220.

Struzik, E. 1989. Arctic oases: exploring the secrets of the mysterious ice holes called polynyas. *Equinox* 48: 38-49.

Sullivan, D.L. 1983. *Marine Environmental Surveillance Monitoring at British Columbia South Coast Pulp Mills 1981-82*. Environment Canada, Environmental Protection Service, Pacific and Yukon Region, Vancouver, Regional Program Report 83-17.

Sullivan, D.L. 1987. *Compilation and Assessment of Research Monitoring and Dumping Information in Active Dump Sites in British Columbia and Yukon Coasts from 1979 to 1987*. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Manuscript Report 87-02.

Sutterlin, N. (ed.). 1978. Recovery potential of oiled marine northern environments. *Special Issue. J. Fish. Res. Bd. Can.* 35(5): 499-795.

Taylor, D.A., M.G. Reed, B.D. Smiley and G.S. Floyd. 1985. *Arctic Industrial Activities Compilation. Volume 1: Beaufort Sea: Marine Dredging Activities 1959 to 1982*. Can. Data Rep. Hydrog. Ocean Sci. 32.

Tetra Tech Inc., 1986. *Development of Sediment Quality Values. Final Report, Puget Sound Dredged Spill Disposal Program*. Report prepared for EPA, NOAA, Washington State Department of Ecology and Department of Natural Resources, Seattle.

Thomas, D.J. and M.C. Hamilton. In Preparation. *The Tuktoyaktuk Harbour, Northwest Territories. Benthic Biological Monitoring Program: Hydrocarbon Effects*. Report prepared by Seakem Oceanography Limited and LGL Limited for Environment Canada, Conservation and Protection, Environmental Protection, Northwest Territories, N.W.T. District Office, Yellowknife, N.W.T.

Thomas, D.J. 1978. *Tingmiark K-91 and Kopanoar D-14: A chemical study one year after the occurrence of the water flow, July 1978*. Report prepared by Seakem Oceanography Limited for Canmar Marine Drilling, Calgary, Alberta.

Thomas, D.J., R.W. Macdonald and A.B. Cornford. 1982. *Arctic Data Compilation and Appraisal. Volume 2: Beaufort Sea: Chemical Oceanography*. Can. Data Rep. Hydrog. Ocean Sci. 5.

Thomas, D.J., P.E. Erikson and J.D. Popham. 1983a. *Chemical and Biological Studies at Strathcona Sound, Northwest Territories, 1982: Final Report*. Report prepared by Arctic Laboratories Limited for Indian and Northern Affairs Canada, Northern Affairs Program, Yellowknife, N.W.T.

Thomas, D.J., P.F. Wainwright, B.D. Arner and W.H. Coedy. 1983b. *Beaufort Sea Coastal Sediment Reconnaissance Survey: a data report on 1982 geochemical and biological sampling*. Report prepared by Arctic Laboratories Limited, Inuvik, N.W.T. and Environment Canada, Environmental Protection Service, Yellowknife, N.W.T.

Thomas, D.J., G.D. Greene, W.S. Duval, K.C. Milne and M.S. Hutcheson. 1983c. *Offshore Oil and Gas Production Waste Characteristics, Treatment Methods, Biological Effects and Their Application to Canadian Regions*. Report prepared for Environment Canada, Environmental Protection Service, Ottawa.

Thomas, D.J., L.C. Martin and J.P. Ruffell. 1985. *Environmental Assessment of Dredging Technology*. Report prepared by Arctic Laboratories Ltd., ESL Environmental Services Ltd. and EBA Engineering Consultants Ltd. for Environment Canada, Environmental Protection, Yellowknife, N.W.T.

Thomas, D.J., R.W. Macdonald and A.B. Cornford. 1986a (in preparation). *Geochemical mass balance calculations for the coastal Beaufort Sea, Northwest Territories, Canada.*

Thomas, D.J., W.S. Duval and W.E. Cross. 1986b. *Development of a Monitoring Programme for Contaminants in Tuktoyaktuk Harbour, Northwest Territories: Final Report*. Report prepared for Environment Canada, Conservation and Protection, Environmental Protection, Yellowknife, N.W.T.

Thomas, M.L.H. (ed.). 1983. *Marine and Coastal Systems of the Quoddy Region, New Brunswick*. Can. Spec. Publ. Fish. Aquat. Sci. 64. 306p.

Thompson, J., R.W. McDonald and C.S. Wong. 1980. Mercury geochemistry in sediment of a contaminated fjord in coastal British Columbia. *Geochem. J.* 17: 71-82.

Thompson, J.A.J., M.G. Sheffer, R.C. Pierce, Y.K. Chau, J.J. Cooney, W.R. Cullen and R.J. Maguire. 1985. *Organotin Compounds in the Aquatic Environment: scientific criteria for assessing their effects on environmental quality*. National Research Council of Canada, Associate Committee on Scientific Criteria for Environmental Quality, Report NRCC No. 22494. 284p.

