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A State of the Environment Report

Contaminants in Canadian Seabirds

SOE Report No. 90-2

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Contaminants in Canadian Seabirds

David Noble

for:

State of the Environment Reporting
Environment Canada

Canadian Wildlife Service
Conservation and Protection
Environment Canada

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Think Recycling!

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Cover photo: A Thick-billed Murre and its egg. The author found low levels of most of the contaminants covered by this study (organochlorines and mercury) in murre eggs collected at Arctic breeding colonies. Canadian Wildlife Service photo.

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Summary

When the persistent organochlorine and heavy metal contaminants accumulate to high enough levels in biological organisms, they cause reproductive failure, congenital abnormalities, and adverse physiological changes.

Since 1968, the Canadian Wildlife Service, which is responsible for safeguarding the health of populations of migratory birds, has analyzed levels of organochlorines and mercury in eggs and tissues of 24 species of marine birds collected from the Atlantic, Pacific, and Arctic coasts. The scientists detected the following contaminants: PCBs, DDE, toxaphene, dieldrin, mercury, HCB, oxychlordane, DDT, DDD, heptachlor epoxide, HCH, mirex, cis-chlordane, nonachlor, and endrin. The service also analyzed a small sample of east coast birds for lead and cadmium.

The seabird monitoring program provides an indication of the relative contamination of maritime regions of Canada. Based on contaminants in seabird eggs, the St. Lawrence River estuary and nearby gulf were among the most contaminated maritime regions in Canada, followed by the Bay of Fundy, the Strait of Georgia, and the west coast of Vancouver Island. Residues among the Arctic Islands, in the marine environment of Newfoundland, and along the coast of northern British Columbia were relatively low. Overall, the residues of most contaminants (particularly PCBs, DDE, and dieldrin) have declined everywhere, although the decline in the St. Lawrence estuary is not statistically significant.

In general, the trends in levels of contaminants follow the patterns of use in North America. DDT (and its metabolites) and dieldrin showed the most significant declines. Both of these compounds have been banned in Canada and the United States since the early 1970s, except for minor uses. Heptachlor epoxide and oxychlordane, which are both found in technical chlordane, appear to be persisting at low levels. Declines of these compounds in some species since 1980 are most likely due to the restrictions imposed in 1978. Although most uses of PCBs and HCB have been revoked, these chemicals continue to enter the environment through accidental industrial discharge. The declines in PCBs in most locations are probably indicative of a gradual global redistribution and dilution and local control measures. The status of other industrial chemicals has yet to be determined.

The environment is our only life-support system. As we approach the twenty-first century, however, there are indications that we are severing this lifeline.

Canada, like many other countries, has implemented State of the Environment (SOE) Reporting. Written for Canadians interested in their environment, SOE Reporting takes many forms: fact sheets, reports, newsletters, data base, and a five-year national report, to be published in 1991. SOE is a partnership that will increasingly involve federal, provincial, and territorial governments, private industry, academia, nongovernmental organizations, and the individual citizen.

Careful, objective analysis and interpretation of data will monitor conditions and significant trends in the health of our environment. Of equal importance are the explanations for these trends and the actions we are taking to sustain and enhance the natural environment. By increasing awareness of the state of our life-support system, we should be stimulated to protect it through better decision making and management.

Contaminants in Canadian Seabirds is one indicator of the health of our country. If you are interested in obtaining more information on SOE Reporting, please write to:

State of the Environment Reporting Branch
Environment Canada
Ottawa, Ontario
K1A 0H3

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Acknowledgements

The data presented in this report were derived from studies that were started in the late 1960s by biologists in the Canadian Wildlife Service. I would therefore like to acknowledge the work carried out by all of those people, which continues today as part of the program of the Toxic Substances Evaluation and Monitoring Division, Wildlife Toxicology and Surveys Branch, of the Canadian Wildlife Service.

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Chapter 1
Introduction

From gulls scavenging along beaches to albatrosses soaring far out at sea, seabirds are among the most visible inhabitants of oceans and coastlines. Along with other marine plants and animals, they are links in complex marine food webs. Some of the larger gulls prey on other seabirds and their eggs, Northern Gannets plunge after mackerel and squid, and storm-petrels patter over the ocean surface, picking up minute food particles and pelagic invertebrates.

Land animals also benefit from marine food webs: the grizzly bear feasts on Pacific salmon, the arctic hare may nibble on seaweed, and the guano from seabird colonies enriches the surrounding soil and its inhabitants.

People are also part of marine food webs. Many Canadians depend directly on resources from the sea. Residents of Newfoundland and native people in the North regularly harvest seabirds or their eggs; along the country's coasts, people catch fish and gather marine algae and shellfish for their own consumption. Marine fisheries play an important role in the economy of Canada: they contributed more than $2 billion in 1985.

Coastal areas with abundant wildlife are important in other ways in the lives of Canadians. They offer opportunities for recreation, relaxation and wildlife appreciation. Marine mammals and colonial seabirds such as the Atlantic Puffin have a special appeal for tourists.

Furthermore, marine plants and animals have roles in ecological processes that are necessary for survival. For example, marine phytoplankton is probably responsible for as much as 90% of this planet's primary production (the conversion of the sun's energy to growth) and thus has an impact on the oxygen/carbon-dioxide balance in the atmosphere.

Spontaneous reactions between organic compounds dissolved in prehistoric oceans were the origins of life on earth. Today, however, there are new deadly organic compounds in the sea that threaten all life. The synthetic organochlorines, because they dissolve in fat rather than water, and either resist breakdown or break into even more persistent molecules, are present in virtually all marine life, from microscopic bacteria to the largest whales. Contamination by these compounds, and by increased levels of heavy metals, has occurred in the last century.

Measuring contaminants in seabirds is a way of keeping track of the influx of organochlorines and heavy metals into the marine environment and monitoring their fates.

Although effects on humans are not the focus of this report, there is no doubt that contaminants in marine food webs potentially threaten human health and economic activities. In order to safeguard human consumers of marine products, federal agencies have developed guidelines for maximum levels of contaminants in a number of commercial species.

Preventing contamination is obviously important. The federal *Pest Control Products Act* restricts pesticide use. The *Canadian Environmental Protection Act* (CEPA) is aimed at controlling the future input of many other toxic substances into our environment.


Canadian Wildlife Service

The Atlantic Puffin feeds by diving offshore for fish and zooplankton. These burrow-nesting birds are eaten in turn by mammals, such as foxes (if they can gain access to the island colonies), and by predatory birds, like gulls.

