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A Review of the Major Marine Environmental Concerns Off the Canadian East Coast in the 1980s

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A REVIEW OF THE MAJOR MARINE ENVIRONMENTAL CONCERNS OFF THE CANADIAN EAST COAST IN THE 1980s

by

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ABSTRACT

Harding, G.C. 1992. A review of the major marine environmental concerns off the Canadian East Coast in the 1980s. Can. Tech. Rep. Fish. Aquat. Sci. 1885: vi + 38 p.

The most serious changes mankind may create inadvertently in the coming decades are known by the terms "greenhouse effect" and "ozone hole." The greenhouse effect could shift Canada's temperate flora and fauna, including Canada's productive East Coast fisheries, further north where the continental shelf space is more restricted and cause inundation and erosion of low-lying areas such as parts of Prince Edward Island. It would alter the way we seek a livelihood but would not be directly life threatening. The harmful effects of increased ultraviolet radiation, from reductions in the stratospheric ozone layer, are far more alarming if continued at the present rate. Marine life, with the exception of those organisms living at the sea surface, is less vulnerable to genetic damage than are their terrestrial counterparts because of the rapid absorption of ultraviolet rays in seawater.

The way fishery resources are harvested must have profound effects on the ecosystem that supports them, although we are unable, at present, to apportion anthropogenic and natural effects. The fishing industry affects the bottom habitat, alters the species composition by favouring so-called "trash" fish, and possibly favours size selection of commercial species. Aquaculture is the most promising approach to increase Canada's marine food requirements in the future with only a localized effect on the environment. Hydroelectric development may have altered marine biological production, but more directed research is needed to assess the problem. Causeway construction has had negative effects on the marine environment but of a very localized nature. Offshore exploration for oil and gas reserves on the East Coast has had no observed adverse effects on the ecosystem to date, although the possibility always exists for an environmental catastrophe if an oil well blows out or a nautical accident occurs.

Some types of pollution are widespread; but most pollutants are concentrated where they are produced, generally close to highly populated areas. The St. Lawrence estuary, not surprisingly, is the most polluted region on the East Coast, although there are a number of trouble spots associated with the larger population centres such as Saint John, N.B., Halifax, N.S., and St. John's, Nfld., harbours. Specific industries located along the Atlantic Coast, such as pulp and paper mills, fish- and food-processing plants, aluminum- and lead-smelting plants, chlor-alkali plants, and a steel mill, have polluted local environments more than have other activities. Those industries located in embayments with restricted water exchange, such as the Saguenay Fjord, P.Q., Belledune Harbour, N.B., and Sydney Harbour, N.S., have caused the most serious environmental problems. Organic and nutrient enrichment and viral, bacterial, and chemical contaminants are the major forms of pollutants from both municipal and industrial effluents. Fecal bacteria and perhaps nutrient enrichment are the most serious obstacles to the expansion of Canada's prosperous aquaculture industry. Progress is being made more quickly in reducing emissions of some forms of pollutants than others. Concentrations of some organochlorines, heavy metals, and organotins have levelled off in marine organisms due to bans or effluent restrictions in the 1970s and 1980s. The legislation necessary to restrict pollutants emitted from smoke stacks, such as nitrous oxide, sulphur dioxide, mercury, lead, dioxins, and polycyclic aromatic hydrocarbons, is slow to come.

RÉSUMÉ

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Les changements les plus graves que l'humanité risque de créer par inadvertance dans les décennies à venir sont désignés sous les noms d'«effet de serre» et de «trou de la couche d'ozone». L'effet de serre pourrait déplacer notre flore et notre faune de climat tempéré, y compris les stocks de poisson productifs de la côte est, vers le nord, là ou le plateau continental présente un espace resteint, ce qui risquerait d'entraîner des inondations et un phénomène d'érosion dans les terres basses, notamment dans certaines parties de l'Île-du-Prince-Édouard. Quoiqu'il nous forcerait à trouver de nouveaux moyens de subsistance, ce changement ne menacerait pas directement nos vies. En revanche, les effets nuisibles de l'accroissement des rayons ultraviolets dû à la diminution de la couche d'ozone stratosphérique, s'ils se poursuivent au rythme actuel, sont beaucoup plus alarmants. Les organismes marins, à l'exception de ceux qui vivent à la surface de l'océan, sont cependant moins susceptibles d'en subir les répercussions génétiques que les organismes terrestres, en raison de l'absorption rapide des rayons ultraviolets par l'eau de mer.

La façon dont les ressources halieutiques sont récoltées doit avoir des effets profonds sur l'écosystème qui les fait vivre, bien que nous soyions dans l'impossibilité de déterminer actuellement dans quelles proportions respectives ces effets sont anthropiques ou naturels. L'industrie de la pêche perturbe l'habitat benthique, modifie la composition de la population de poissons en favorisant la prédominance des poissons dits «sans valeur» et encourage peut-être même la sélection des espèces commerciales selon la taille. L'aquiculture est le moyen le plus prometteur d'augmenter à l'avenir notre quantité de produits alimentaires d'origine marine. De plus, ses effets sur l'environnement sont localisés. Les aménagements hydro-électriques ont pu nuire à la production biologique marine, mais des recherches plus directes sont nécessaires pour le déterminer précisément. Pour sa part, la construction de chaussées a eu des effets négatifs sur le milieu marin, mais très localisés. La prospection du pétrole et du gaz extracôtiers sur la côte est n'a pas eu de répercussions néfastes sur l'écosystème jusqu'ici, quoique la possibilité d'une catastrophe environnementale due à l'explosion d'un puits ou à un accident en mer existe toujours.

Certaines formes de pollution sont très étendues, mais la plupart des polluants restent concentrés là où ils sont produits, généralement à proximité des régions très peuplées. L'estuaire du Saint-Laurent, cela n'a rien d'étonnant, est l'endroit le plus pollué de la côte est, bien que des problèmes de pollution se présentent aussi ailleurs, dans des centres populeux comme les ports de Saint John (N.-B.), Halifax (N.-É.) et St. John's (T.-N.). Certaines industries de la côte Atlantique, notamment des usines de pâtes et papier, des usines de transformation du poisson et d'autres aliments, des fonderies d'aluminium et de plomb, des fabriques de chlore et de soude caustique ainsi qu'une aciérie, ont plus que d'autres pollué l'environnement local. Ce sont les industries qui sont situées dans des baies à circulation d'eau limitée, comme le fjord Saguenay, au Québec, le port de Belledune, au Nouveau-Brunswick et le port de Sydney, en Nouvelle-Écosse, qui ont créé le plus de pollution. L'enrichissement en matières organiques et nutritives ainsi que les contaminants viraux, bactériens et chimiques provenant des effluents municipaux et industriels sont les principales causes de pollution. Les bactéries fécales et peut-être l'enrichissement en matières nutritives sont les obstacles les plus graves à l'expansion d'une industrie aquicole

prospère. On parvient plus rapidement à réduire les émissions de certains types de polluants que d'autres. Ainsi, les concentrations de certains organochlorés, métaux lourds et composés organostanniques dans les organismes marins se sont stabilisées par suite des interdictions ou des restrictions sur la décharge d'effluents imposées dans les années 70 et 80. En revanche, la législation nécessaire pour restreindre l'émission de polluants émanant des cheminées, comme l'oxyde nitreux, l'anhydride sulfureux, le mercure, le plomb, les dioxines et les hydrocarbures aromatiques polycycliques, tarde à venir.

INTRODUCTION

It has been difficult to evaluate the effects of mankind on the marine environment with any certainty because so little is known about natural causes of variation in marine ecosystems. In this report, I describe briefly Canada's East Coast environment, as it is presently understood, and then discuss the major environmental concerns of the 1980s and at the present time. More general topics of widespread importance, such as particular classes of toxic chemicals and effects of "greenhouse" gasses and ozone depletion, are considered first. This is followed by more-specific problems of a more-localized nature such as municipal, industrial, and resource wastes; effects of dredging and dumping at sea; effects of human harvesting of renewable resources; effects of hydroelectric and coastal development on marine ecosystems; effects of inadvertent species introductions, including fish diseases; and the problem of litter. The approach taken is necessarily very general, but hopefully the references given will provide one wishing greater detail with a quick access into present concerns about the East Coast environment.

NATURAL ENVIRONMENTAL FEATURES OF THE EAST COAST

The East Coast of Canada extends from the Gulf of Maine to the northern tip of Labrador - a shoreline distance of approximately 10,000 km (Fig. 1). The federal government of Canada extended jurisdiction over the fisheries offshore to 200 naut. mi. (370 km) in 1977 which includes most of the continental shelf, with the exception of the "nose" and "tail" of the Grand Banks and the Flemish Cap. The continental shelf extends ~200 km off Nova Scotia, ~500 km on the Grand Banks, then narrows to less than 200 km along the Labrador coast. The bathymetry of the region is highly complex. The water depths range between 75 and 250 m on the shelf and extend to over 300 m in the Laurentian and Fundian Channels and in the Labrador Marginal trough.

The coastlines along Canada's East Coast are submerging, with the exception of Québec, Labrador, and parts of Newfoundland which are isostatically rebounding from the last ice age (Egginton and Andrews 1989). Tidal measurements taken continuously at Halifax, N.S., since 1920 confirm that this coastline is submerging at the rate of 0.4 m every 100 yr. On a global scale, the activities of mankind are increasing the carbon dioxide and methane content of the atmosphere at an increasing rate, and this is predicted to alter the climate of the world by reducing back radiation of heat energy into space (Schneider 1989; Crutzen 1991). The greenhouse effect is also predicted to increase temperatures disproportionately toward higher latitudes in the northern hemisphere (Stouffer et al. 1989). A conservative estimate is that an additional increase in sea level of $0.4 \text{ m} \cdot 100 \text{ yr}^{-1}$ is expected as a result of global warming by greenhouse gases (Egginton and Andrews 1989). If this occurs, some of the low-lying coastline of Eastern Canada will be inundated with severe erosion occurring in regions with unconsolidated sediments.