Thompson, J.A.J., M.D. Nassichuk, D.W. Patton, B.J. Reid and M.A. Farrell. 1986. *Examination of Tissue Metal Burdens and Metal-Binding Proteins in the King Crab (Lithodes aequispina Benedict) from Alice Arm and Hastings Arm, British Columbia*. Can. Tech. Rep. Fish. Aquat. Sci. 1440. 44 pp.

Thurston, H. 1990. *Tidal Life. A Natural History of the Bay of Fundy*. Camden House Publishers, Camden East, Ont. 167p.

Tremblay, G.H. and C. Gobeil. 1990. Dissolved arsenic in the St. Lawrence Estuary and the Saguenay Fjord, Canada. *Mar. Pollut. Bull.* 21(10): 465-469.

Turney, L., W.J. McDonald, T. Sackmann and E. Svendsen. 1986. *Compilation of Historical Drill Waste Data Associated with Exploratory Drilling in the Canadian Beaufort Sea, Arctic Islands and Davis Strait (1976-1985)*. Report prepared by ESL Environmental Sciences Limited for Fisheries and Oceans Canada, Indian and Northern Affairs Canada, Environment Canada and Canada Oil and Gas Lands Administration, Ottawa.

Twitchell, K. 1991. The not-so pristine Arctic. *Canadian Geographic* 111(1): 53-60.

United Nations Environment Program. 1985. Protection of the marine environment against pollution from land-based sources. Montreal Guidelines. *Environ. Policy and Law* 14(2/3): 77-83.

Uthe, J.F. and C.L. Chou. 1985. *Studies on cadmium in sea scallops (Placopecten magellanicus) from clean and contaminated areas*. International Council for the Exploration of the Sea, Copenhagen. C.M. 1985/E: 2. 8p.

Uthe, J.F. and C.L. Chou. 1985. *Cadmium in american lobster (Homarus americanus) from the area of Belledune Harbour, New Brunswick, Canada – a summary of five year study*. Can. Tech. Rep. Fish. Aquat. Sci. 1342. 20p.

Uthe, J.F. and C.J. Musial. 1986. Polycyclic aromatic hydrocarbon contamination of american lobster (*Homarus americanus*) in the proximity of a coal-coking plant. *Bull. Environ. Contam. Toxicol.* 37: 730-38.

Uthe, J.F., C.L. Chou, D.H. Loring, R.T.T. Rantala, J.M. Bewers, J. Dalziel, P.A. Yeats and R.L. Charron. 1986. Effect of waste treatment at a lead smelter on cadmium levels in american lobster (*Homarus americanus*), sediments and seawater in the adjacent coastal zone. *Mar. Poll. Bull.* 17(3): 118-23.

Uthe, J.F. and C.L. Chou. 1987. Cadmium in sea scallop (*Placopecten magellanicus*) tissues from clean and contaminated areas. *Can. J. Fish. Aquat. Sci.* 44: 91-98.

Uthe, J.F. and V. Zitko. 1988. An overview of marine environmental quality issues on the Atlantic coast of Canada. In: *Canadian Conference on Marine Environmental Quality: Proceedings*. Halifax, N.S., 29 February - 3 March 1988. P.G. Wells and J. Gratwick (eds.). International Institute for Transportation and Ocean Policy Studies, Halifax. pp. 199-208.

Uthe, J.F., C.L. Chou, N.J. Prouse and C.J. Musial. 1989. Heavy metal, polycyclic aromatic hydrocarbon, and polychlorinated biphenyl concentrations in american lobsters (*Homarus americanus*) from Halifax Harbour. In: *Investigations of Marine Environmental Quality in Halifax Harbour*. H.B. Nicholls (ed.). Can. Tech. Rep. Fish. Aquat. Sci. 1693.

Vandermeulen, J.H. 1989. *PAH and Heavy Metal Pollution of the Sydney Estuary: summary and review of studies to 1987*. Can. Tech. Rep. Hydrog. Ocean Sci. 108. 48p.

Van Dusen, K. and A.C. Johnson Hayden. 1989. *The Gulf of Maine. Sustaining Our Common Heritage*. Maine State Planning Office, Augusta, Maine. 63p.

Verrall, R. 1981. Acoustic transmission losses and ambient noise in Parry Channel. In: *The Question of Sound from Icebreaker Operation: Proceedings of a Workshop, 23-24 February 1981*. Arctic Pilot Project, Petro-Canada Limited, Calgary, Alberta. pp. 220-33.

Vladykov, V.D. 1944. Studies of aquatic mammals. III. Hunting, biology and economic value of the white whale or beluga (*Delphinapterus leucas*) in the St. Lawrence River and Gulf. *Contributions of the Department of Fisheries Quebec* 14: 5-194. Can. Trans. Fish. Aquat. Sci. 4739.