Signs of trouble in marine ecosystems

The story of the discovery of persistent pollutants in the marine environment began, like many of our current environmental issues, in the 1960s. That was the era when Rachel Carson published *Silent Spring*, blaming the widespread use of deadly pesticides for extensive environmental damage. Carson (1962) considered DDT to be the main cause of the large numbers of songbirds found dead in areas that had been sprayed with pesticides. Her book sparked a heated controversy about the environmental effects of DDT and other synthetic chlorinated insecticides. Some hailed these compounds as the answer to global problems caused by insect-borne diseases, such as malaria and typhus, and as powerful weapons against insect infestations of forests and crops. Others, as more reports of wildlife mortality began to pour in from all over North America and Europe, claimed that the organochlorine insecticides (e.g., DDT, dieldrin, heptachlor, endrin) were accumulating in the environment and were ultimately a danger to all living things.

At first, the marine environment received little attention. Although pesticides had been sprayed on coastal salt marshes in some countries and also entered the oceans in contaminated water and waste, the immense volume of the oceans was expected to dilute the organochlorines to negligible concentrations.

However, this attitude changed when problems with seabirds arose. One of the earliest incidents occurred in 1964 in the Dutch Wadden Sea, when hundreds of terns, spoonbills, cormorants, and eiders were found dying with symptoms characteristic of pesticide poisoning (Koeman *et al.* 1968). Investigations revealed the presence of organochlorine pesticides — dieldrin, endrin, and telodrin — in the tissues of these birds, with the highest levels in birds collected near a local pesticide manufacturing plant. At about the same time, Moore and Tatton (1965) reported the presence of a number of organochlorine contaminants in the eggs of seabirds in Britain.

Within a few years, scientists reported problems in North American seabirds. High concentrations of DDT compounds were detected in fish and fish-eating birds from Los Angeles Harbour in the late 1960s. Numbers of Brown Pelicans and Double-crested Cormorants were declining, and many biologists believed that the nesting failures were due to DDT in the eggs (Blus *et al.* 1971; Gress *et al.* 1973). A local DDT factory that was dumping its wastes into the Los Angeles sewer system was found to be the source (Anderson *et al.* 1975).

In Canada, biologists studying the Northern Gannet on Bonaventure Island, on the Gaspé coast of Québec, noticed that many eggs never hatched or were mysteriously lost

Although virtually all uses of the organochlorines are currently banned or restricted in Canada, contamination of the marine environment continues to be a cause for public concern. This concern is reflected in the media.


UWO scientists fears PCBs may doom ocean mammals
Whales, dolphins and seals are in jeopardy, says geneticist Joe Cummins.
By Peter Geigen-Mill
The London Free Press

Scientists turning to gangling seabird as barometer of Canada's environmental health
By LARRY PYNN
Southam News
OTTAWA (SN) -- The double-crested cormorant - a dark, flourishes all the way from Vancouver Island to the Maritim barometer of Canada's environmental health.

Cadmium, mercury found in flesh of Arctic whales
BY MIRO CERNETIG
The Globe and Mail
INUVIK, NWT

Toxic substances accumulate in wildlife

(Nettleship 1975). Breeding success was very low, and the numbers of birds at the colony appeared to be decreasing. As found with the pelicans in California, many gannet eggs were laid with very thin shells; nine out of ten unhatched eggs found in 1969 were completely lacking the outside cover of the eggshell (Elliott *et al.* 1988*b*).

Fish-eating birds breeding in the Great Lakes were also in trouble. Gilbertson (1974), Gilman and co-workers (1977), and Weseloh and co-workers (1983) reported reproductive failures and hatching deformities in gulls, cormorants, and terns nesting in the Great Lakes. Pollutants in the Great Lakes system may affect coastal seabird populations because of transport by the St. Lawrence River.

The scientific response

The preceding reports of reproductive problems and population declines in fish-eating birds feeding at sea and in freshwater systems prompted scientific investigations of the levels of contaminants in seabirds and in the marine environment.

Some research focused on trying to establish the relationship between the concentrations of toxic chemicals in eggs and the observed reproductive failures of many fish-eating birds. Although there was circumstantial evidence that the two were related, the mechanism by which the chemical altered the reproductive process had yet to be worked out. Some scientists did not believe that a cause-and-effect relationship existed, and this controversy slowed the process of imposing more restrictions on the use of organochlorine insecticides.

Other research focused on studying the effects observed in the colonies. Since the late 1960s, Canadian Wildlife Service biologists have visited seabird colonies and measured changes in numbers, breeding success, eggshell thickness, hatching rates, incidences of birth defects in the nestlings, and even subtle changes in biochemistry and tissue structure. They have collected eggs and tissues from many of the seabird species that breed in Canada and analyzed them for the presence of contaminants. The scientists have attempted to establish whether the observed effects should be attributed to toxic chemicals or other factors. Seabird populations may decline for many reasons, including high rates of drowning in fishing nets, hunting or trapping of adults, egging or disturbance at the breeding colonies, introduced mammalian predators, competition from fisheries, or habitat destruction.[1]

This account is based on a Canadian Wildlife Service technical report (Noble and Elliott 1986), which reviewed much of the available data on contaminants in seabirds in Canada. It briefly describes the contaminants and how they behave and presents the results of a program initiated by the Canadian Wildlife Service in the 1960s to track levels of environmental contaminants in seabirds on the east and west coasts and in the Arctic.

1 Not all human activities are detrimental to seabirds. Many species (gulls, fulmars, shearwaters, and pelicans) have learned to profit from people, by such activities as following fishing boats or scavenging in garbage dumps. Other species will readily nest in artificial habitat such as on dikes, breakwaters, or buildings.