The oceanography of the East Coast is dominated by cold, low-saline water generally flowing southward along the continental shelf and is known as the Baffin Land and Labrador Currents north of Newfoundland (Sutcliffe et al. 1983; Greenberg and Petrie 1988). This shelf water mixes with freshwater along the way, chiefly from the Hudson Bay and St. Lawrence River drainage basins, continues as a residual surface flow southwest along the Scotian Shelf, and retains its identity well into the Gulf of Maine at mid-depths (Sutcliffe et al. 1976; Smith and Schwing 1991). Shelf water, extending from

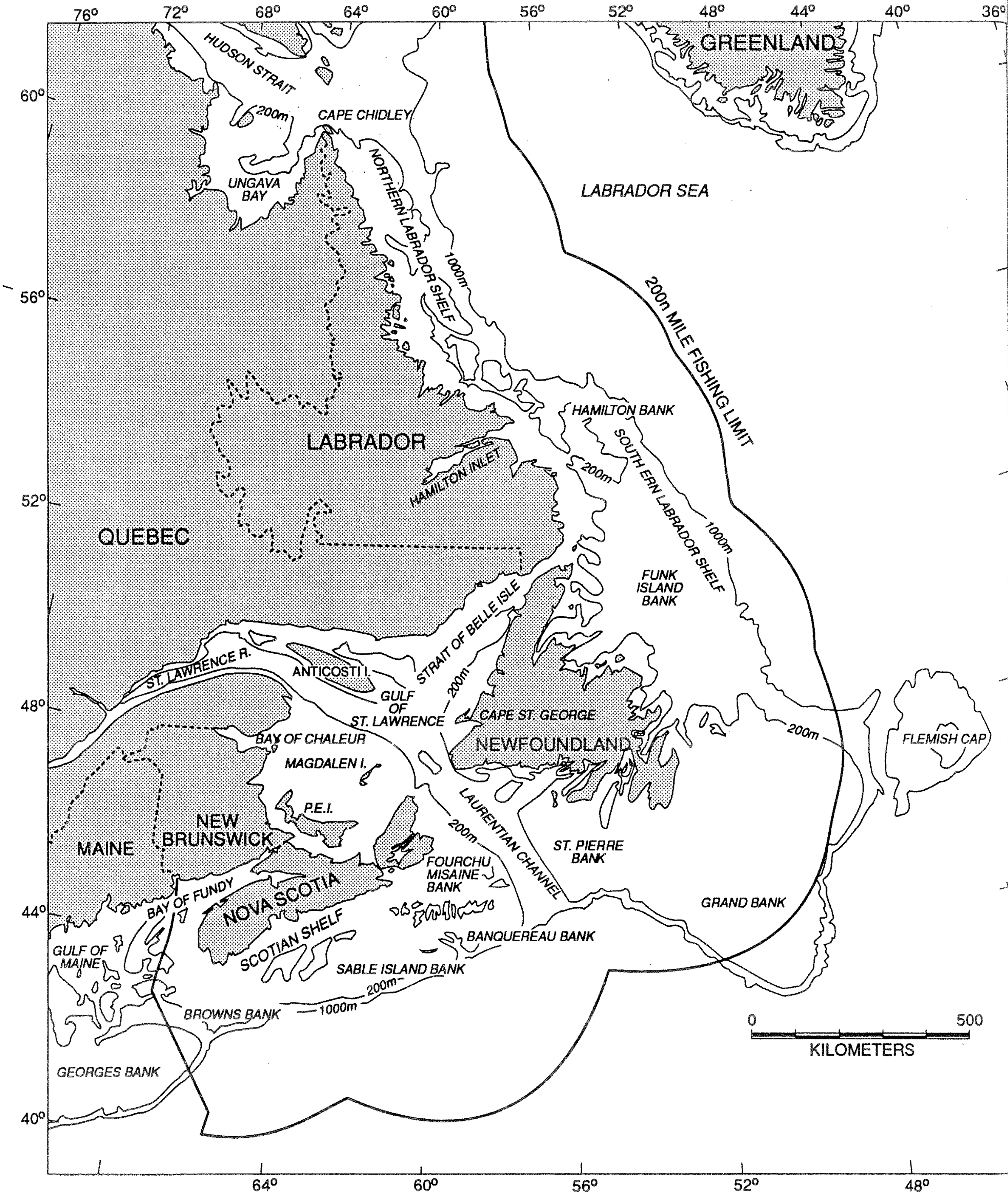

Fig. 1. Physiography of the East Coast of Canada.

the Grand Banks to Browns Bank off Nova Scotia, mixes with warm saline water brought north from the subtropics by the Gulf Stream to form the Slope Water beyond the Shelf break.

The East Coast is dominated by a continental climate with extremes of cold winters and warm summers (Isemer and Hasse 1985; 1987). In winter, low-pressure zones, often stalling for days, pass through the area from the direction of the Great Lakes or along the United States seaboard. Prevailing winds of 18 to 24 knots blow from the northwest and north, while prevailing summer winds generally come from a southwesterly direction with mean speeds of 10 to 14 knots. The interaction of atmospheric and oceanographic circulation results in extreme geographic gradients and seasonal changes in the important physical variables on the East Coast. Sea-surface temperature variability is dominated by the seasonal cycle, with the average difference between the coldest (March) and warmest (August) months, ranging from 4°C just south of Cape Farewell, Greenland, to 17°C on the Scotian Shelf. The water temperature also varies with depth. A major feature of the water column in the summer is the presence of a temperature inversion at mid-depths, if water depths are sufficient for the intrusion of warmer water from the Atlantic Ocean along the bottom. The cold intermediate layer is formed locally at the sea surface in the winter, following the turnover of the water column, by atmospheric cooling. Each summer, surface stratification reoccurs due to the combined factors of reduced salinity from freshwater runoff and melting ice, and solar heating.

Twice-daily observations of surface temperature at St. Andrews, N.B., which began in 1921, form the longest continuous data series along the Canadian Atlantic Coast. Compared to the annual mean temperature for all years (7.1°C), temperatures were below average from the 1920s to the mid-1940s, followed by a 20-yr period of above-normal values (Fig. 2). Subsequently, the trend appears to be repeating itself with below-average surface temperatures in the late 1960s followed by variable but above-average temperatures in the 1970s and early 1980s. Past changes in sea temperature are known to have displaced the geographic centres of commercially important fish species north or south (Dunbar and Thomson 1979; Frank et al. 1988). An anticipated 4°C rise in sea-surface temperature in the next century because of greenhouse gases should result in major alterations in marine ecosystems such that southern, less commercially valuable fish species would proliferate on Canada's rich offshore banks.

The annual temperature anomalies north and south of Yarmouth, N.S., tended to be out of phase during the last warm cycle, 1972 to 1989 (Drinkwater and Trites 1991). This is based on the analysis of sea-surface temperature from 24 subareas of the northwestern Atlantic, extending from Cape Hatteras, U.S.A., to southern Greenland. Surface temperatures north and south of Yarmouth were above and below average between 1976 to 1984 and 1987 to 1988, respectively. Thompson et al. (1988) propose that most of this observed temperature variability in the North Atlantic can be explained by winter heat exchange with the atmosphere.

Mean annual freshwater runoff is also a result of atmospheric weather patterns. The discharge from the St. Lawrence River remains well above average (1.02×10^4 $m^3 \cdot s^{-1}$) since the 1970s, although it is presently less than the record levels attained in the mid-1970s (Fig. 3). This increased flow should slightly decrease salinities as far as the Scotian Shelf (see Sutcliffe et al. 1976; Koslow et al. 1986). It is projected that the overall effect on the marine ecosystem would be to stimulate primary production in the immediate vicinity of the St. Lawrence estuary and in the Gaspé Current through nutrient entrainment (Therriault and Levasseur 1986). However, increased freshwater

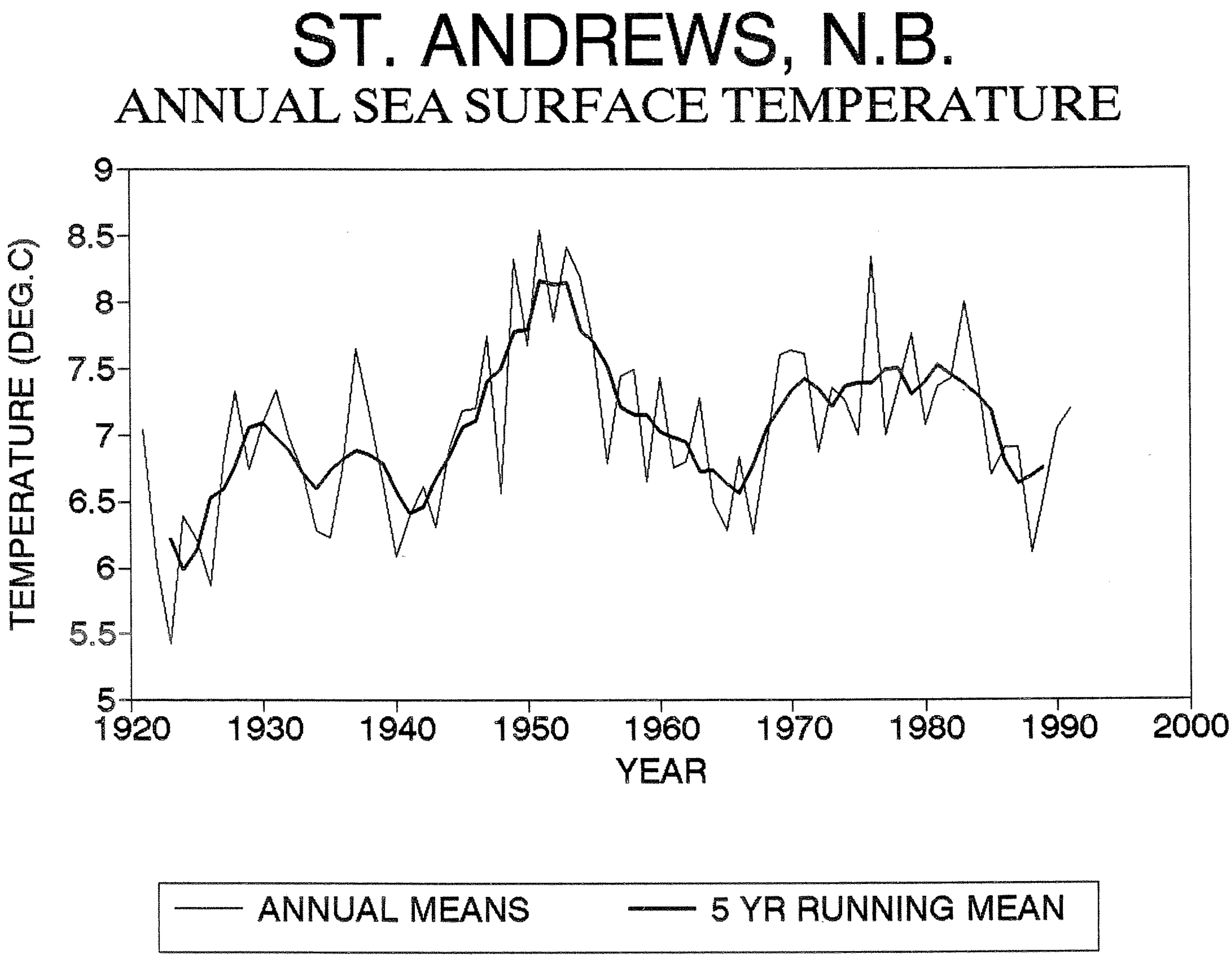

Fig. 2. Sea surface temperature recorded at St. Andrews, N.B. (K. Drinkwater, Department of Fisheries and Oceans, Dartmouth, N.S.).