Wagemann, R. and D.C.G. Muir. 1984. *Concentrations of Heavy Metals and Organochlorines in Marine Mammals of Northern Waters: overview and evaluation*. Department of Fisheries and Oceans, Winnipeg, Manitoba. Can. Tech. Rep. Fish. Aquat. Sci. 1279.

Waldichuk, M. and R.J. Buchanan. 1980. *Significance of Environmental Changes due to Mine Waste Disposal into Rupert Inlet*. (Canada) Department of Fisheries and Oceans and British Columbia Ministry of Environment, West Vancouver and Victoria, B.C. 56p.

Waldichuk, M. 1983. Pollution in the Strait of Georgia: a review. *Can. J. Fish. Aquat. Sci.* 40(7): 1142-1167.

Waldichuk, M. 1985. Biological availability of metal to marine organisms. *Mar. Poll. Bull.* 16(1): 7-11.

Waldichuk, M. 1988a. The nature and extent of marine contamination by land-based sources in Canada. In: *Canadian Conference on Marine Environmental Quality: Proceedings*. Halifax, N.S., 29 February - 3 March 1988. P.G. Wells and J. Gratwick (eds.). International Institute for Transportation and Ocean Policy Studies, Halifax. pp. 75-135.

Waldichuk, M. 1988b. Effects of solid wood wastes on marine benthic organisms and habitats. In: *Oceanic Processes in Marine Pollution. Vol. 5. Urban Wastes in Coastal Marine Environments*. D.A. Wolfe and T.P. O'Connor (eds.). Robert E. Krieger Publishing Company, Malabar, Florida, 273p.

Waldichuk, M. 1988c. Alberni Inlet, British Columbia: a multi-use fjord system with fisheries resources and a large waste-disposal component. In: *Proceedings 7th International Ocean Disposal Symposium*, 21-25 September 1987, Wolfville, N.S. Environment Canada, Ottawa. pp. 107-136.

Waldichuk, M. 1989a. Point Grey dumpsites: effects of waste disposal and constraints under Canadian regulations. In: *Oceanic Processes in Marine Pollution. Vol. 4. Scientific Monitoring Strategies for Ocean Waste Disposal.* D.W. Hood, A. Schoener and P.K. Park (eds.). Robert E. Krieger Publishing Company, Malabar, Florida, pp. 187-208.

Waldichuk, M. 1989b. The *Nestucca* oil spill. *Mar. Poll. Bull.* 20(9): 419-420.

Waldichuk, M. 1989c. Burrard Inlet oil spills. *Mar. Poll. Bull.* 20(9): 423-424.

Waldichuk, M. 1989d. Arctic contaminants. *Mar. Poll. Bull.* 20: 532-533.

Ward, R.E. 1990. Metal concentrations and digestive gland lysosomal stability in mussels from Halifax Inlet, Canada. *Mar. Poll. Bull.* 21(5): 237-240.

Ware, D.M. and R.F. Addison. 1973. PCB residues in plankton from the Gulf of St. Lawrence. *Nature* 246: 219-21.

Waterman, M. 1990. Pollution-prevention tactics in the Gulf of Maine. *EPA Jour.* 16(6): 17-19.

Waters, R.D. 1985. *Initial Environmental Assessment Profile of Vancouver Harbour.* Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Vancouver, Regional Manuscript Report 85-07.

Waters, R.D. 1988. *State of the Environment Data Review and Selection*. Report to Environment Canada, Conservation and Protection, Environmental Protection, Marine Programs, Ottawa (unpublished).

Wedel, H.H. 1990. *NOGAP Programs for IWD in the 1990's*. Strategic Planning Document. Report prepared by Northwind Consultants for Inland Water Directorate, Environment Canada, Yellowknife, N.W.T.

Wells, P.G., R.A. Matheson, D.A. Lord and K.G. Doe. 1979. *Environmental monitoring of the 1978 spruce budworm spray program in New Brunswick, Canada – Field sampling and aquatic toxicity studies with fish*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S. Surveillance Report. EPS-5-AR-79-1. 14p.

Wells, P.G., R.P. Côté, D. Kelley and A. McIver. 1986. Protecting marine environmental quality from land-based pollutants – the role of frameworks, strategies and marine ecotoxicology. In: *Proceedings of the Eighth Canadian Waste Management Conference*. Halifax, Nova Scotia, 3-5 September 1986. pp. 51-72.

Wells, P.G., L. Harding, J. Karau and G. Packman. 1987. Marine environmental quality in Canada. In: *Oceans 87: The Ocean "An International Workplace." Proceedings. Volume 5*. Marine Technology Society and IEEE Ocean Engineering Society, Halifax, N.S., 28 September - 1 October 1987. pp. 1633-36.

Wells, P.G. 1988. Introduction: marine environmental quality in Canada – background and objectives of the Halifax Conference 1988. In: *Canadian Conference on Marine*

Environmental Quality: Proceedings. Halifax, N.S., 29 February - 3 March 1988. P.G. Wells and J. Gratwick (eds.). International Institute for Transportation and Ocean Policy Studies, Halifax. pp. 3-5.