Chapter 2

The contaminants

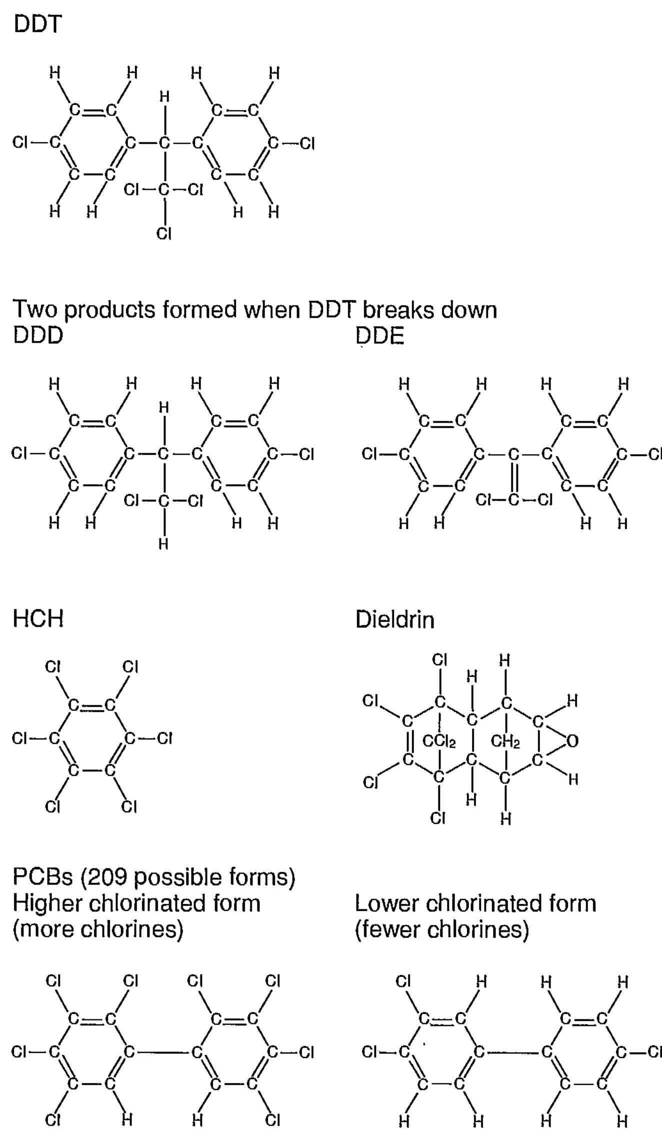
One of the effects of human activities during the past century has been the synthesis and production of over 50 000 new chemical substances, many of which are readily broken down to new compounds by natural processes. Human activities have also increased the levels of certain naturally occurring substances in the environment. The research reported here looked at levels of fat-soluble chlorinated pesticides; chlorinated industrial chemicals; and mercury, lead, and cadmium in Canada's marine environment. Appendix 1 briefly discusses other marine pollutants, such as petroleum hydrocarbons, radionuclides (from nuclear generating stations and nuclear weapons testing), and nonbiodegradable material such as plastics and styrofoam.

Organochlorine pesticides

The early (first generation) synthetic pesticides were organochlorines, also known as chlorinated hydrocarbons: compounds made up mainly of carbon, hydrogen, and chlorine (Figure 1). The organochlorine pesticides include dieldrin, heptachlor, chlordane, hexachlorocyclohexane (HCH), mirex, toxaphene, and dichlorodiphenyltrichloroethane (DDT), which degrades mainly to dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE). No organochlorine pesticides were ever manufactured in Canada and none were ever directly applied to Canadian ocean waters; however, pesticides in this group were widely applied to control agricultural and forest pests, and reached the oceans indirectly.

DDT, a broad-spectrum insecticide, was first used in North America in public health campaigns to control lice and on agricultural crops in the 1940s (Carson 1962). Its low cost and remarkable effectiveness against agricultural pests led to its global popularity. In Canada, it was used to control biting flies and spruce budworms and to destroy insect pests on orchard, vegetable, and tobacco crops and on lawns, until restrictions were imposed in the early 1970s. Forest spraying was the main use. More than 7 million kg of DDT were sprayed on forests in New Brunswick and Quebec between the early 1950s and the late 1960s (Nigam 1975).

Figure 1
The molecular structures of some organochlorines



In the 1950s and 1960s, DDT was sprayed from the air on forests in Quebec and New Brunswick to destroy spruce budworms, which fed on trees valued by the pulp and paper industry.

DDT is usually very stable in soil or water, but it may be transformed by metabolic processes in living systems into its breakdown products, DDD and DDE. The persistence of DDE, which was not widely suspected during the early years of usage, leads to its accumulation in biological tissues and its biomagnification in food chains (see box on page 23).

Dieldrin and aldrin, which rapidly degrades to dieldrin, were extensively used in Canada, mainly in the control of crop pests found in the soil (such as wireworm, root weevils), but also on lawns and golf courses, and in seed treatments (Frank *et al.* 1975). These compounds were usually applied directly to the soil. Like DDT, dieldrin is very persistent in the soil and in biological tissue.

Heptachlor was also widely used in Canada on agricultural crops and for protecting seeds and bulbs. Like dieldrin, it was often applied to the soil. Heptachlor is rapidly degraded to heptachlor epoxide, a persistent contaminant in most biological systems.

Technical chlordane is a mixture of chemicals including heptachlor, nonachlors, and chlordane (Cochrane and Greenhalgh 1976). Although the heptachlor component is degraded to heptachlor epoxide, one of the most persistent breakdown products of chlordane in seabirds is oxychlordane. Not only persistent, oxychlordane is more toxic than most other organochlorines (Stickel *et al.* 1979). The retention of the various breakdown products of chlordane varies among species.

Hexachlorocyclohexane (HCH) was widely used in Canada until 1970 in the control of soil pests, wood borers, and lice and ticks on livestock, and as a household insecticide. BHC, the original pesticide formulation, consists of a mixture of alpha, beta, and gamma HCH, and is still used extensively outside North America. HCH is less persistent than other organochlorines and is seldom found at high levels in birds (Kan 1978). The currently used formulation, lindane, consists of more than 99% gamma-HCH. (It has not been used in Canada to treat wood for export since the late 1970s. Before that, lindane contamination of sediments in estuaries and bays on the British Columbia coast occurred when the chemical was used to protect wood for export and was discharged in wash water and tailings.)

Use of *hexachlorobenzene* (HCB) as a fungicide in Canada was outlawed in 1970. However, the compound still occurs, with other chlorinated benzenes, as a contaminant in industrial effluent (Hallett *et al.* 1982). HCB does not appear to be easily metabolized by birds and is very persistent in tissues (Kan 1978).

Mirex, although used in the United States in the control of fire ants, has never been registered as a pesticide in Canada. It is sometimes used as a flame retardant and has been detected in industrial effluent in the Great Lakes (Norstrom *et al.* 1980).

Toxaphene is a broad spectrum pecticide that was used in Canada to control insect pests and in fish eradication programs (Eisler and Jacknow 1985). It has been shown to biomagnify in aquatic food webs, but is usually not detected in birds. Its use in controlling fish was discontinued by 1970, and all uses were banned in Canada in 1980.