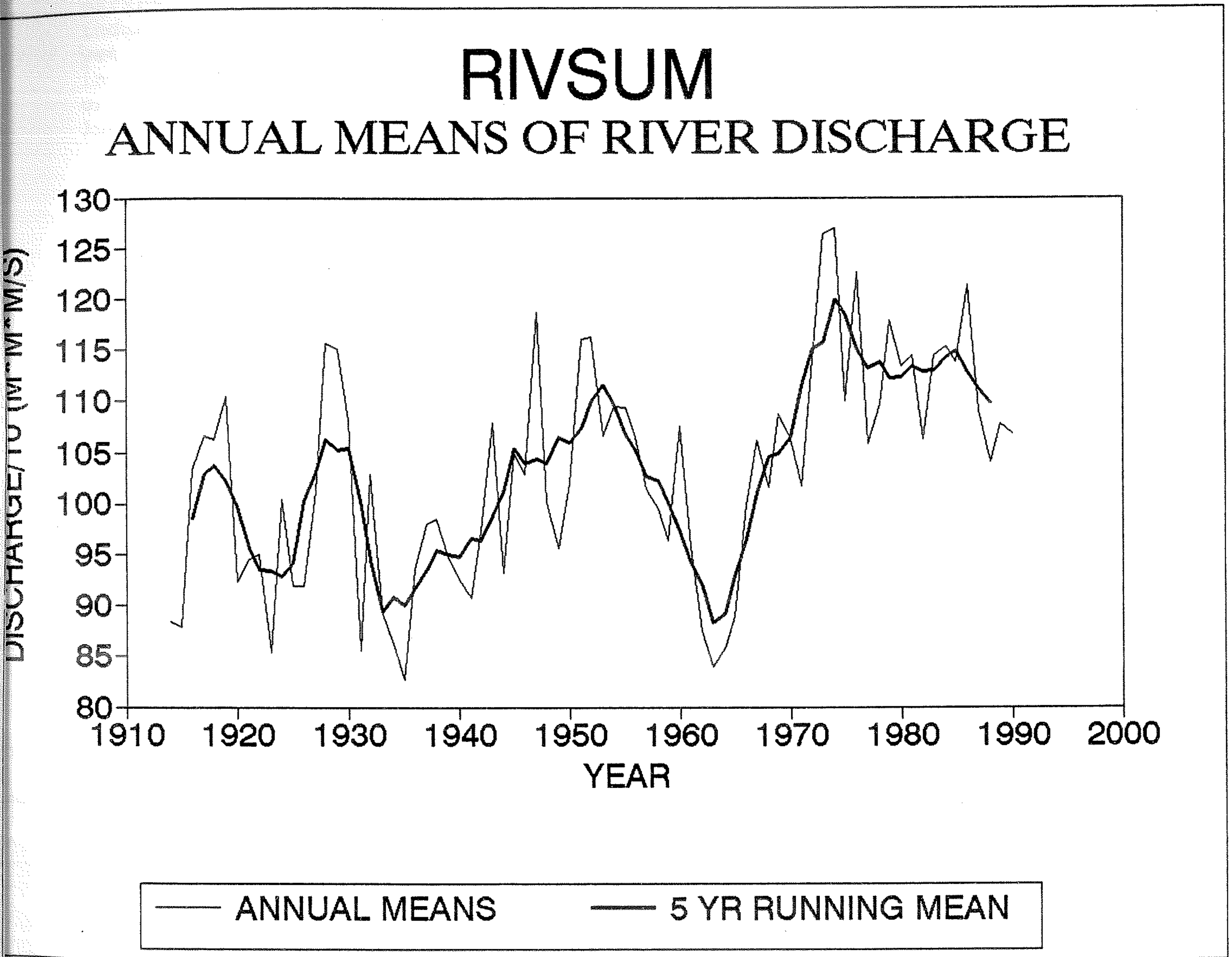

Fig. 3. St. Lawrence River discharge volume (K. Drinkwater, Department of Fisheries and Oceans, Dartmouth, N.S.).

runoff could have the opposite effect on phytoplankton populations further downstream in the southern Gulf of St. Lawrence where a more diffuse residual flow under more-stratified conditions would reduce nutrient flux into the surface waters (see Bugden et al. 1982).

Nitrogen in the form of nitrate, nitrite, or ammonia, rapidly becomes the limiting nutrient for plant growth once sufficient light levels and water-column stability are established in the spring. The other essential nutrients - phosphate and silicate - also decline to seasonal low levels between May and August, but both are present in excess of demand (Subba Rao and Smith 1987).

Many physical and chemical properties of the marine environment are modified by organisms, and this interaction determines the type of marine community which ultimately succeeds in any particular region. Gradual interannual changes in the functioning of biological communities in response to a variable environment are what concern us here, although seasonal changes, related chiefly to the solar cycle, dominate. Temperature, salinity, nutrients, turbidity, wind field, and bottom depth are the most important variables controlling water movement and biological productivity. The production of surface waters, together with the type of bottom substrate, has the strongest influence on the bottom community. Organic input or energy available are thought to determine the size of demersal fish populations and the benthic faunal community that can be supported (Rowe 1971; Hargrave and Phillips 1986). Currents and turbulence near the bottom determine whether this sedimenting material is deposited and gradually decomposed anaerobically or is recycled more rapidly by aerobic microorganisms on resuspension.

Many regions with high phytoplankton production are not necessarily located over areas of deposition where plant detritus, which fuels the bottom community, accumulates. Turbulent waters over much of Canada's East Coast continental shelves, banks, and shallow embayments, such as the southern Gulf of St. Lawrence, Scotian Shelf, Bay of Fundy, Ungava Bay, etc., keep the "rain" of organic detritus intermittently resuspended. This material is gradually displaced and settles in deeper waters off the continental shelf or over continental basins and channels (Pocklington 1988; Grant et al. 1987).

Conditions for sustained moderate-to-high productivity exist along the Atlantic Coast in deep estuaries with strong freshwater outflow, along lee shores and on offshore banks and other locations where nutrients essential for plant growth are upwelled from subsurface waters. Equally important for sustained plant growth is that the depth of the upper mixed layer does not greatly exceed light penetration or the photic zone. The most important fisheries resources of the Atlantic Coast coincide with or are slightly "downstream" from these productive regions (see Scarratt 1982). Foremost of these regions are the mouth of the Bay of Fundy, southwestern Nova Scotia, Georges Bank, Scotian Shelf and Slope, parts of the southern Gulf of St. Lawrence, St. Pierre Bank to the southeastern edge of Grand Banks, the eastern coast of Newfoundland, and Hamilton Bank.

ANTHROPOGENIC INFLUENCES ON THE EAST COAST

HALOGENATED HYDROCARBONS

In addition to these natural fluctuations there are the recent and increasingly deleterious effects of human populations and industrial growth. By far the more worrisome effects are from synthetic chemicals in Canada's wastes which are not readily broken down and are quite toxic to marine life.

Some halogenated hydrocarbons are produced for their toxic properties, such as the DDT, cyclodiene, HCH, polychlorocamphene insecticide groups, pentachlorophenol (PCP), whereas others have miscellaneous industrial usage as lubricants, etc., such as polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB) (Goldberg 1991; Mes et al. 1991; Morita 1991). Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are unintentional by-products of waste incineration and industrial processes (Tanabe 1988; Bellin and Barnes 1991). Chlorinated compounds such as polychlorinated terphenyls (PCTs), chlorobiphenyl derivatives, chlorinated paraffins, and many other polyhalogenated organics have been produced for industrial use or as by-products of process or waste treatment but have not yet been reported in the environment. This may be due to their recent introduction, the fact that they are expensive and time consuming to detect, or the lack of scientists qualified to work on analysis problems (Addison 1982; Harding 1986; Muir et al. 1988).

Chlorinated hydrocarbons are lipophilic, relatively insoluble in seawater, and extremely resistant to chemical or microbial degradation. These properties were responsible for the observed biomagnification in the food web of the southern Gulf of St. Lawrence during the late 1970s: from 1 to 20 ppt (pg PCBs/mL) in unfiltered seawater, to 1 to 10 ppb (wet) in plankton, to ~200 ppb (wet) in mackerel. PCBs were introduced in the late 1920s and reached maximum production for industry in the late 1960s and early 1970s, but most countries had drastically reduced production by the late 1970s (Bletchley 1984). All non-electrical uses of PCBs were banned in Canada in 1976. PCBs in zooplankton from the southern Gulf of St. Lawrence declined sharply during the 1970s, but levels have since stabilized at approximately 4 ng/g wet weight. In a temporal study of PCB, α-HCH, and HCB levels in the livers of cod from the southern Gulf of St. Lawrence, significant declines in PCB, from 1.88 to 1.45 $\mu g \cdot g$ wet^{-1} (geometric means) and HCB, from 42.8 to 21.4 ng $\cdot$ g wet^{-1}, concentrations were observed between 1977 and 1985 (Misra and Uthe 1987; Misra et al. 1989).

The recovery of the breeding gannet population on Bonaventure Island, P.Q., in the Gulf of St. Lawrence by 1984, from their conspicuously reduced abundance in the mid-1970s, coincides with the exponential decline of s-DDT, dieldrin, PCBs, HCB, cis-chlordane, cis-nonachlor, and oxychlordane residues in their eggs and presumably in their food (Noble and Elliott 1986; Chapdelaine et al. 1987; Elliott et al. 1988). It is thought that DDE-induced egg-shell thinning and the combined embryotoxicity of organochlorine residues could have substantially contributed to the low hatching success documented between 1966 and 1974 (Chapdelaine et al. 1987). Heptachlor epoxide and α-HCH residues in gannet eggs have remained between 20-50 ng $\cdot$ g wet^{-1} throughout this period (Noble and Elliott 1986; Elliott et al. 1988).

POLYCYCLIC AROMATIC HYDROCARBONS

Polycyclic aromatic hydrocarbons (PAHs) are another group of compounds which are of environmental concern because some of them are carcinogenic. PAHs are produced by the combustion of all organic materials, including forest fires; but the chief source is through the combustion of fossil fuels, specifically coal (Eaton et al. 1986). PAH emissions condense on soot and other atmospheric particles and are precipitated at various distances from the source or through direct industrial discharge to fresh or salt water. By far the greatest quantities of PAHs produced in North America are released to the atmosphere. Long-range transport results in deposition of only a few nanograms of PAH per square centimetre each year, which is extremely difficult to measure directly (Eisenreich et al. 1981). Shellfish surveys in the Gulf of St. Lawrence indicate that PAH levels there are generally low; however, there are presently two known problem spots in Atlantic Canada: at Sydney Harbour, N.S. (Sirota et al. 1984; Uthe and Musial 1986), and at the Saguenay River, P.Q. (Cossa et al. 1983).

TRIBUTYLTINS

Tributyltins (TBTs), the most toxic of the organotin compounds, have been detected or measured in significant quantities in both seawater (<20 $ng \cdot L^{-1}$) and sediment (<10-140 $ng \cdot g\ dry^{-1}$) of various harbours along the Atlantic Coast of Canada (Maguire et al. 1986). TBTs are acutely toxic to marine invertebrates, such as copepods, bivalve larvae, and crab and lobster larvae, at levels between 0.1-5 $\mu g \cdot L^{-1}$ (U'ren 1983; Beaumont and Budd 1984; Laughlin and French 1984). High levels of methyltin (2-17 $\mu g \cdot g\ dry^{-1}$) were found also in sediments from several harbours in New Brunswick (Maguire et al. 1986).

The most likely sources of the organotins found in the marine environment are from antifouling paints on boat and ship hulls, preservatives used on docks and lobster traps, and antifouling agents used on fish aquaculture pens (Maguire 1987; Kieley 1989). Land-based uses such as wood preservatives, pesticides, fungicides in the textile industry, and slimicides for the cooling water of pulp and paper mills could also be important locally (Kieley 1989). TBTs are bioconcentrated and known to affect reproduction, growth, and survival in shellfish at levels currently found in polluted harbours (see Alzieu et al. 1989) and therefore are of concern to Canada's expanding aquaculture industry. TBT concentrations were measured in mussels collected in the late 1980s from Halifax Harbour (107 ± 43 $ng \cdot g\ wet^{-1}$), salmon aquaculture sites in Bras D'or Lakes, N.S., and Lime Kiln Bay, N.B. (165 ± 149 $ng \cdot g\ wet^{-1}$), pleasure craft harbours along the southern shore of Nova Scotia (53 ± 34 $ng \cdot g\ wet^{-1}$), and control sites along the eastern shore of Nova Scotia (<2 $ng \cdot g\ wet^{-1}$), although water levels were below 25 $ng \cdot L^{-1}$ (W.R. Ernst [Environment Canada], pers. comm.). Agriculture Canada prohibited the use of TBT antifouling net dips used in the aquaculture industry in 1987 and disallowed the continued use of TBT lobster trap preservatives in 1988 (Kieley 1989). From December 31, 1989, all antifouling paints had to be registered with Agriculture Canada for private use, and it was only permissible to use TBT-based paints on commercial vessels longer than 25 m if the release rates were less than 4 mg TBT $\cdot\ cm^{-2} \cdot d^{-1}$ (Agriculture Canada 1989). There is presently an international movement toward the use of TBT-free antifouling coatings in the future on large commercial vessels (Anonymous 1991).