Wells, P.G. and J. Gratwick (eds.). 1988. *Canadian Conference on Marine Environmental Quality: Proceedings*. Halifax, Nova Scotia, 29 February - 3 March 1988. International Institute for Transportation and Ocean Policy Studies, Halifax. 320p.

Wells, P.G. and R.P. Côté. 1988. Protecting marine environmental quality from land-based pollutants. The strategic role of ecotoxicology. *Marine Policy* 12(1): 9-21.

Whitehead, P.E. 1989. Toxic chemicals in Great Blue Heron (*Ardea Herodias*) eggs in the Strait of Georgia. In: *The Ecology and Status of Marine and Shoreline Birds in the Strait of Georgia, British Columbia*. K. Vermeer and R.W. Butler (eds.). Proceedings of a Symposium sponsored by the Pacific Northwest Bird and Mammal Society and the Canadian Wildlife Service, Sidney, B.C., 11 December 1987. Environment Canada, Canadian Wildlife Service, Ottawa. Spec. Publ. Can. Wildl. Serv. pp. 177-183.

Wilson, R.C.H., I.C. Travers and Ian Campbell. 1976. *Mercury in the Atlantic Provinces: A Report to the Atlantic Regional Board Executive Fisheries and the Environment*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S., Surveillance Report. EPS-5-AR-77-10. 49p.

Wilson, R.C.H., P.B. Eaton, S.E. Hall and H.H. Stone. 1980. *Environmental Quality in the Atlantic Provinces 1979*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth, N.S.

Wilson, R.C.H. and R.F. Addison (eds.). 1984. *Health of the Northwest Atlantic: A Report to the Interdepartmental Committee on Environmental Issues*. Environment Canada, Department of Fisheries and Oceans, Department of Energy, Mines and Resources, Ottawa. 174p.

Wiltshire, J.F. 1978. *Investigation of PCB contamination of marine sediments associated with fish plant operations in southern Nova Scotia*. Environment Canada, Environmental Protection Service, Atlantic Region, Dartmouth. EPS-5-AR-78-8.

Wong, C.S., W.J. Cretney, P. Christensen and R.W. Macdonald. 1976. *Hydrocarbon Levels in the Marine Environment of the Southern Beaufort Sea*. Technical Report No. 38. Beaufort Sea Project, Department of the Environment, Victoria, B.C.

Wong, M.P. 1986. *Chemical residues in fish and wildlife harvested in Northern Canada*. Indian and Northern Affairs Canada, Northern Affairs Program, Northern Environment Directorate, Ottawa, Environmental Studies No. 46.

World Commission on Environment and Development. 1987. *Our Common Future*. Oxford University Press, New York. 400p.

Wright, J.L.C., R.K. Boyd, A.S.W. de Freitas, M. Falk, R.A. Foxall, W.D. Jamieson, M.V. Laycock, A.W. McCulloch, A.G. McInnes, P. Odense, V.P. Pathak, M.A. Quilliam, M.A. Ragan, P.G. Sim, P. Thibault, J.A. Walter, M. Gilgan, D.J.A. Richard and D. Dewar. 1989. Identification of domoic acid, a neuroexcitatory amino acid, in toxic mussels from eastern Prince Edward Island. *Can. J. Chem.* 67:481-490.

Yeats, P.A. and D.H. Loring. 1988. Dissolved and particulate metal distributions in the St. Lawrence estuary. Abstract of paper presented at *International Symposium on the Fate and Effects of Toxic Chemicals in Large Rivers and their Estuaries*, Quebec City, P.Q., October 1988. Canada Centre for Inland Waters, Burlington, Ontario (unpublished).

Zitko, V. 1971. Polychlorinated biphenyls and organochlorine pesticides in some freshwater and marine fishes. *Bull. Environ. Contam. Toxicol.* 6: 464-70.

Zitko, V. and P.M.K. Choi. 1971. *PCB and Other Industrial Halogenated Hydrocarbons in the Environment*. Fish. Res. Board Can. Tech. Rep. 272, Biological Station, St. Andrews, N.B.

Zitko, V., O. Hutzinger, W.D. Jamieson and P.M.K. Choi. 1972. Polychlorinated terphenyls in the environment. *Bull. Environ. Contam. Toxicol.* 7(4): 200-201.

Zitko, V., P.M.K. Choi, D.J. Wildish, C.F. Monaghan and N.A. Lister. 1974. The distribution of PCB and p,p'-DDE residues in Atlantic herring (*Clupea harengus harengus*) and yellow perch (*Perca flavescens*) in eastern Canada-1972. *Pestic. Monit. J.* 8: 105-109.

Zitko, V. 1976. Levels of chlorinated hydrocarbons in eggs of Double-crested Cormorants from 1971 to 1975. *Bull. Environ. Contam. Toxicol.* 16(4): 399-405.