Chlorinated industrial chemicals

Chlorinated industrial chemicals differ from pesticides in that they are not directly applied, but are both intentionally and accidentally discharged into the environment. The organochlorines in this group are polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and HCB. (HCB is discussed under "Organochlorine pesticides.")

PCBs, the best known of these industrial contaminants, have a basic two-ringed structure with 10 attachment points for chlorines (Figure 1), resulting in over 200 possible structures (congeners). These congeners differ in the amount of chlorine present. Most technical mixtures (mixtures produced by ordinary commercial processes) contain congeners with 3–6 chlorine bonds. PCBs had a wide range of uses, including hydraulic fluids, lubricants, plasticizers, and pesticide extenders and, most frequently, in closed-circuit electrical heat-transfer systems (Nisbet and Sarofim 1972; Tanabe 1988).

Since 1972, the Monsanto Corporation, the sole manufacturer of PCBs in North America, has restricted sales

Environment Canada

Workers at Dorval airport near Montreal drain transformers that contain PCBs.

except for closed-circuit uses (Peakall 1972). Nevertheless, in 1977 the dangers of PCB use were the main impetus for the *Canadian Environmental Control Act* and the U.S. *Toxic Substances Control Act*, which revoked all nonelectrical uses of PCBs (Canadian Council of Resource and Environment Ministers 1986). The fire at the PCB storage facility in Saint-Basile-le-Grand, Quebec, triggered public fears about PCBs. In 1988, the Canadian Council of Ministers of the Environment pledged to remove all PCBs from use in Canada by 1993. In 1989, strict regulations on the transport, storage, and disposal of PCBs came into effect.

PCBs continue to reach the marine environment through accidental spills, in industrial effluent, in leakage from transformers, when wastes containing PCBs are dumped at sea, and when PCB-impregnated products are incinerated at sub-optimal temperatures. In a recent publication, Tanabe (1988) estimated that 375 000 t of PCBs were present in the environment. Most (61%) of that is believed to be in the seawater of the open ocean!

Although all PCBs are chemically stable and therefore very persistent, those with fewer chlorines tend to be more easily metabolized by birds than the higher chlorinated forms. In fact, PCBs behave very similarly to DDT compounds in the marine environment. DDE and the higher chlorinated PCBs are more prevalent in animals feeding at higher trophic levels (Tanabe *et al.* 1984).

Chlorinated dioxins and furans are another particularly hazardous group of industrial chemicals recently detected in Herring Gulls from the Great Lakes, Great Blue Herons and Pelagic Cormorants from the Strait of Georgia, and Double-crested Comorants from across Canada. Likely sources of dioxins and furans in the environment have been identified as use of chlorophenols in the wood industry, the bleaching of wood pulp using chlorine, incineration of chlorine-containing materials (including additives used in leaded gas and diesel fuel), and incidental contamination in the manufacture of common herbicides (Elliott *et al.* 1988*a*). One isomer (2,3,7,8-tetrachlorodibenzo-p-dioxin, or 2,3,7,8-TCDD) is toxic at only a few micrograms per kilogram (µg/kg, equivalent to parts per billion). Currently, research is underway to identify the sources of dioxins and furans found in fish-eating birds from the west coast and to determine whether these contaminants are affecting the health of marine birds. It was in 1980–81 that chemists developed tests to detect dioxins and furans. Although retrospective analysis of eggs and tissues stored in the National Specimen Bank (see box) is possible, most data on these microcontaminants in marine birds begins in the 1980s.

Chronology of pesticide use in Canada

Peak use of most organochlorine pesticides (DDT, aldrin/dieldrin, heptachlor, toxaphene, HCH) was during the 1950s and 1960s. For example, between 1952 and 1969, over 5 million kg of DDT were sprayed annually on forests in New Brunswick, with lesser amounts in Nova Scotia, Prince Edward Island, Quebec, and Maine (Nigam 1975).

The earliest restrictions on use of organochlorine pesticides came into effect between 1969 and 1971 (Figure 2), as evidence of the dangers increased (Noble and Elliott 1986). During the mid-1970s, stricter restrictions were imposed on the use of DDT, aldrin/dieldrin, and heptachlor. Due to stockpiling, however, use of some of these pesticides probably continued for several years. Chlordane use in Canada increased during the 1970s, when it replaced the banned pesticides, but in 1978, most of its uses were also revoked. Toxaphene was banned in 1980.

Retrospective analysis

As analytical techniques improve, our capacity to detect and identify different compounds increases. This is why portions of each sample are stored in a special freezer in the National Specimen Bank, located in Hull, Quebec (Elliott *et al.* 1988*c*).

Storage at temperatures below -40°C prevents further degradation of most organic contaminants. Therefore, the entire series of samples is available for analysis, if desired. Retrospective analysis of a series of samples allows scientists to apply the same analytical techniques on all samples and makes it possible to identify substances for which analytical techniques were not available when the tissue was collected.

Figure 2
Chronology of organochlorine use in North America

1929	First commercial production of PCBs
1947	First widespread use of DDT
1950s	First uses of dieldrin and heptachlor
1960s	Peak use of organochlorine pesticides
1965	Population decline of Peregrine Falcon focused attention on DDT
1970	Initial restrictions on the use of HCB, HCH, toxaphene, and heptachlor. (Heptachlor continued to be used in midwestern United States.)
	Reduction of mercury use in chlor-alkali plants
	Scientific investigation confirmed the presence of PCBs in the U.S. environment
1971	Initial restrictions on the use of DDT and dieldrin
1972	PCB manufacturer began voluntarily to restrict sales
1973	Use of HCB as a fungicide banned
1975	DDT banned except for a few minor uses
1976	Almost all uses of heptachlor banned
	The *Toxic Substances Control Act* passed in the United States
	The *Environmental Contaminants Act* passed in Canada prohibiting all "open" uses of PCBs
1978	Some restrictions on the use of chlordane in Canada.
	U.S. banned all uses of mirex
1980	Mexico restricted use of DDT, HCH, dieldrin, and heptachlor.
	Further restrictions on use of toxaphene in Canada
1980–81	Chemists developed tests to detect chlorinated dibenzo-dioxins and chlorinated dibenzofurans
1982	Heptachlor restricted in midwestern United States
1985	Registration of all DDT products discontinued in Canada
1986	Further restrictions on the use of chlordane
1988	The *Canadian Environmental Protection Act* (CEPA) passed
1988	Use of existing stocks of discontinued DDT products stopped
1990	No further manufacturing of dieldrin, aldrin, endrin

In 1989, the following organochlorine pesticides were registered for use in Canada.