TRACE METALS

Mankind has also introduced trace metals into the marine environment as a direct result of mining, smelting, and general industrialization. The main source on the Atlantic Coast is the St. Lawrence River, with fine-grain sediments serving as the ultimate repository for heavy metals in deeper waters of the Gulf of St. Lawrence (Loring 1988). Metal contamination here, however, is relatively low (10-1,000x) compared to European estuaries, with the exception of mercury, cobalt, nickel, and arsenic (Loring 1988). High levels of lead, zinc, copper, mercury, and cadmium in the parts-per-million range are reported in the upper St. Lawrence estuary (Allan 1988). Sediments in Saguenay Fjord have elevated levels of zinc, lead, and mercury (Smith 1988). Cadmium and zinc levels are elevated in sediments and fauna along the industrialized southern shore of Baie des Chaleurs (Ray et al. 1980; Loring et al. 1980). The lobster fishery was closed in Belledune Harbour, N.B., in 1980 due to high cadmium levels and is restricted to the present day (Uthe et al.

1986). High levels of zinc, copper, and lead are reported variously from Hawes Bay, Tilt Cove, and Botwood which includes the Atlantic and Gulf Coasts of Newfoundland (Barrie 1984). Relative to the less-inhabited bays along the Atlantic Coast, Halifax Harbour has bottom sediments enriched in copper, zinc, lead, and mercury (Buckley and Hargrave 1989). The high levels of dissolved and particulate iron and manganese observed in late summer to early winter in Bedford Basin waters, Halifax Inlet, were attributed to remobilization from anoxic bottom sediments (Dalziel et al. 1991).

RADIOACTIVE INPUTS

Radioactive inputs to Eastern Canada from anthropogenic sources are derived from atmospheric nuclear weapons tests, routine nuclear reactor releases, and long-range atmospheric transport associated with accidents such as the Chernobyl event in the former USSR. In addition to artificially produced radioactivity, there is a broad range of naturally occurring radionuclides which constitutes the overall environmental radiation background. Several longer-lived radioisotopes (>25 yr), such as Cs-137, Sr-90, Pu-239, and Pu-240, have been retained in the environment since their introduction from nuclear weapons tests conducted mainly in the 1950s and 1960s, with smaller quantities introduced in the 1980 Chinese test and the recent breakup of the Russian satellite COSMOS. An atmospheric plume of radioactivity derived from releases from the Chernobyl nuclear reactor accident passed over Eastern Canada between May 7 and June 6, 1986 (Smith and Ellis 1990). Accidents of this nature, however infrequent, will continue to provide inputs of radioactivity to the environment.

GREENHOUSE GASES

The exponential buildup in the global atmosphere of carbon dioxide (CO_2) and other radiatively active gases since industrialization began around 1850 is thought to be one of the paramount environmental problems facing the world today (Oeschger and Siegenthaler 1988; Schneider 1989). Increasing amounts of carbon dioxide (CO_2) and other infrared-absorbing (greenhouse) gases, such as methane (CH_4), nitrous oxide (N_2O), ozone (O_3), chlorofluorocarbons (CFCs), and other hydrocarbons, are being released to the atmosphere by combustion of fossil and organic fuels and other anthropogenic activities (Crutzen 1991; Johnson et al. 1992; Thompson 1992). It is possible that land-clearing and agricultural practices worldwide are also responsible for significantly altering the balance of greenhouse gases in the atmosphere by reducing CO_2 removal through photosynthesis and increasing the decomposition of organics in exposed soil. This observed increase of infrared-absorbing gases released to the troposphere is proposed to be responsible for the measured rise in the world temperature by approximately 0.5°C over the past century (Jones and Wigley 1990). Sea level should also rise as a consequence of global heating due to both thermal expansion of water and melting of glaciers. The results from tidal gauge networks, however, are ambiguous because of local geological and isostatic movements of the Earth's surface and subsidence near cities built on loose sediments (Belperio 1989).

The acceptance of a human-induced greenhouse effect is not universal, with some scientists proposing that global temperatures have not risen as much as expected from modelling studies with observed atmospheric levels of infrared-absorbing gases. This discrepancy in model results has been attributed to a simultaneous increase in industrial sulphur dioxide emissions (Charlson et al. 1992). Particulate sulphate in the troposphere increases, both directly and indirectly (through cloud formation as condensation nuclei), the scattering of incoming shortwave radiation; and this is calculated to be enough to balance the absorbtion of longwave energy by greenhouse gases (Charlson et al. 1992). The changes in planetary albedo due to sulphate particle formation are difficult to model because of their little-known patchy distributions (Falkowski et al. 1992) and non-linear relationships with emissions and particle characteristics (Charlson et al. 1992).

If greenhouse warming occurs or indeed has started to occur, it could compound the problem by reversing the CO_2 flux from the atmosphere to the oceans and increase oceanic and terrestrial methane production from sedimentary deposits (Schneider 1989; Crutzen 1991; Shaver et al. 1992). There are many other uncertainties involved in predicting greenhouse events ranging from specific chemical reactions, biological production, and cloud cover and formation to alteration of ocean circulation and deepwater formation (Gillis 1991; Schneider 1989; Gordon et al. 1992; Thompson 1992). Canada is involved for the next decade in an international study of the flux of CO_2 into the oceans, its utilization by phytoplankton, and its subsequent fate as organic or calcareous materials (Gillis 1991).

As part of the greenhouse effect, it is loosely predicted that along the Atlantic Coast of Canada air temperature and precipitation will increase and become more pronounced north of latitude 45°N, whereas wind speeds will be moderated (see Wright et al. 1986). With these ameliorating conditions, the winter freeze-up and spring breakup of pack ice will be delayed and advanced, respectively, and the Gulf of St. Lawrence may experience winters without ice cover. It is deduced from this that whole marine communities will compensate for the changing environmental conditions by shifting northward either through migration or selective recruitment and that migratory species might arrive north earlier and depart later (Dunbar and Thomson 1979; Frank et al. 1988). The resultant increase in precipitation, runoff, and ice melt should make the buoyancy-driven Labrador Current stronger. Likewise, the enhanced estuarine flow in the Gulf of St. Lawrence should affect the characteristics and flow along the Scotian Shelf, Slope Water formation, and the Gulf of Maine. Perhaps, more importantly, the increased buoyancy input, solar radiation, and reduced wind stress could result in shallower and warmer mixed layers over the continental shelves. It has been argued that this increased stratification could result in an ecosystem shift due to a combination of enhanced microbial activity and nutrient recycling together with reduced sedimentation (Frank et al. 1988). This new ecosystem might be expected to support a largely pelagic, rather than the present demersal, fish community, with an overall reduction in fish production (Frank et al. 1988). All of these changes imply a radical change in life for the Maritime people of Canada.

OZONE DEPLETION

Stratospheric ozone (O_3) absorbs incoming ultraviolet radiation (UV) from the sun, and this protects organisms from the damaging effect of UV radiation on cellular DNA. Photolysis of oxygen (O_2) to atomic oxygen (O) occurs in the stratosphere followed by recombination with O or O_2 to form O_2 or O_3, respectively. The stratosphere is in a dynamic state with O_3 also combining with O to form O_2 (McElroy and Salawitch 1989). Anthropogenic contributions to the stratosphere are altering this dynamic equilibrium. Nitric oxide (NO) released from the exhausts of high-flying supersonic aircraft are believed to be involved in the catalytic sequence (Crutzen 1970):

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O \rightarrow NO + O_2$$

Chlorine (Cl) radicals, derived from industrial chlorofluorocarbons (CFCs), such as C Cl_3 F and C Cl_2 F_2, together with naturally occurring bromine radicals (Br), are similarly known to catalyze the breakdown of ozone (Molina and Rowland 1974).

$$Cl + O_3 \rightarrow Cl\ O + O_2$$
$$Cl\ O + O \rightarrow Cl + O_2$$

Atmospheric circulation plays a large role in determining the global distribution of the ozone layer. Once the polar vortex forms in the winter and cools to -77°C in the absence of solar heating, stratospheric clouds form by heteromolecular HNO_3-H_2O condensation of polar air (Crutzen and Arnold 1986). This removal of HNO_3 into cloud particles activates inert chlorine species (HCl and Cl O NO_2) into photolytically unstable chlorine species (Cl_2, Cl NO_2, and HO Cl) which are transformed into ozone-reactive species (Cl and Cl O) when the rays of the rising sun first enter the polar vortex in spring (Cicerone et al. 1991). Ozone destruction is limited in time because the arrival of sunshine and the breakup of the polar vortex over the North Atlantic occur within weeks of each other (Hofmann et al. 1989). In the past decade, stratospheric ozone levels have dropped 3% over temperate latitudes of North America (Stolarski et al. 1991). Stratospheric ozone was reduced by a record 20% this past spring over Europe (Pearce 1992). The part played by mankind in this reduction is still unclear because a natural cooling trend has coincided with ozone depletion, and other anthropogenic compounds which are beneficial to ozone stabilization have also accumulated in the stratosphere (Schoeberl and Kreuger 1986; McElroy and Salawich 1989).

Solar mid-ultraviolet radiation (UV-B, 280-320 mm), increased by stratospheric ozone depletion, penetrates the upper ~10% of the coastal marine photic zone before it is reduced to 1% of its surface irradiance (Worrest 1982; Helbling et al. 1992). UV penetration in the open ocean would be greater because there are fewer light-absorbing particles present. It has long been known (mid-1920s) that the UV component of sunlight can damage marine organisms. UV light has been shown, recently, to reduce primary production by ~50% in surface water, although the reduction throughout the entire photic zone is closer to 2% (Worrest 1982; Helbling et al. 1992). The community diversity of phytoplankters is decreased by UV radiation because different species are more-or-less vulnerable. Fortunately, little of the ultraviolet energy reaching the sea is in the UV-B spectrum which causes the most inhibition of photosynthesis (Helbling et al. 1992). These factors, in turn, can affect the trophic dynamics of the ecosystem by altering total food availability and prey selection by zooplankters. Likewise, the metabolism, survival, and reproduction of bacterioplankton have been shown to be adversely affected by UV radiation (Worrest 1982). This also has serious consequences for the marine environment, given the predicted future rise in irradiation with further erosion of the ozone layer. Bacterioplankton are responsible for recycling the necessary nutrients for primary production, particularly during periods of water-column stratification. UV-B radiation increases the mortality of copepods and decreases the fecundity of the survivors and their offspring (Dey et al. 1988). Larval stages are more sensitive to UV-B radiation than are older stages. Seasonal congregations of zooplankters near the sea surface, combined with their apparent inability to detect and avoid the lethal effects of UV radiation, make them vulnerable to increasing radiation (Dey et al. 1988). Benthic organisms and fish are likewise adversely affected by ultraviolet radiation. Fish species such as mackerel are particularly vulnerable because their free-floating eggs are buoyant. In conclusion, it is generally understood that potentially the most serious threat of UV radiation to the marine ecosystem is to the primary producers and the necessary bacterioplankters because the phytoplankton requires sunlight to fix energy and must remain in the photic zone.