Zitko, V. 1978. Nonachlor and chlordane in aquatic fauna. *Chemosphere* 1: 3-7.

Zitko, V. 1980. *PCBs and Other Organochlorine Compounds in Sharks and Tunas.* International Council for Exploration of the Sea, Copenhagen. Marine Environmental Quality Committee C.M. 1980/E: 21. 10p.

Zitko, V. 1988. Environmental impact of organic chemicals. In: *Environmental Protection of the North Sea.* International Technical Conference, London, 24-27 March 1987. P.J. Newman and A.R. Agg (eds.). Heinemann Prof. Publishers, Oxford, U.K. pp. 41-65.

Glossary

Absorption	Disappearance through incorporation in something else.
Acute	Having a sudden onset, lasting a short time. Can be used to define either the exposure or the response to an exposure (effect).
Adsorption	The retention of gases, dissolved materials, or ions on the surface of solid particles, including organisms and substrates.
Anadromous Fish	Fish species which ascend freshwater streams from the ocean to spawn (e.g., salmon).
Anthropogenic	Created by humans.
Aquaculture	Cultivation of fish, molluscs, and other aquatic organisms in fresh or salt water (estuaries and bays) for human consumption.
Arctic Haze	Suspended air particles, primarily sulphates, originating from industrial activities in Europe, the Asiatic USSR and, to a lesser extent, southern portions of North America, which reduces visibility to 30 km or less in winter months.
Bathymetry	The measurement of ocean depths to determine the sea floor topography.
Beneficiation	Improving the chemical or physical properties of raw ore so that the metal can be recovered at a profit.
Benthos	All marine organisms living on or in the bottom of the sea.
Berm	A layer of large rock or other relatively heavy, stable material placed at the outside bottom of the artificial islands to increase its stability.
Bioaccumulation	The process by which chemicals are taken up by organisms from air or water directly or through the consumption of food leading to a concentration of the substance in organism tissues.
Bioassay	The employment of living organisms to determine the biological effect of some substance, factor or condition.
Bioavailability	That portion of a chemical compound or element that can be taken up readily by living organisms.
Bioconcentration	Ability of organisms to selectively accumulate certain chemicals, elements or substances within its body or within certain cells. A process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (i.e., by gill) and elimination.
Biogenic	Essential to the maintenance of life or that produced by the actions of living organisms.

Biological Oxygen Demand (BOD/BOD5) Measure of oxygen depletion of water due to bacterial decay of organic pollutants. Gives an indication of how much organic matter is in the water.

Biomagnification Buildup of contaminants in organisms in successively higher trophic levels.

Biomass As measured by ecologists, the dried weight of all organic matter in the ecosystem. In the energy field, any form of organic matter (from both plants and animals) from which energy can be derived by burning or bioconversion such as fermentation.

Biome Major biotic units characterized by plant and animal communities having similarities in form and environmental conditions. For example, one of several immense terrestrial regions, each characterized throughout its extent by similar plants, animals, climate, and soil type.

Biota Collectively, the plants, micro-organisms, and animals of a region.

Bloom A relatively high concentration of phytoplankton in a body of water as a result of proliferation during favourable growing conditions generated by nutrient or sunlight availability which is readily visible.

Carcinogen A chemical or physical agent that causes cancer to develop, often decades after the original exposure.

Cetaceans Members of the mammalian order *Cetacea*, including whales, dolphins and porpoises.

Chemical Oxygen Demand (COD) A measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water. The COD test is used to determine the degree of pollution in an effluent.

Chlorophenols A group of toxic chemicals created by the chlorination of phenols. Used as preservatives in paints, drilling muds, photographic solutions, hides and leathers, and textiles. Also used as biocides, herbicides, and insecticides, and most commonly, for wood preservation.

Chlorophenates (CP/PCP/TTCP) Neutralized chlorophenols.

Chronic A stimulus that is lingering or of long duration, for example, a chronic toxicity test is equivalent to a long-term toxicity test.

Coal Tar A tar obtained from carbonization of coal, usually in coke ovens or retorts, containing several hundred organic chemicals.

Coastal The region extending seaward and inland from the shoreline that is influenced by and exerts an influence on the uses of the seas and their resources and biota.

Coke Oven A closed refractory chamber, or retort, in which coal is converted to coke by carbonization.

Coliform A group of bacteria used as an indicator of sanitary quality in water. The total coliform group is an indicator of sanitary significance because the organisms are usually present in large numbers in the intestinal tracts of humans and other warm-blooded animals, and exposure to them in drinking water causes diseases such as cholera.

Congener Belonging to the same genus, kind or race; allied in nature or origin.

Contaminant Any physical, chemical or biological substance which is introduced into the environment. Does not imply an effect (see *Pollution*). Usually refers to man-made substances.