Chemical	Permitted use
methoxychlor	vegetable crops
endosulfan	vegetable crops
lindane	livestock, orchards seed treatment on canola
chlordane	termite control
aldrin/dieldrin	termite control
heptachlor	nursery seed dips
dicofol	orchards
endrin	grain, canola, potatoes, flax, mustard

Methoxychlor, endosulfan, and lindane do not appear to last long in the environment. Chlordane, aldrin, and dieldrin can be applied only by licensed operators and under provincial permits. Endrin has not been used in Canada for several years. The few remaining uses of dieldrin and heptachlor in nurseries probably do not contribute significantly to environmental levels outside greenhouses. The effects of dicofol (which may contain DDT compounds) are currently being investigated. The registration of all DDT products was discontinued in 1985. The terms of discontinuation allowed for the use and sale of existing stocks until 31 December 1990. These discontinued products were used for bat control and required provincial use permits. Ontario was the only province where many permits were granted, and it stopped granting permits in 1988 due to pressure from naturalists' societies.

Chronology of pesticide use on a global scale

The timing of pesticide use and restriction in the United States closely parallels the pattern in Canada, with a few exceptions (Figure 2). For instance, the use of heptachlor was retained in most of the midwestern states until 1982. Pesticide applications of mirex were permitted in the U.S. until 1978, and until 1982 toxaphene was widely used against pests of cotton. Due to the greater amount of arable land, total amount of all pesticides used in the United States was about 10 times greater than in Canada.

Restrictions on the use of organochlorine pesticides in western Europe were imposed at about the same time as in North America. However, as western agricultural practices were increasingly adopted in developing countries, the use of organochlorine pesticides in those countries increased dramatically. DDT and BHC are probably the most widely used. Pesticide use in these areas is undoubtedly responsible for some of the continuing input of organochlorines into the atmosphere and long-range transport to other parts of the world.

Organochlorine use in Latin America may have a significant impact on Canadian seabirds that winter in the Gulf of Mexico (such as Northern Gannets) or farther south (such as Common and Arctic Terns). In Latin America, Brazil and Mexico are the major users of pesticides, but the amounts used are much less than those used in the U.S. during the 1960s. Regulations introduced in the mid-1980s by countries such as Ecuador, Mexico, Peru, and Venezuela resulted in a 20% reduction in organochlorine use in Latin America between 1978 and 1984 (Burton and Philogene 1986). Many countries have begun to switch to the less persistent organophosphates and pyrethroid pesticides, so organochlorine pesticide use in Latin America has likely passed its peak.

Heavy metals

The heavy metals currently suspected of having detrimental effects on the health of seabirds are lead, cadmium, and mercury, all of which are naturally occurring elements (Noble and Elliott 1986).

Mercury occurs naturally at low levels in ocean waters with no toxic effects on marine organisms. However, elevated concentrations as the result of human activities can be extremely dangerous.

In Canada, the major human-derived sources of mercury in the 1960s were chlor-alkali plants that produced bleach and other caustic fluids and pulpmills that used mercurial slimicides (Fimreite *et al.* 1971). These industries tended to be located on the shores of large rivers such as the St. Lawrence River, and along the coast (for example, Chaleur Bay, New Brunswick, and the Strait of Georgia, British Columbia).

In 1970, legislation was passed to reduce mercury discharge from all possible sources, including smelters, municipal wastewater treatment plants, and pulpmills. An additional use of mercury — in seed dressings — was cancelled in 1973.

Today, anthropogenic sources of mercury in the environment include leaching from areas of historical industrial activity, smelting processes, coal-burning plants, and the release of mercury following flooding behind hydroelectric dams (Bodaly *et al.* 1984).

Much of the mercury released by these processes is inorganic, but bacteria can transform it to methylmercury. Methylmercury differs from inorganic forms of mercury in being efficiently absorbed from food and, like organochlorines, readily biomagnified through food chains (Scheuhammer 1987). It is chemically stable and accumulates in a variety of tissues including muscle tissue. Because most of the mercury stored in fish muscle is methylmercury, fish-eating birds are exposed mainly to that form.

Mercury's capacity to biomagnify in aquatic food webs was revealed by the presence of high concentrations of mercury in fish-eating birds sampled in the late 1960s in areas near chlor-alkali plants or pulpmills using slimicides (Fimreite *et al.* 1971).

Cadmium, another naturally occurring element, is often found at elevated levels in marine organisms. In Britain, seabirds that feed on pelagic zooplankton, such as puffins and storm-petrels (Osborn *et al.* 1979), and their predators (Hutton 1981) had the highest concentrations of cadmium in their tissues. Industrial sources of cadmium in Canada include base metal mines, smelters, fertilizer plants, and thermal power plants.

Lead is a contaminant in the effluent from lead smelters, thermal power plants, and metal mines, in sewage sludges, and in automobile emissions. Where seabirds are hunted, as in Newfoundland and parts of the Arctic, lead poisoning of birds from embedded lead shot, which affects some waterfowl inland, is a possibility, but not yet reported. Lead in the tissues may, in turn, affect predators that feed on the seabirds.

Chapter 3
Movements of contaminants

By the 1960s, DDT and other organochlorine contaminants had spread to the most remote areas of the world. Bogan and Bourne (1972) found a Glaucous Gull dying on Bear Island in the Arctic (north of Norway) in 1969, with high levels of DDT and PCBs in its liver. Sladen and co-workers (1966) found DDT and PCBs in eggs of Adelie Penguins in the sub-Antarctic. As these penguins do not migrate outside the sub-antarctic zone, this proved that organochlorines could be transported tremendous distances.

Organochlorine dynamics in the marine ecosystem

Most uncontained organochlorines eventually evaporate to the atmosphere (Figure 3). Once in the upper atmosphere, organochlorines may be carried by air masses for several months before being re-deposited to earth and the oceans in rain or snow (Norstrom *et al.* 1988). Because organochlorines deposited on the ocean surface often evaporate again, this is a continuous cycle. Transport in the atmosphere is probably the main route by which organochlorines reach the ocean.

Another major route of pollutants to the ocean is river runoff. Although organochlorines are not easily dissolved in water, they readily attach themselves to small particles which are carried by water currents. Pollutants deposited on lakes or discharged directly into rivers are carried downstream towards the coast. Therefore, the mouths of rivers draining large watersheds of agricultural or sprayed forest land are likely to be highly contaminated.