The Montreal Protocol on Substances that Deplete the Ozone Layer, agreed to in 1987, was recently ratified by more than 40 nations and represents a previously unheralded cooperation of industry and government in response to a global environmental problem. Recent inadequacies of the scientific models used for the 1987 Montreal Protocol have arisen which indicate, together with the discovery of an "ozone hole" over the North Atlantic, that even more stringent action is required.

MUNICIPAL SEWAGE

It is difficult to consider the subject of municipal wastes in isolation because industrial effluents are often discharged in close proximity or through the same sewer systems. It has been shown in Halifax Harbour, however, that copper and mercury enrichment in the bottom sediments, relative to lead and zinc, can be used to distinguish a municipal or domestic source from solid or industrial wastes (Buckley and Hargrave 1989). Domestic wastes cause problems in direct proportion to the types of industries present and the size of the population producing them. The St. Lawrence River drainage basin supports 5.8 million people in Québec, yet only 8% of their municipal wastes undergo some form of treatment (Statistics Canada 1986). Newfoundland has recently constructed municipal sewers but has little treatment of domestic wastes for its 0.5 million people. In New Brunswick and Nova Scotia (1.6 million people), only one-third of the population is serviced by either primary or secondary waste-water treatment (Wells and Rolston 1991). Presently, cities such as Halifax, N.S., are the norm, in that they pour millions of gallons of untreated sewage daily into coastal inlets and bays. Charlottetown, P.E.I., provides an example of the advantages to be gained from installing a sewage-treatment plant. Shellfish harvesting and recreational use have been restored since 1975 in 1,000 ha of its harbour (Eaton et al. 1986).

A major concern of discharging untreated municipal wastes into estuarine and coastal waters is its high organic content which places a strong biological oxygen demand (BOD) on the environment, rendering it unsuitable at the extreme for most aquatic life. The complex mix of domestic and industrial wastes in municipal outfalls results in widespread contamination of estuarine and coastal environments (Allan 1988; Mueller and Anderson 1983), with largely unknown effects on the ecosystem. Equally important are the human pathogens transmitted to coastal waters in domestic wastes. Various bacterial, viral, fungal, and parasitic pathogens make swimming and consumption of shellfish from these areas extremely dangerous to human health (Menon and Klaamas 1984).

Increasing numbers of shellfish-harvesting areas have been closed in the Maritimes since 1940 due to fecal contamination (Menon 1988). This increased volume of municipal wastes in coastal waters presently is limiting the expansion of the lucrative aquaculture business. For example, of the 146 tested sites for which Newfoundland aquaculturalists have applied for permits up to January 1989, 30% were turned down by officials due to high coliform counts (U.P. Williams [Department of Fisheries and Oceans], pers. comm.). Fish plants also require a source of clean water for fish processing, which can be costly if local waters are contaminated by sewage.

There is concern over discharging domestic wastes directly to the marine environment because of its role in the eutrophication of coastal waters. The dinoflagellate *Alexandrium tamarensis*, which causes Paralytic Shellfish Poisoning (PSP), occurs naturally in the lower St. Lawrence estuary near freshwater plumes from northern shore rivers (Therriault and Levasseur 1986). A bloom of this dinoflagellate along the Gaspé coast was suspected to have been caused by increased nutrients from sewage outfalls along the St. Lawrence River (Messieh and El-Sabh 1988). In 1988, PSP toxins, which have never been reported south of the Gaspé peninsula in the Gulf of St. Lawrence, were found in mussels from Baie des Chaleurs, along the northeastern coast of New Brunswick, and northwestern Prince Edward Island. Trites and Drinkwater (1991) applied a circulation model, using residual and wind-driven currents, to demonstrate that an *Alexandrium* bloom originating on the northern Gaspé in certain years could have far-reaching effects on the shellfish aquaculture industry in the western Gulf of St. Lawrence. The large number of shellfish areas closed due to high fecal coliform counts (>14 bacteria/100 mL seawater) provide an indirect measure of the severity of domestic sewage problems in Atlantic Coastal waters (Menon 1988). Disinfection is required after secondary treatment of domestic sewage before it can safely be allowed to enter a shellfish-harvesting area (Menon and Klaamas 1984). An alternative is the construction of an outfall-diffuser system (>5 km from shore) (Mueller and Anderson 1983) which allows greater dilution of pathogens seaward of aquaculture locations.

INDUSTRIAL AND RESOURCE PROCESSING WASTES

Industry generally requires the proximity of large volumes of water and is therefore located along Canada's major water courses. Industrialization is concentrated along the St. Lawrence River and to a lesser extent the Saguenay Fjord, southern Baie des Chaleurs, and the Saint John River. Newcastle, N.B., Sydney, N.S., and Halifax, N.S, are industrialized ports outside this region. Pulp and paper, fish- and food-processing plants, petroleum refineries, coal mining and processing, fossil fuel and nuclear thermal-generating stations, the base metal industry, ore smelting and loading areas, steel manufacture, and the chlor-alkali industry are the major polluters associated with industry on the Atlantic Coast.

Pulp and paper plants discharge large quantities of wood fibre and related organics which can locally smother and asphyxiate marine benthic organisms and alter the species composition of communities by depleting bottom waters of oxygen (McLeay 1987). This can be particularly severe in embayments with limited flushing. The latest fish kill in Boat Harbour, N.S., involving silversides, occurred in late summer of 1991, when the entire embayment became anoxic due to conditions created by organic effluents from the pulp and paper plant (W. Horn [Environment Canada], pers. comm.). After the introduction of the Federal Pulp and Paper Effluent Regulations of the Fisheries Act in 1971, discharges of substances increasing the BOD and suspended solids have steadily declined. Most of the pulp and paper mills in Canada fail acute toxicity tests for fish and are degrading local environments (P.W. Wells [Environment Canada], pers. comm.), although it is not altogether clear how to equate environmental effects to specific or combinations of contaminants when hundreds of compounds are present in pulp mill effluent (Owens 1991). Furthermore, the chlorine bleaching method used in the Kraft and sulphite mills (e.g. in the Miramichi estuary) is causing concern because extremely toxic chlorinated organics, such as dioxins and furans, are being formed (Clement et al. 1987).

Fish- and food-processing plant effluents in general place a high BOD on receiving water without secondary treatment and sometimes contain unacceptable levels of fecal bacteria and chemical contaminants. In Blacks Harbour, N.B., an area of approximately 0.9 km^2, the surface waters can become anoxic when the fish-meal plant is operating during the summer season (Wildish and Zitko

1991). This is particularly worrisome to the salmon aquaculturists in the neighbouring areas, although tidal mixing is thought to be sufficient to dissipate and oxygenate the organic effluent to date (Wildish et al. 1990). The sediments of Petit-de-Grât, N.S., were found to contain up to 20 ppm PCBs ($\mu g \cdot g^{-1}$) adjacent to the fish-meal plant. It was found that fish offal discharged into the harbour was the sole source of PCBs in 1981 although past leakage of plant equipment, when lubricants and hydraulic fluids were known to contain PCBs, could not be ruled out (Ernst et al. 1982).

Petroleum refineries are in general compliance with the 1974 National Petroleum Refining Effluent Regulations and Guidelines of the Fisheries Act. This Act regulates the amount of oil and grease, phenols, sulphide, ammonia nitrogen, total suspended solids, and pH levels, and sets guidelines for acute fish-toxicity limits. In 1987, the four refineries in Atlantic Canada were within federal guidelines between 70% and 100% of the time. However, the amount of each category of pollutant released increased between 1983 and 1987 due to increased production (Losier 1989). Bioassay data for 1986 to 1987 indicate that the Irving Oil refinery in Saint John, N.B., violated the federal toxicity criteria one-third of the time. Refineries are also significant airborne sources of carcinogenic PAHs and contribute to the acid rain problem.

The number of reported oil and other hazardous material spills has steadily increased over the 1974 to 1988 interval, and most of these occurred during transportation. Almost 20 yr after the vessel ARROW disaster in Chedabucto Bay, N.S., Bunker C tar still persists and is available to intertidal biota in mud flats of protected embayments (J.H. Vandermeulen [Department of Fisheries and Oceans], pers. comm.). Oil spills are likely to occur where ships refuel, and this could result in tainting of commercial shellfish to make them unmarketable (Williams et al. 1989). The lobster fishery in neighbouring Cape Breton, N.S., was not affected by tainting following the breakup of the KURDISTAN oil tanker in 1979, although hydrocarbon levels in lobsters from contaminated areas were two to three times that of control animals (Scarratt 1980). Neither was there any evidence of oil contamination in lobsters following an accidental crude oil spill at the wharf of the Come-by-Chance oil refinery, Placentia Bay, Nfld. (Williams et al. 1988).

The known effect of exploratory drilling for oil and gas on the East Coast has been minimal because the least toxic water-based drilling muds were used (Gordon 1988). Smothering of benthos by discarded drilling mud and cuttings is generally very localized in nature, depending on the turbulence and bottom currents of the region. The environmental effect of a well blowout is much more serious. One blowout had occurred by 1987 on the Canadian East Coast out of 260 wells drilled (Gordon 1988). In February 1984, condensate escaped at the platform level of UNIACKE G-72 near Sable Island, N.S. Most of this material was lost by evaporation within the first day, but a surface slick was observed up to 10 km from the rig. No adverse biological effects were observed (Gordon 1988). An oil well blowout of heavier oil would result in much more serious environmental consequences (National Research Council [U.S.A.] 1985). Mesoplankton to macroplankton size classes of the pelagic community, which includes the ichthyoplankton, are the most vulnerable organisms to dispersed oil within the water column (National Research Council [U.S.A.] 1985). Planktotrophic larvae of benthic invertebrates and demersal and pelagic fishes represent a special case because they are present in the water column for a limited time and often in a confined area, yet represent a year-class of an organism. An oil blowout on the scale of the 1976 ARGO MERCHANT grounding and spill on Nantucket Shoals (National Research Council [U.S.A.] 1985) could wipe out a year-class in a region of confined circulation such as Georges Bank, yet not be felt by fishermen for years. In 1989, the Nova Scotian and Canadian governments banned offshore oil exploration over the Georges Bank region until the Year 2000 in order to allow sufficient time for scientific background knowledge to accumulate on concerns voiced by the fishing industry. It is expected that the relatively small Panuke/Cohasset Field on the Scotian Shelf will commence production of gas condensate in late 1992. The offshore oil-gas resource in the Hibernia Field on the Grand Banks is now not expected to be developed for many years to come.

Following the increased cost of imported petroleum products in the 1970s, coal re-emerged as a major energy source in Nova Scotia and New Brunswick. Waste waters from coal mining contribute trace metals, particularly iron, and suspended solids to the marine environment. The 60-yr-old practice of discarding mine tailings along the shore locally in Cape Breton (No. 26 Colliery) has led to short-term smothering of the intertidal and nearshore marine habitat. Thermal-generating stations, particularly those using coal, emit PAHs and the gases sulphur dioxide and nitrous oxide which form the major components of acid rain. Increased acidity of rainfall has little effect on the buffering system of seawater, but it does affect anadromous fish such as salmon which spend the early part of their life in freshwater (Uthe and Zitko 1988). The problem is particularly severe in the southern uplands of Nova Scotia where 18 of the spawning rivers, all with a pH less than 4.7, have lost their salmon populations (Watt 1987).