Criterion (water quality) An estimate of the concentration of a chemical or other constituent in water which if not exceeded, will not harm an organism, an organism community, or a prescribed water use or quality with an adequate degree of safety. Term is also used in some countries to describe the scientific data and information used for deriving an environmental limit, guideline, or objective.

Crustaceans A class of arthropods which breathes by means of gills or similar structures and have bodies which are covered by a hard shell or crust (e.g., crabs, lobsters, shrimps, barnacles).

DDT An organochlorine insecticide used first to control malaria-carrying mosquitos and lice and later to control a variety of insect pests, but now banned in some countries because of its persistence in the environment, its ability to bioaccumulate, and its high toxicity. Dichlorodiphenyltrichloroethane.

Depuration A process that results in elimination of a material from an aquatic organism.

Dioxins A family of 75 related chemical compounds known as polychlorinated dibenzo-*p*-dioxins, largely formed as by-products in the manufacture of other chemicals. Sources include municipal incinerators, wood waste, slash burning, fuel wood burning, motor vehicles, forest fires, some herbicides, the wood preservative pentachlorophenol (PCP), and sewage sludge. Some are hazardous to humans at low levels.

Dredge Spoil Sediments and materials removed from the seabed as a result of dredging activity.

Drilling Mud A suspension of finely divided heavy material containing chemicals such as bentonite and barite, pumped through the drill pipe during rotary drilling to seal off porous zones and flush out chippings, and to lubricate and cool the drill bit.

Drilling Cuttings	Cuttings of rock and other subterranean materials brought to the surface during the drilling of well holes.
Echolocation	An auditory feedback mechanism, in bats, porpoises, seals and certain other animals, whereby reflected ultrasonic sounds are utilized in orientation.
Ecology	Study of living organisms and their relationships to one another and the environment.
Ecosystem	The physical and chemical environment of a community of organisms, and all the interactions between those organisms and between organisms and their environment. Also, a community of organisms occupying a given region within a biome.
Ecotoxicology	The study of the fate and effects of pollutants in natural ecosystems or its components (individuals, populations, communities).
Effluent	A complex waste material which is a by-product of human activity (i.e., liquid industrial discharge or sewage) which may be discharged into the environment.
Elevated Levels	Levels which are significantly higher statistically than those occurring naturally.
Endangered Species	A plant, animal or microorganism that is in immediate danger of biological extinction (see *Threatened and Rare Species*).
Environmental Impact Assessment	Formal process or document prepared primarily to identify potential impacts of proposed laws or projects that may affect the environment.
Environmental Quality	The condition of an environment (air, land, water, including biota) measured relative to each intended use for specific portions of the environment. It is usually assessed against objectives and limits set by environmental and resource agencies, but it often includes subjective perceptions of what is considered desirable or acceptable.
Epibenthic	Organisms living near or upon the sea floor.
Estuary	That portion of a coastal stream influenced by the tides of the body of water into which it flows where salt and fresh waters mix, such as inlets or mouths of rivers.
Eulachons	An anadromous smelt species (*Thaleichtys pacificus*) found only on the west coast of North America. Utilized commercially as human food and as food for fur-bearing mammals.
Fjord	A long, deep, narrow arm of sea between high cliffs.
Flux	The amount of some quantity flowing across a given area per unit of time.

Food Chain
A specific nutrient and energy pathway in ecosystems proceeding from producer to consumer.

Food Web
Complex intermeshing of individual food chains in an ecosystem.

Furans
A similar family to dioxins, furans or polychlorinated dibenzofurans contain 135 related chemical compounds. Found in many of the same sources as dioxins, through similar processes.

Geoduck
A large edible clam (*Glycineris generosa*) from the Pacific coast.

Guideline
Directing principle for action. Also, environmental guidelines are numerical concentrations or narrative statements recommended to support and maintain a designated use, e.g., water use.

Habitat
A geographic area that can provide for the key activities of life.

Halocline
A well-defined vertical gradient of salinity in the oceans and seas.

Hazardous Waste
Any harmful solid, liquid or gaseous waste product of manufacturing or other human activities which by its nature is inherently dangerous to handle or dispose of.

Heavy Metals
Metallic elements with relatively high atomic weights (5.0 specific gravity), such as lead, cadmium, arsenic, and mercury. Generally toxic in relatively low concentrations to plant and animal life.

Hydrocarbons
Organic molecules containing hydrogen and carbon. Major components of petroleum released during the incomplete combustion of organic fuels, they react with nitrogen oxides and sunlight to form photochemical oxidants in photochemical smog.

Inorganic
Matter other than plant or animal, and not containing a combination of carbon/hydrogen/oxygen as in living things.

Invertebrates
Animals without internal skeletal structure. Range from protozoans to sea squirts, and include insects, molluscs and crayfish.

Isomer
One of two or more chemical substances having the same molecular weight and percentage elementary composition but differing in structure and properties.

Kraft Pulp Mill
Produces paper made primarily from wood pulp produced by the sulphite pulping process (sodium sulphite is used in the caustic soda pulp digesting liquor). Produces comparatively unbleached, coarse paper of great strength.