Industrial pollutants also enter the oceans by direct discharge from factories along the coasts, through the flushing out of ships' holds at sea or in port, and through ocean dumping of waste material.

In the oceans, currents transport suspended pollutants long distances. Some coastal areas of Canada may receive a considerable load of organochlorines in currents originating near areas of high pesticide use. For example, many chemicals used in California may be carried north by the Davidson Current to the shores of Vancouver Island. In contrast, the Labrador Current, which flows southward into

Herring Gulls feed on land and close to the shore during the breeding season. They readily adapt their feeding habits to eat what is available, including garbage.

the Gulf of St. Lawrence, is likely to be relatively pristine. The quantity of organochlorines transported by ocean currents depends on the density of suspended particles in the water. Along with such factors as temperature and salinity, this varies seasonally.

Within the water column, the movements of organochlorines are poorly understood. Pollutants are eventually transferred to the sediments of the ocean floor, more rapidly in shallow water, and more slowly where the water is constantly being mixed. Organochlorines deep in the sediments are inactive, and may persist for centuries. A certain amount slowly re-enters the water column. However, large quantities may be released when the sediments are disturbed drastically, such as in dredging operations. Estuaries receive the suspended material in river runoff, and therefore high pollutant concentrations may be found in the sediments and the bottom-feeding animals associated with them. This includes seabirds, such as Double-crested Cormorants and Black Guillemots, that feed mainly on benthic fish.

Another zone of concentration is the surface micro-layer of the ocean. This surface layer is often rich in nutrients because of the high density of sunlight-dependent phytoplankton and the deposition of airborne particles right at the surface. Atmospherically deposited pollutants fall directly on this surface and are absorbed by the high concentration of fat particles there (Seba and Corcoran 1969). The higher concentrations of organochlorines in this surface layer are believed to be responsible for the elevated levels reported in some surface-feeding seabirds (Pearce *et al.* 1979).

Biomagnification

Animals may accumulate contaminants over time if the amount that they consume is greater than the amount they can rid themselves of by excretion and metabolism. Biomagnification is the process by which contaminants are accumulated to higher concentrations by each trophic level of the food chain (see box on page 23). Organochlorines attached to particulate matter are absorbed by small zooplankton, which are in turn ingested by larger zooplankton and other marine invertebrates. The fat-soluble organochlorines accumulate in the fatty tissues of fish that feed on zooplankton and are transferred up the food chain to the predators of fish, such as seabirds and marine mammals. Generally, organochlorine concentrations in seabirds are often several orders of magnitude greater than those in fish, and those in fish are several times higher than those in zooplankton, which are in turn significantly greater than those in the surrounding seawater.

In terms of biomagnification of toxic substances, it is the number of steps in the food chain (trophic levels) that is important, as well as the capability of each prey species to break down toxic chemicals. For example, although organochlorines are readily accumulated in the fat of fish, there is less evidence that they are accumulated in the bodies of such invertebrates as mussels or crustaceans.

Seals, which feed on a diet similar to that of seabirds, have equivalent concentrations of most organochlorines. However, some marine mammals (particularly small whales) are less able to metabolize certain PCBs than seabirds or terrestrial mammals (Tanabe *et al.* 1987). In a study of contaminants in an arctic food chain, polar bears, which prey on seals, were found to have the highest concentrations of most organochlorines. Moreover, the proportions of different components had changed considerably from those in their prey (Muir *et al.* 1988). As the organochlorine molecules moved up the food chain, the more readily metabolized compounds were eliminated so that only a few particularly persistent forms were present at high concentrations in the top predator. Figures 4 and 5 show examples of biomagnification in two marine systems.

Organochlorine dynamics within a seabird

Organochlorines enter seabirds in their food (Figure 6). After absorption from the gastrointestinal tract, the chemicals