Waste heat, from fossil fuel and nuclear thermal-generating plants, has a brief existence in the marine environment, being detectable only 1 to 25 ha around the outflow (Eaton et al. 1984). There are no known cases of adverse effects to date. A commercial salmon aquaculture operation at the Lingan generating station in Cape Breton, taking advantage of the warm effluent for faster fish growth, has proven successful (P. Eaton [Environment Canada], pers. comm.). The results of an extensive monitoring program before and after the construction of the Point Lepreau, N.B., nuclear power station indicate that only tritium is being released in quantities significantly above background and that there is no evidence for environmental damage at these low levels (J. Smith [Department of Fisheries and Oceans], pers. comm.).

The Sydney Steel Company (SYSCO) steel plant and its predecessor have been discharging toxic wastes into the southern arm of Sydney Harbour, N.S., via a tar pond for 90 yr. Principal sources of the toxic tar pond material are from the high-temperature coking operations associated with SYSCO and waste effluent from the use of coal in power generation. The most carcinogenic compounds in the complex mix found in the tar pond are some PAHs (Matheson et al. 1983). It is estimated that the total quantity of PAH compounds in the Muggah Creek estuary up to 1985 was 35 million kg (Eaton et al. 1986). Research is not yet completed; but early results indicate that flatfish in Sydney Harbour have a higher incidence of liver "tumors" or growths than fish taken from a nearby unindustrialized region, St. Georges Bay, N.S. (V. Vignier [Department of Fisheries and Oceans], pers. comm.). Marine invertebrates such as bivalve molluscs and crustaceans lack mixed-function oxidase which normally break down PAHs and therefore accumulate substantial levels of PAHs (Eaton et al. 1984). High levels of benzo[a]pyrene were recorded in lobster tissues (21 to 78 $\mu g \cdot g^{-1}$) near Sydney in 1982; and this has resulted in the indefinite closure of this fishery in the Harbour by health officials. Excavation and incineration of close to 100 yr of accumulation (1899 to present) of tar pond materials at SYSCO is planned for the 1990s under Canada's Green Plan program. Problems may arise during their removal and from incomplete combustion of PAHs which will then be dispersed broadly in the atmosphere. Despite the planned cleaning operation, the sediments of Sydney Harbour will continue to be a source of PAHs and trace metals for the fauna in the bay for years to come.

The chlor-alkali industries situated along the St. Lawrence and Saguenay Rivers, P.Q., near Dalhousie, N.B., and at Abercrombie, N.S., have contaminated the marine sediments and biota with mercury (Allan 1988; Loring 1988; Smith 1988). Commercial fisheries were closed on the St. Lawrence River in 1970 because of high mercury (Hg) content (Messieh and El-Sabh 1988). Mercury is the trace metal which poses the greatest health risk to humans because in its methylated form it accumulates with increasing size or age of organism (Bernhard 1985). Continual consumption of contaminated fish causes irreversible neurological damage to humans, as evidenced by the disaster at Minamata Bay in Japan (Bacci 1989) and at Grassy Narrows, near Dryden, Ont. Early regulations introduced in 1972 and 1978 reduced effluent and emissions of mercury by 80% and 90%, respectively, over the decade in Atlantic Canada (Eaton et al. 1986). However, high levels of mercury continue to reside in the bottom sediments of the St. Lawrence estuary, Saguenay Fjord, and Restigouche River. Mercury levels in shellfish in Saguenay Fjord have decreased 20-fold since the early 1970s (Cossa and Desjardins 1984).

The Atlantic base metal industry for lead, zinc, and copper ores operated at reduced capacity during the 1980s with many mine closures (Eaton et al. 1986). Trace metals are released into aqueous form during the mining and milling process and also from rock pile and tailing pond runoff. Once trace metals reach estuarine conditions they absorb readily onto particles because of their reduced solubility under saline conditions. This can result in high trace metal levels in the sediments of confined estuaries and bays (Loring 1988). For example, the shipping channels in Bathurst Harbour, N.B., have been allowed to fill in since 1976 because cadmium, lead, copper, zinc, and mercury levels in bottom muds are too high to permit regular dredging and disposal. Asbestos mining near Baie Verte, Nfld., has resulted in local smothering of marine habitat by runoff from tailings (Wells and Rolston 1991). Many abandoned mines are now being sloped and replanted with trees to reduce long-term discharges. Mining of gravel and sand from marine beaches is strictly prohibited now. In Nova Scotia, for example, several of the larger recreational beaches near major urban centres have nearly disappeared as a result of commercial sediment extraction (Taylor et al. 1985). Similarly, sea bed mining for sand and gravel could have adverse effects on coastal erosion if conducted too close to shore - a possible scenario if fill is required for the proposed "fixed link" to Prince Edward Island. The placer mining proposed for extracting gold deposits from marine sediments off Lunenburg, N.S., should have negligible environmental effects if material is returned in place.

Ore-loading areas in Dalhousie, N.B. (1964-), Hawes Bay (1974-), Tilt Cove (1900-), and Botwood (1950-), Nfld., have resulted in high levels of zinc, lead, and copper locally in the sediments as a result of spillage, runoff, and wind-blown dust (Eaton et al. 1986). In the 1980s successful efforts were made to reduce this loss; however, levels of trace metals already in the sediments around loading terminals exceed Ocean Dumping Control Act (now Canadian Environmental Protection Act, CEPA, Part VI) limits and present a dredging and disposal problem.

A number of metal-smelting operations on the Atlantic Coast present environmental concerns. Cadmium is a waste product of the lead smelter in Belledune, N.B. (1966-). Cadmium subsequently turned up in high levels in sediments and fauna and resulted in the closure of the lobster fishery in 1980 within Belledune Harbour and restricted it to a tail-and-claw fishery 1 to 6 km from Belledune (Hildebrand 1984). Mussels were contaminated 20 km downstream toward Bathurst, N.B. Effluent treatment and the relocation of the outfall to the outside of Belledune Harbour resulted in a reduction and dispersion of cadmium (Uthe et al. 1986) such that the lobster fishery was reopened in the Harbour in 1988 for marketing claw and tail meat only (D. Maynard [Department of Fisheries and Oceans], pers. comm.).

Aluminum-smelting plants on the Saguenay Fjord have contributed to the high levels of lead, zinc, and mercury in Fjord sediments from aqueous and aerial effluents (Martel et al. 1986; Smith 1988). These sediment levels remain high despite 10 yr of reduced atmospheric input due to federal regulations. The electrolytic process used in these aluminum smelters produces large quantities of PAHs. A time series of PAH flux to anoxic unbioturbated sediments in Saguenay Fjord was derived by dating sediment cores (Smith and Levy 1990). The peak flux of PAHs to this Fjord was between 1964 and 1976 and coincides with discharge of liquid wastes into the river from the then newly installed atmospheric "scrubbers." PAH flux to the Fjord declined to pre-scrubber levels by the 1980s after the problem was first recognized then rectified by combustion of effluents to destroy PAHs. However, large quantities of PAHs are still being dispersed from the stacks and are borne atmospherically to soils and sediments of the Saguenay River drainage basin (Smith and Levy 1990).

The phosphorus in waste water from the phosphorus-production plant in Placentia Bay, Nfld., which caused massive fish kills in 1969, has been reduced by 70% to 90%. This allowed the fishery to reopen in 1984 up to 100 m from the plant wharf (Eaton et al. 1986). The phosphorus plant has since been closed (August 1989), but the decommissioning and clean-up of the site is expected to continue for another 10 yr (U.P. Williams [Department of Fisheries and Oceans], pers. comm.).

DREDGING AND DUMPING

Dumping at sea has been regulated by the Ocean Dumping Control Act from June 1975 and now comes under the Canadian Environmental Protection Act (CEPA, Part VI) since June 1988. Under this Act, permits are required for dumping dredged material and disposing of craft and scrap metal, chemical, radioactive, and fish plant wastes. Incineration of toxic wastes at sea, also covered by this Act, has not been permitted pending further evaluation of the environmental consequences. Dredged material must not exceed set levels for mercury, cadmium, organochlorines, petroleum residues, persistent plastics, and radioactive materials for disposal at sea, and must not contain excessive amounts of arsenic, lead, copper, zinc, nickel, chromium, and other pesticides (Environment Canada 1988).

In Atlantic Canada between 1.8 and 8.2 million m^3 of silt is dredged from shipping channels annually, compared to 0.8 million m^3 in Québec (Wells et al. 1987). In general, the suspension and dispersion of dredged sediments is not believed to have only a local effect on sensitive organisms, such as the filter-feeding black mussel, *Mytilus edulis* (Bergeron et al. 1990). A number of locations present special problems. At Dalhousie, N.B., the harbour is dredged, on average, every other year. Cadmium and possibly mercury contamination of these sediments have necessitated "land" disposal of the dredged spoils in three dyked regions of the harbour, which act as sequential settling ponds. Presently, the upper pond is almost filled; and it is planned to have it landscaped and planted as a park (R. Woodworth [Department of Public Works], pers. comm.). The land disposal approach will be taken with the expansion of the harbour at Belledune because the sediments contain excessive levels of cadmium. Bedrock extracted at Belledune should be disposed of at sea and will be beneficial as lobster habitat (Scarratt 1968).

The maintenance of a channel through the Miramichi estuary requires ~0.1 million m^3 of "clean" silt to be disposed of each year into the Gulf. Sediments in the upper estuary and river to Newcastle, N.B., present a disposal problem yet to be resolved because of excessive cadmium and oil and grease levels. It is also suspected that the chlorinated dibenzo-p-dioxins and dibenzofurans found in lobsters in the estuary in 1983 (Clement et al. 1987) may have originated from the Newcastle, N.B., pulp and paper mill and may still be present in the sediments. The port of Saint John, N.B., presents no contaminant problem because the harbour deposits are not allowed to build up before they are removed (0.5 million m^3 yr^{-1}) beyond the outer harbour. Both St. John's, Nfld., and Halifax Harbour, N.S., have small dredging operations of <10,000 m^3 per year where the spoils are dumped a short distance away. There is some concern that the oxidation of Halifax Harbour sediments, as a result of the introduction of sewage-treatment facilities and dredging operations, might release potentially toxic metals such as mercury, cadmium, chromium, nickel, lead, copper, and zinc which are presently bonded to or complexed with anaerobic organic-rich deposits (Buckley and Hargrave 1989). This could make them available for uptake by lobsters and other species caught commercially in the Harbour.

Fish offal, mainly remains from processing herring, is disposed of in two main locations in Atlantic Canada (D. Aggett [Environment Canada], pers. comm.). Between 20,000 and 40,000 t of fish offal are dumped each year 25 naut. mi. west of Yarmouth, N.S., in a highly dispersive physical regime outside regions of major fishing activity. The dump site 35 naut. mi. east northeast of Miscou Island, N.B., was little used in 1989 because most of the herring from the roe fishery was taken by reduction plants for fish meal production. There are dump sites for small quantities of fish offal scattered around the Atlantic Provinces, particularly off Newfoundland.

There are a few examples of chemicals that have been disposed of at sea on the East Coast (D. Aggett [Environment Canada], pers. comm.). Lime sludge (30,000 m^3), used to deacidify runoff from a runway extension at the Halifax International Airport, N.S., was dumped off Halifax Harbour in 1988. Brine solution, shipped from Sarnia, Ont., has been dispersed off Cape Breton, N.S., for the last 4 yr (1986-). The phosphate fertilizer plant at Belledune, N.B., disposes an unwanted by-product - plaster of Paris ($CaSo_4 \cdot 1/2\ H_2O$), in the immediate vicinity in the Baie des Chaleurs.