LC50 — The median lethal concentration, that is, the concentration of a chemical which is lethal to 50 percent of the exposed test organisms within a designated time, usually one to four days.

Leachate — Liquids that have percolated through a soil and that contain substances in solution or suspension.

Littoral — Of or pertaining to a shore, especially a seashore; the specific zone of the sea floor lying between tide levels.

Loading — Addition of organic wastes to soils at such a rate as to benefit plant growth and help to meet fertility requirements of a particular water body or soil; the quantity of waste added that would not tax the ability of the water body or soil to degrade and assimilate the waste nor to contribute to environmental degradation.

Long-range trans-boundary air pollution — Transport of air-borne contaminants and pollutants between adjacent geographical areas.

Marine Environment — The maritime area extending, in the case of watercourses, up to the freshwater limit and including intertidal zones and the shoreline, estuary, bay, harbour, nearshore and offshore waters.

Marine Environmental Quality — The condition of a marine environment measured relative to each intended use of that environment, assessed against objectives and limits set by agencies and subjective perceptions.

Marine Mammals — Animals of the class *Mammalia* having mammae for nourishment of young, e.g., whales, seals, polar bears, and living in or depending upon the sea.

Monitoring — Testing on a routine basis, with some degree of control, to ensure that the quality of water or effluent has not exceeded some prescribed criteria range.

Nearshore — The zone extending seaward from the shore to a distance where the water column is under minimal influence from continental conditions.

Nitrous Oxide — A gas formed in great part from atmospheric nitrogen and oxygen when combustion takes place in high temperatures and pressure; while not a pollutant, it converts to nitrogen dioxide which is a major constituent of photochemical smog and acid rain.

Non-point Source Pollution — Diffuse source of pollution such as an eroding field, urban and suburban lands, and forests.

Nutrients (as pollution) — Elements or compounds essential as raw materials for organic growth and development such as carbon, oxygen, nitrogen, and phosphorous.

Objective
Point or thing aimed at. Environmentally, an objective is an numerical concentration or narrative statement which has been established to support and protect the designated uses of water at a specified site.

Oceanography
The scientific study and exploration of the oceans and seas in all their aspects, including all processes in the oceans and interactions and relations with earth and the universe.

Offshore
The comparatively flat zone of variable width extending from the outer margin of the shoreface to the edge of the continental shelf.

Organic
Of chemical compounds based on carbon chains or rings, and also containing hydrogen with or without oxygen, nitrogen or other elements.

Organochlorine/ organohalogen
A chlorine containing hydrocarbon, in some cases containing oxygen and other elements such as phosphorus. Includes many pesticides and industrial chemicals.

Organotins
Chemicals with 1 to 4 carbon atoms covalently bonded to the tin atom. A powerful biocidal agent against a wide spectrum of fouling and boring organisms (mainly as tributyltins). Large-scale use in marine antifouling paints, as preservatives, plastic stabilizers and in lubricants. Difficult to control leaching in aquatic environment. High toxicity to all marine organisms.

Paralytic Shellfish Poisoning (PSP)
Poisoning caused by a naturally occurring organism produced by the dinoflagellate *Alexandrium excavata* (microscopic planktonic organism) which "blooms" in warm weather to create "red tides." These wash shellfish beds and the shellfish accumulate the poison as they strain the water.

Parts per billion (ppb)
One unit of chemical (usually expressed as mass) per 1,000,000,000 units of the medium (e.g., water) or organism (e.g., tissue) in which it is contained. For water, the ratio commonly used is micrograms of chemical per litre of water, $1 \mu g/L = 1$ ppb; for tissues, $1 \mu g/kg = 1$ $ng/g = 1$ ppb.

Parts per million (ppm)
One unit of chemical (usually expressed as mass) per 1,000,000 units of the medium (e.g., water) or organism (e.g., tissue) in which it is contained. For water, the ratio commonly used is milligrams of chemical per litre of water, $1 mg/L = 1$ ppm; for tissues, $1 mg/kg = 1 \mu g/g = 1$ ppm.

Parts per thousand (ppt) One unit of chemical (usually expressed as mass) per 1,000 units of the medium (e.g., water) or organism (e.g., tissue) in which it is contained. For water, the ratio commonly used is grams of chemical per litre of water, 1 g/L = 1 ppt; for tissues, 1 g/kg = 1 ppt.

Phthalate Ester Any group of plastics or plasticizers made by the direct action of alcohol on phthalic anhydride; generally characterized by moderate cost, good stability and good general properties.

Point-source Pollution Easily discernible stationary source of pollution such as a factory.

Pollution The introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as to harm living resources and marine life, be hazardous to human health, hinder marine activities, including fishing and other marine uses, or impair the quality of sea water and reduce amenities.