Figure 3
Movement of organochlorines (OCs) in the marine ecosystem

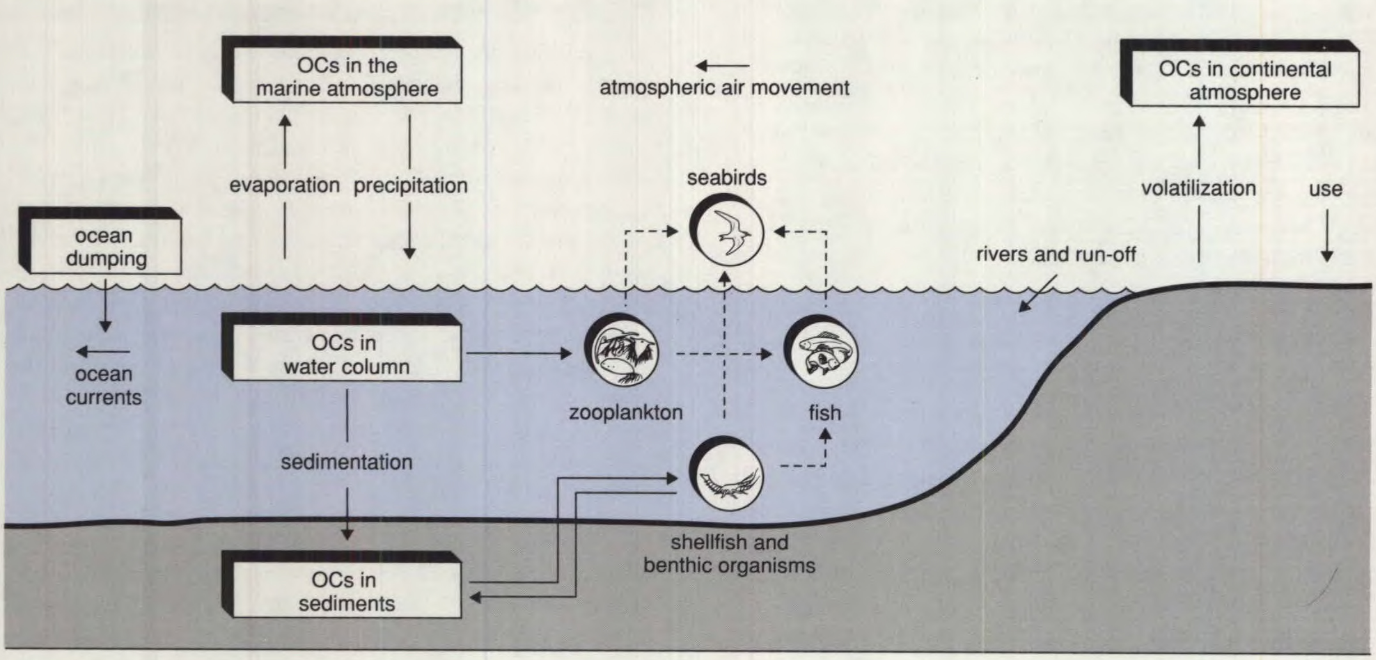
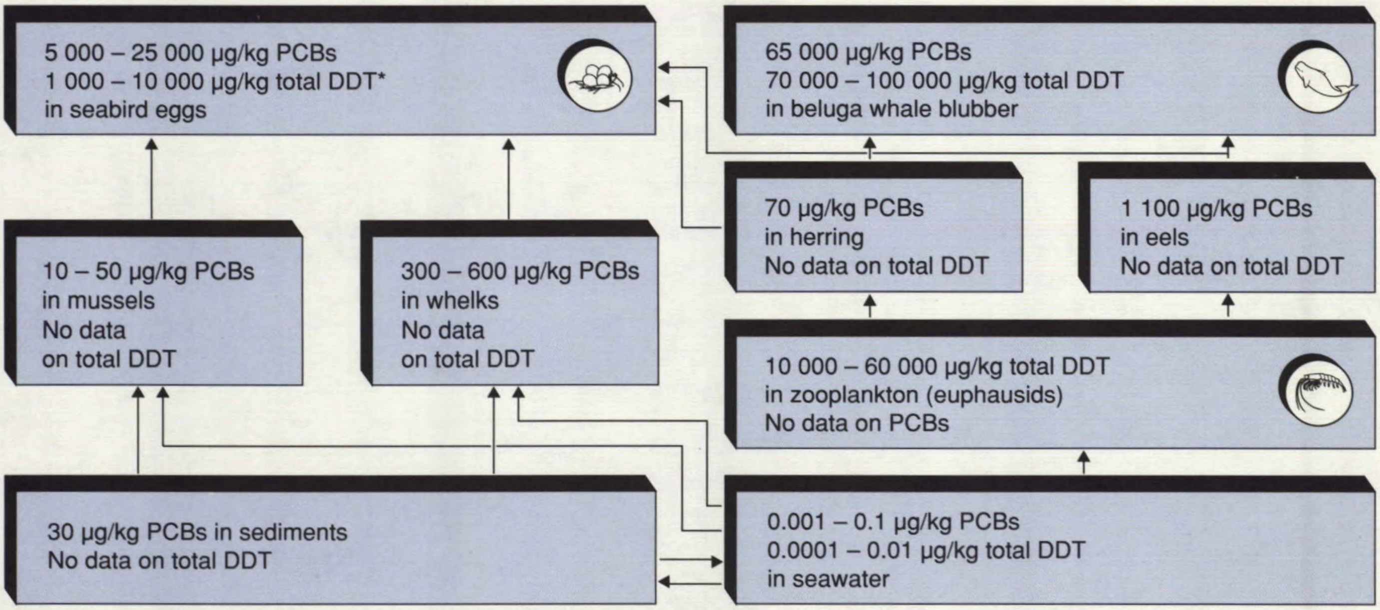
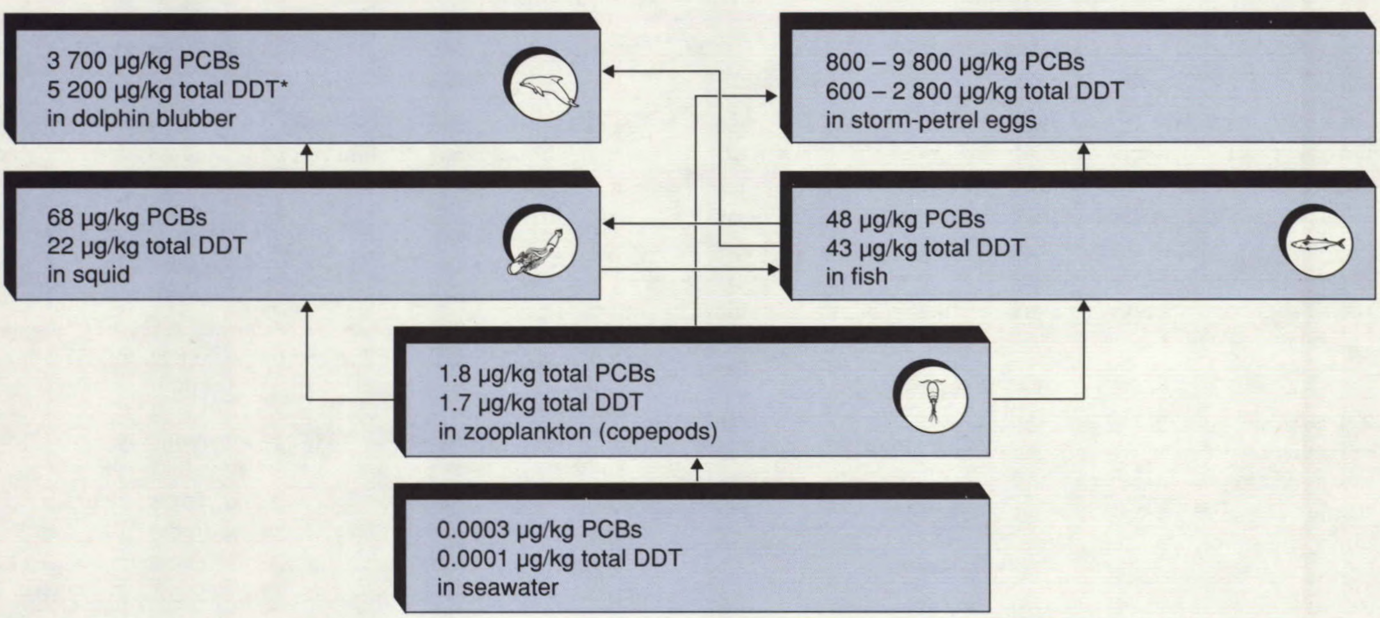