High-level radioactive waste disposal at sea, such as spent nuclear fuel, is banned under the London Dumping Convention of 1983, of which Canada is a signatory. There is also a voluntary moratorium on low-level radioactive waste disposal pending a review of the scientific basis for dumping at sea. Canada currently stores all high-level waste in water-cooled, land-based storage facilities. Canada, nevertheless, has made substantial scientific contributions to the assessment of subseabed disposal of radioactive wastes on the marine environment (B.T. Hargrave [Department of Fisheries and Oceans], pers. comm.).

Ships, firearms, and scrap metal have designated sea disposal sites around most of Canada's larger ports.

RENEWABLE RESOURCES

The effects of agriculture and forestry on the marine environment are, to a large degree, similar. Cultivating fields and clear-cutting woodlands release soil particles and nutrients which are carried with rain water via surface waterways and ground waters to estuarine habitats. Retaining or creating vegetation buffer zones along watercourses, as has been recently practiced in forestry, greatly ameliorates these losses. Soil erosion causes siltation in coastal waters which physically smothers existing habitats. It also introduces heavy metals, anthropogenic compounds such as pesticides, fertilizers, etc., and various organics which may be toxic to marine life. The addition of organics increases biological oxygen demand which can lead to anaerobic conditions in the sediment.

Eutrophication of coastal waters by nutrients from terrigenous sources can also result in anaerobic conditions if water circulation and bacterial decomposition of algal remains are confined by bottom topography or man-made structures such as causeways. The notorious 1987 winter *Nitzschia* bloom in Cardigan Bay, P.E.I., which caused neurotoxic amnesic shellfish poisoning (ASP) from domoic acid in humans consuming cultivated blue mussels (Quilliam and Wright 1988; Wright et al. 1989), coincided with high nutrient levels and may well be associated with local agricultural practices of tilling and fertilizing the soil (Bates et al. 1989; Gordon 1991). A number of shellfish-growing areas in predominantly agricultural areas are also closed seasonally due to increased coliform counts following heavy rainfalls. Many areas are also closed due to sewage pollution, and these areas are increasing in number and area annually. The rapidly expanding aquaculture business also concentrates nutrients and organics locally through settling of feces from cultivated fish or shellfish, and this could result in all of the deleterious effects of eutrophication (Wildish et al. 1990a; 1990b). Mussel cultivation relies on naturally supplied food and therefore is practiced usually in tidally well-mixed areas which should disperse their excrement. Salmon are fed when kept in sea pens, and this represents a large local addition of organic material to the ecosystem. Toxic microalgal blooms have caused mortalities of caged salmon in Norway and Scotland (Saunders 1991), though it is not known whether the presence of fish wastes and uneaten food could be responsible for encouraging toxic algal blooms.

On a larger scale, there is little evidence that modified seasonal input of nutrients from terrigenous sources through hydroelectric development has altered biological production significantly enough to affect fisheries yield in regions such as the Gulf of St. Lawrence (Bugden et al. 1982; Sinclair et al. 1986). Riverine nitrogen, generally considered to be the limiting nutrient, contributes less than 2% of the total nitrogen budget of the Gulf of St. Lawrence; and this is approximately equivalent to that derived from the atmosphere (Yeats 1988). On the other hand, the relative importance of deepwater nutrient entrainment by surface currents, caused at least partially by freshwater runoff, is dealt with in the following section.

Another concern is the increasing use of pesticides in agriculture and forestry (Eidt et al. 1988). The use of phenoxy herbicides (2, 4, 5-T and 2, 4-D), which are particularly toxic to salmonids at low pH (<5), was phased out in the 1980s due to mounting scientific and public pressure and have been replaced by the more benign glyphosate (Eaton et al. 1986). Metabolites of the insecticide DDT, discontinued after 1967 in New Brunswick due to irrefutable evidence of food-chain magnification, were still present in the early 1980s in Gulf of St. Lawrence herring stocks (Khalil et al. 1985). The important trends of spraying less chemical per hectare and using environmentally less-noxious insecticides in forestry have continued into the 1980s (Eidt et al. 1988). Both fenitrothion and aminocarb are readily degraded by microbes and sunlight and therefore are short-lived in the environment. Nevertheless, fenitrothion was detected in shellfish (>40 ppb wet) and sediments (<70 ppb) from Buctouche Harbour and estuary, N.B., immediately after budworm spraying operations in the watershed (Lord et al. 1978; Wells et al. 1979). The bacterial pathogen *Bacillus thuringiensis* (Bt), which has no discernable effects on aquatic ecosystems, accounted for 64% of the hectares sprayed in Eastern Canada by 1986 (Eidt et al. 1988).

Over 90% of the pesticide use in Canada is agricultural. In the east the fungicides mancozeb, captan, and chorothanonil; the herbicides dinoseb and diquat; and the insecticides phorate, carbofuran, and aldicarb are used for potato, tobacco, fruit, and vegetable farming (Eaton et al. 1986). Although trace amounts of agricultural pesticides have been detected in freshwater and groundwater, nothing is known about their concentrations and effects in the marine environment.

Aquaculture presents other concerns for the health of the environment because species introduced for cultivation can transmit diseases to cultured and native species alike. For example, the bacterial disease enteric redmouth was introduced in 1976 to marine pen-reared rainbow trout and Atlantic salmon in Nova Scotia from the United States' Midwest (J. Cornick [Department of Fisheries and Oceans], pers. comm.). Similarly, shell disease (ostracoblade) was introduced to the Maritimes with infected European oysters from the United States. Regulatory Committees and quarantines are used to reduce the likelihood of introducing further diseases. The environmental effects of fungicides and antibiotics used by fish farmers is not known but are believed to be localized.

The fishing industry affects the marine environment by altering the bottom habitat, the species composition, and possibly favours size selection of commercial species. In Atlantic Canada there are ~300 scallop draggers and 700 fish trawlers which sweep ~30,000 km^2 of the shelf each year (Messieh et al. 1991). This activity resuspends sediments and damages bottom organisms, which makes them more vulnerable to bacterial infection and scavengers. Large quantities of fish are selectively removed from the East Coast ecosystem each year. For example, in 1989 685 x 10^3 t of groundfish, 359 x 10^3 t of pelagic fish, and 228 x 10^3 t of shellfish were marketed (J. Kane [Statistics Canada], pers. comm.). These catch statistics do not account for the by-catch of small fish or unmarketable species which are dumped back overboard. The selective removal of this amount of biomass each year from the upper trophic levels is obviously a major factor affecting the East Coast ecosystem. However, it has not been possible to distinguish the effects of fishing pressure from environmental change on wild fish populations. For example, the cause of the population decline of the northern cod off Newfoundland and Labrador in the late 1980s and early 1990s, which has led to widespread fish plant closures, is generally attributed to overfishing and adverse environmental conditions (Northern Cod Review Panel 1990; Paranjape and Sheldon 1991). It stands to reason that heavily exploited stocks of fish are more vulnerable to minor adverse changes in environmental conditions. Skud (1982) postulates and argues the case that the abundances of planktivorous fishes, such as herring and mackerel, are determined by competition for resources and that any population equilibrium can be upset by human exploitation, changing the dominant into the subordinate species. The sandlance replaced the heavily fished herring stocks on Georges Bank in the late 1970s; and it is thought that the yellowtail flounder, windowpane, longhorn sculpin, and skate populations increased because of selective fishing for haddock on Georges Bank and Grand Banks (Grosslein et al. 1980; Overholtz and Tyler 1986; Pitt 1970; Sherman et al. 1981). Similarly, it is not known what part fishing activity has played in the observed 20-yr cycle between bountiful kelp beds and sea urchin-dominated barrens (Johnson and Mann 1988). Otherwise, the composition and rank of commercial species in Canadian waters has remained remarkably constant over the last century.

It appears that, in general, the East Coast ecosystem has adapted to high fishing pressure. The sudden removal of fishing pressure can also affect an ecosystem. In the last decade we have witnessed the exponential growth of the harp seal population (three times) since the ban on commercial hunting. The present Newfoundland/Gulf of St. Lawrence harp seal population is estimated at approximately 4 million individuals with a food requirement of ~4 million to

5 million t (N. I-Hsun [Fisheries and Oceans], pers. comm.). However, it is believed that harp seals affect the groundfish populations primarily by competing with them for food rather than preying on them.

Finally, it is not clear from field data whether the mesh size of fishing gear has genetically selected for faster growing and earlier maturing individuals in nature.

HYDROELECTRIC DEVELOPMENT

Hydroelectric development on major rivers is seasonally altering the physical structure of the water column in coastal waters. The landings of commercial species of fish (1940s to 1960s) in the Gulf of St. Lawrence were shown to have a strong covariation with prior river discharge (Sutcliffe 1972; 1973). The lag time in years is species dependent and approximately matches the age of recruitment which suggests that river runoff may affect the egg or larval stages.

Freshwater runoff is known to stimulate phytoplankton growth in the St. Lawrence estuary and downstream in the Gaspé Current by nutrient entrainment from deeper waters (Therriault and Levasseur 1986; De Lafontaine et al. 1991), although the role played by atmospheric forcing in this process of surface enrichment has not yet been evaluated (Bugden et al. 1982). The estuarine circulation within the Gulf is believed to be responsible for creating nitrate concentrations two to three times higher than those found at comparable depths on the Scotian Shelf (Coote and Yeats 1979). It is important that studies be done to investigate whether enhanced nutrients within the Gulf translate into higher biological productivity (De Lafontaine et al. 1991).

Bugden et al. (1982) found that river runoff and cod recruitment in the Gulf of St. Lawrence, between 1957 and 1976, were significantly correlated at the year prior to spawning, when the oocytes are developed. Of the four Québec fisheries originally correlated with river runoff (Sutcliffe 1972; 1973), haddock no longer migrates into the Gulf of St. Lawrence, halibut landings diverged from predicted values in the late 1970s, and soft-shell clam and lobster landings were reasonably well predicted into the 1980s (using the combined spring runoff from the St. Lawrence, Ottawa, and Saguenay Rivers: RIVSUM [Sheldon et al. 1982; Drinkwater 1987]). In the late 1980s, Québec lobster predictions from RIVSUM failed (Drinkwater et al. 1991). It is perhaps surprising that these predictions have lasted as long as they did, given the underlying assumption of linearity. Bugden et al. (1982) point out that the entrainment of salt and nutrients, the presumed basis for river runoff/fish-landing correlations, is not directly proportional to river runoff, nor is the shape of this non-linearity known. Neither is the secondary effect of fishing effort on yield likely to be linear. Also, Skud (1982) has shown that when dominance shifts occur between two or more competing fish species under intense fishing pressure, environmental correlations with species abundance change in sign. All these factors, and others not yet comprehended, considerably complicate any environmental model needed for fishery prediction.

Koslow (1984), Koslow et al. (1986), and Sinclair et al. (1986) have considered an alternative hypothesis that fish recruitment success is determined more by large-scale atmospheric circulation which, in turn, influences ocean currents. Koslow (1984) found that cod recruitment was similar over broad areas from the Labrador Sea to the Scotian Shelf, with the notable exception of cod stocks within the Gulf of St. Lawrence. The relationship between river runoff into the Gulf of St. Lawrence and its effects on the marine ecosystem warrant much more thorough studies because spring runoff rates have already been reduced by 15 to 35% by the Manicougan-Outardes-Bersimis hydroelectric development completed in the spring of 1970.