Polychlorinated biphenyls (PCBs) Group of at least 50 different chlorinated organic compounds, that are non-corroding and resistant to heat and biological degradation. They were used for many years as insulation in electrical equipment. Capable of biomagnification. Disrupts reproduction in gulls and possibly other organisms high on the food chain.

Polycyclic Aromatic Hydrocarbons (PAHs) Among the oldest known carcinogens in humans, PAHs are released into the environment from atmospheric emissions, especially the burning of fossil fuels. Sources include thermal power plants, coke ovens, sewage, wood smoke, and used lubricating oils.

Polynya A water area, other than a lead, lane or crack, which is surrounded by sea ice.

Population A group of organisms of the same species living within a specified region.

Primary Wastewater Treatment First step in sewage treatment to remove large solid objects by screens (filters) and sediment and organic matter in settling chambers. See *Secondary and Tertiary Wastewater Treatment.*

Propeller Cavitation The formation of vapour or gas-filled cavities in water or on the surface of a rotating propeller occurring when the pressure falls below the vapour pressure of water thus creating noise which is transmitted through the water column.

Rare Species Not endangered but, because of small population size, is at risk of becoming endangered.

Recolonization Reappearance of a population of organisms in a given location or habitat.

Red Tide A reddish discolouration of coastal surface waters due to concentrations of certain toxin-producing dinoflagellates (microscopic planktonic organisms) and often a cause of major fish kills and paralytic shellfish poisoning.

Secondary Wastewater Treatment After primary treatment, removal of biodegradable organic matter from sewage using bacteria and other microorganisms, inactivated sludge or trickle filters. Also removes some of the phosphorus (30%) and nitrate (50%). See *Primary and Tertiary Wastewater Treatment.*

Sediment Soil particles, sand and other mineral or organic matter eroded from land and carried in surface waters.

Sessile Organisms fixed in one position to a substrate and immobile.

Shellfish An aquatic invertebrate, such as a mollusc or crustacean, that has a shell or exoskeleton. Usually refers to molluscs such as clams, mussels, and quahogs.

Siltation Sediments deposited by water in channels, harbours, etc.

Species A group of plants, animals or microorganisms that have a high degree of similarity and generally can interbreed only among themselves.

Standard The limiting concentration of a chemical or degree of intensity of some other adverse condition, e.g., pH, which is permitted in an effluent or waterway. Standards are established for regulatory purposes and are determined from a judgement of the criteria involved and are dependent upon the use of the water to be protected.

Substrate (Biological) Base of substance upon which an organism is growing; (Chemical) a substance undergoing oxidization; (Hydrological) the bottom material of a waterway.

Sulphite Pulp Mill Wood chips digested with a solution of magnesium, ammonium or calcium bisulphate, with free sulphur dioxide present. Used to make paper and paper products from spruce or coniferous woods.

Sulphur Oxides Sulphur dioxide and sulphur trioxide, common air pollutants arising from combustion of coal, oil, gasoline, and diesel fuel. Also produced by natural sources such as bacterial decay and hot springs. Sulphur dioxide reacts with oxygen to form sulphur trioxide, which may react with water to form sulphuric acid.

Surfactant A material that facilitates and accentuates the emulsifying, dispersing, spreading, wetting and other surface-modifying properties of substances (herbicide formulation).

Suspended Solids Any solid substance present in water in an undissolved state, usually contributing directly to turbidity.

Tailings Second grade or waste rock fragments derived from screening or processing of raw ores.

Teleost Fish Fish species distinguished by paired bracing bones in the support of skeleton and caudal fin.

Teratogen A chemical or physical agent capable of causing developmental and birth defects.

Tertiary Wastewater Treatment Removal of nitrates, phosphates, chlorinated compounds, salts, acids, metals, and toxic organics after secondary treatment. See *Primary and Secondary Wastewater Treatment.*

Threatened Species Plant, animal or microorganisms which are abundant in parts of their range but are severely depleted in others.

Toxicity The inherent potential or capacity of a material to cause adverse effects in a living organism.

Trophic Relating to processes of energy and nutrient transfer from one or more organisms to others in an ecosystem.

Turbidity The cloudy conditions caused by suspended solids in liquid.

Uptake A process by which materials are transferred into and onto an aquatic organism.

Waste Material that has no original value or no value for the ordinary or main purpose of manufacture or use; damaged or defective articles of manufacture; or superfluous or rejected matter or refuse.

Wastewater Water that carries wastes from homes, businesses, and industries; a mixture of water and dissolved or suspended solids.

Water Quality Guideline Numerical concentration limit or narrative statement recommended to support and maintain a designated water use.

Water Quality Objective Numerical concentration limit or narrative statement which has been negotiated to support and protect the designated uses of water at a specified site.

Water Quality Standard An objective that is recognized in enforceable environmental control laws of a level of government.

Wetlands Land areas along fresh and salt water (coastal wetlands, such as salt marshes, tidal basins, and mangrove swamps) that are flooded all or part of the time.