Hydroelectric developments in the Hudson Bay region have changed the seasonal pattern of freshwater runoff, from one with a prominent spring freshet to a more-balanced seasonal outflow, due to the high winter demand for power in the south (Prinsenberg 1980). The diversion of the Churchill River into the Nelson River in northern Manitoba, and the construction of multiple dams along these watercourses in the late 1970s, increased flow from 3,400 to 4,100 $m^3 \cdot s^{-1}$ in February (Prinsenberg 1980). A similar hydroelectric diversion of the Eastmain River into the La Grande River in northern Québec increased winter flow (February) of the combined Rivers from 930 $m^3 \cdot s^{-1}$ before 1980 to 2,600 $m^3 \cdot s^{-1}$ in 1984, with plans to increase this to >6,000 $m^3 \cdot s^{-1}$ in the future (Prinsenberg 1980; Ingram and Larouche 1987).

Coastal stratification in the Hudson Bay region increased in the winter months, following the construction of these hydroelectric developments, because the increased freshwater outflow occurs when ice cover reduces the vertical mixing processes. There are further hydroelectric projects in the planning stage for the Great Whale and Little Whale Rivers in northern Québec and the Nottaway-Broadback-Rupert Rivers in northern Ontario (Prinsenberg 1980; 1991). On completion, it is estimated that the winter runoff into James Bay will double, whereas runoff directly into Hudson Bay would increase by 52% (Princenberg 1991). Presently, around the La Grande River hydroelectric complex the 25 salinity isohaline forms a coastal plume under the ice up to 20 km wide, extending over a 1,800 to >4,300 km^2 area (Ingram and Larouche 1987). The advection of the La Grande River plume, as winter power demand increases in the future, could extend as far as the Great Whale River project (Prinsenberg 1991).

The ecological implications of these hydro developments on the marine environment are not fully understood. Increased winter runoff reduces biological production at the ice-water interface the following spring because low-salinity water both inhibits ice algae growth and isolates them from their nutrient supply in deeper saline waters (Gosselin et al. 1985; Ingram and Larouche 1987). Not surprisingly, the ice meiofauna which consumes ice algae is reduced by an order-of-magnitude in the La Grande River plume (Grainger 1988). Ice algae, although responsible for only 3% of the total annual production in Hudson Bay, are important for the timing of secondary producers and the spring phytoplankton bloom (Gosselin et al. 1985; Tourangeau and Runge 1991).

The magnitude of the spring freshet affects the timing and pattern of ice breakup in James Bay by reducing the ice albedo, supplying heat to melt the ice, and by insulating the pack ice from the underlying colder, more-saline waters (Princenberg 1980). Hydroelectric development has markedly reduced this spring runoff, and this may be enough to delay the phytoplankton bloom and thereby shorten an already brief growing season for larval fishes and benthic invertebrates (Morin et al. 1980).

The species composition found at the mouths of diverted rivers is altered considerably from a freshwater-dominated community to a more marine-oriented one, as exemplified by a study of the Eastmain estuary (Ochman and Dodson 1982). It is not known how serious an effect this altered freshwater runoff will have on seal and beluga populations which congregate at river mouths during the summer months (Mansfield 1967; Sergeant 1973; Finley 1983; St. Aubin et al. 1990). Hydroelectric barrages are having a profound effect on anadromous fishes, not only by severely diminishing their lotic spawning areas but by reducing the distance their larvae are passively transported into the marine coastal zone (Morin 1991; Ochman and Dodson 1982). It is not known how important this marine phase is for coregonid fishes.

Sutcliffe et al. (1983) hypothesized that reducing the spring freshet by hydroelectric regulation in the Hudson Bay area may affect northern cod populations along the Labrador coast. Increased runoff was thought to interfere with vertical mixing at the mouth of Hudson Strait and thereby suppress nutrient enrichment at the base of the food chain. This hypothesis is based on an inverse correlation between summer surface salinities and northern cod stocks. The summer surface salinities off St. John's, Nfld., are now known to be more influenced by ice melt along the Labrador coast than by river runoff from Hudson Bay (Myers et al. 1990). Nevertheless, it is important that research be continued on possible "downstream" effects of altering the physical environment on marine ecosystems because even more grandiose plans are being considered to convert James Bay into a freshwater reservoir for water sales to the United States market (Bourassa 1985; Milko 1986).

COASTAL DEVELOPMENT

Major habitat losses have occurred since the 1950s along the St. Lawrence and Saguenay Rivers due to seaway construction, landfilling for various developments, and highway enlargements. Anadromous fish landings in the St. Lawrence estuary, such as gaspareau, smelt, sturgeon, salmon, and tomcod were much reduced by the 1980s; but it is difficult to evaluate the contributing effects of riverine habitat loss from overfishing and natural environmental change (Marquis et al. 1991; Robitaille and Vigneault 1990). The damage done to anadromous fish populations, such as the salmon, by water diversion dams and waterway alterations is widespread throughout the Atlantic region (Watt 1989).

Tidal power barrages, causeways, and wharves also influence the quality of estuaries and coastal waters. The tidal power station constructed between 1980 and 1984 on the Annapolis River, N.S., has caused some changes in sedimentation in the area; however, the earlier installation of the causeway between 1958 and 1960 is thought to have had a much greater impact (Prouse et al. 1988). The hydro development has increased tidal amplitude upstream by 1 m, which has led to undercutting and erosion of the banks of the River.

Causeway construction can interrupt the migration, spawning runs, and larval transport of fish and invertebrates. Causeways at Canso Strait and Barrington Passage, N.S., have been implicated in this problem (McCracken 1979). The most spectacular effect of causeway and pier construction can be seen along the Bay of Fundy where strong tidal currents maintain material in a dynamic equilibrium. The construction of a causeway at Windsor, N.S., in 1970 has caused a net siltation of 2 m for a distance of 2 km seaward on the Avon River (Amos 1977). Similar changes have occurred at Moncton and Memramcook, N.B. The causeway at the L'Etang estuary, N.B., has inhibited the dispersion of high BOD wastes from the sulphite pulp mill and has worsened environmental conditions, causing closure of shellfish beds (Wildish et al. 1974; 1988). A similar situation exists in Canso Strait, N.S. (McCracken 1979). The proposed crossing to Prince Edward Island is currently undergoing an environmental impact assessment to predict any changes to the ecology of Northumberland Strait which might result if the project proceeds.

OTHER ISSUES

The introduction of diseases and parasites with non-indigenous salmonids and shellfish by the aquaculture industry has occurred in spite of improving regulations. Benthic organisms and marine plants have been introduced around the world from attached stages fouling vessel hulls. Recent alterations of the marine community by species introductions, such as those documented in European waters, have not occurred off Atlantic Canada. However, it has been suggested that the ecologically important common periwinkle, *Littorina littorea*, and the burrowing amphipod, *Corophium volutator*, were introduced in the last century; but the supporting evidence is not conclusive. Another avenue for introductions is in the discharge of ballast water by ships from foreign ports (Williams et al. 1988; Gordon 1991). Three harmful species have been introduced to the Great Lakes in this fashion, but no marine or brackish-water species are known to have been introduced to the East Coast of Canada to date (Locke et al. 1991). The current change to container shipping will present a greater chance of introducing species to the ports of Saint John, N.B., and Halifax, N.S., due to the enormous ballast volumes of these ships.

The scientific knowledge of bacterial diseases of strictly marine fish species is limited. There are three bacterial diseases that are known to pose a threat to the fast-growing salmonid aquaculture business in Atlantic Canada (G. Olivier [Department of Fisheries and Oceans], pers. comm.). Vaccines are available for vibriosis and furunculosis, and both diseases are treatable with antibiotics. Bacterial kidney disease is hard to diagnose, difficult to treat with antibiotics, and transmitted from generation to generation in the egg. Efforts to control this disease are aimed toward its eradication. Infectious pancreatic necrosis virus is ubiquitous to the Atlantic Coast, although major losses of fish have not occurred in recent years.

The aesthetic value of the coastal environment for recreational use by both local people and tourists is not only influenced by municipal and industrial sewage treatment but also by garbage. Litter, though for the most part relatively innocuous, has an exaggerated effect on the perceived beauty of a region. Plastic makes up the bulk of the persistent litter obvious to anyone visiting the seashore because of its buoyancy. A detailed study of the shores of Halifax Harbour, N.S., in 1989 revealed that 62% of the garbage gathered originated from recreational littering and municipal sewage (Ross et al. 1991). In contrast, the litter accumulation on Sable Island, 160 km off the coast of Nova Scotia, originated from the shipping and particularly the fishing industry (Lucas 1992). The rate of accumulation was remarkably constant and consistent between April and November 1984 to 1986. Plastics represented nearly 94% of the total, metal and glass containers making up the balance. Most of the plastic items, known as user-plastics, were molded containers, sheeting, strapping, bags, and fishing-related gear. Ghost netting and traps (lost or abandoned gear that continue to fish), together with plastic strapping, are the most harmful to the environment because they snare lobsters, crabs, fish, birds, seals, and whales (Breen 1990). Exploratory studies on lost gillnets in Newfoundland bays recovered 324 nets in 44 d at sea which were estimated to have been fishing between 1 and 4 yr (Brothers 1989). On average, 24 kg of groundfish and 13 kg of crab were recovered per ghost net. More importantly, between 44% and 84% of the groundfish and between 94% and 98% of the crab recovered were still alive. It is a vicious cycle whereby dying organisms entice scavengers which in turn become entangled.

CONCLUSION AND RECOMMENDATIONS

Urban population growth along the Atlantic seaboard will result in an increased demand for both energy and materials. Greater population densities in a few larger cities will exacerbate present sewage-related problems, and this may conflict with the traditional fishery and the expanding aquaculture industry through eutrophication and the introduction of pathogens and toxic materials. Increased industrialization and utilization of renewable resources will result in further environmental compromises. Decisions will be made on whether future increased power demands can be met by solar, wind, fossil fuel, hydro, tidal, or nuclear power generation. Economic and environmental concerns will have to be considered together to ensure reduced conflicts and greater long-term sustainability of coastal regions.

Effluents from various industries and municipalities are regularly monitored for BOD, suspended solids, and selected chemicals; but there is an urgent need to study their ecological effects on organisms in the receiving waters. There is a surprising lack of regional conformity in what is measured and monitored. This severely limits environmental interpretation that can be made for the region. The chemical contaminant time-trend studies on Atlantic cod (Misra et al. 1989) and seabirds (Noble and Elliott 1986) should be continued; otherwise, we have lost one important basis for assessing changes in the health of the environment. The range of compounds analyzed should be expanded as new toxic and carcinogenic materials, such as chlorinated dioxins and furans from the paper industry, appear in marine foodstuffs. The most concentrated pollution in the Atlantic region will continue to come from the St. Lawrence River valley where the maximum urban population lives, and it is here and downstream that emphasis on environmental monitoring and regulating should be placed in the coming years. This does not mean that the smaller-scale pollution problems that exist in Baie-des-Chaleurs, N.B., Sydney Harbour, N.S., Saguenay Fjord, P.Q., etc., and future developments, such as the Hibernia oil field, should be ignored. Pollutant input to Canada is coming increasingly from atmospheric sources which originate largely from beyond Canada's borders. It is equally important that airborne pollutants, such as chlorinated and polycyclic aromatic hydrocarbons, be monitored at locations remote from industrial sources. At present, this long-range atmospheric transport represents an uncontrollable source which will require international cooperation in the future.

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