Figure 4
Organochlorines in a food chain in the St. Lawrence estuary



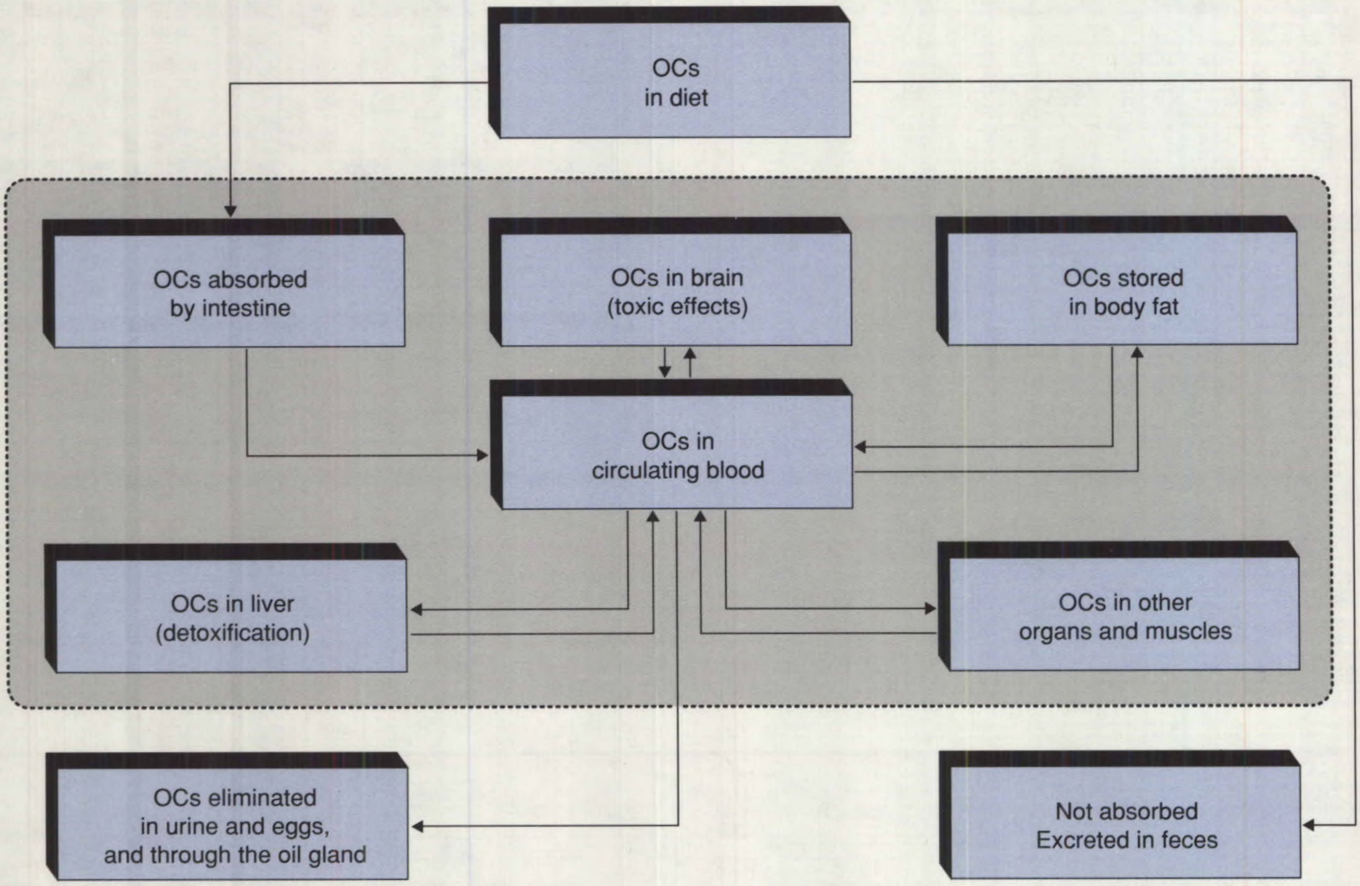
SOURCE: Data from Delval *et al.* (1986); Massé *et al.* (1986); Noble and Elliott (1986).
* Total DDT = DDD + DDE + DDT.

Figure 5
Organochlorines in a North Pacific food chain



SOURCE: Data from Tanabe *et al.* (1984) and Noble and Elliott (1986).
* Total DDT = DDD + DDE + DDT.

Figure 6
Organochlorine (OC) dynamics within a seabird

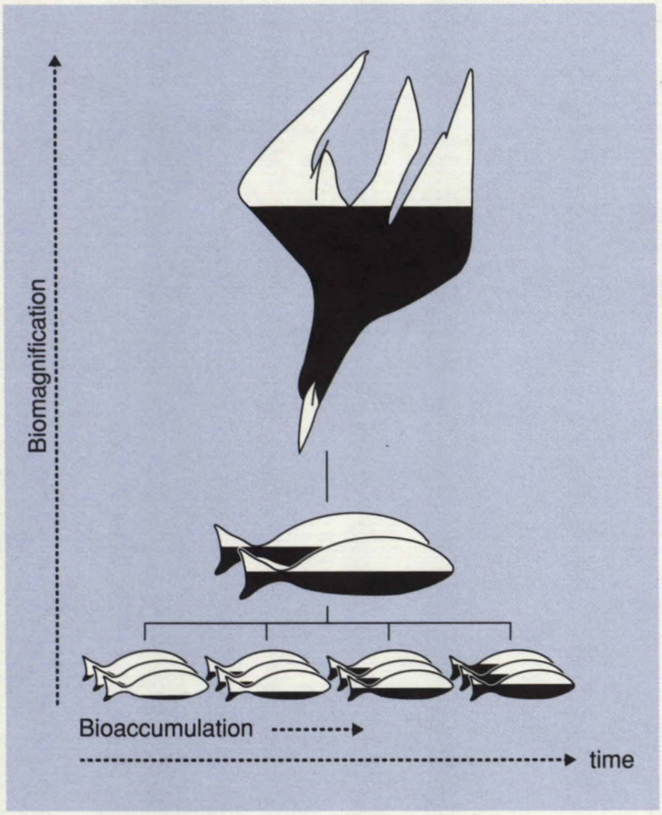


enter the bloodstream. Organochlorines in blood pass through the liver where a small proportion are detoxified. The rest continue to circulate in the bloodstream to other parts of the body. A certain amount is deposited in fat, most of which is in a thick insulating layer under the skin. A large proportion of the organochlorines are stored in this layer, where they remain immobile and relatively harmless, until that fat is metabolized.

Organochlorines in the bloodstream are also transported to the brain, and this is where they exert their immediate toxic effects — on the central nervous system. If the food items eaten are highly contaminated, enough organochlorines may be carried to the brain to seriously affect the bird. The damage to the central nervous system may cause convulsions, tremors, and loss of coordination. Those symptoms make it impossible for the bird to feed, so it may start to metabolize its stored fat. This releases more organochlorines into the bloodstream, thus accelerating the neural damage and eventually leading to death.

Organochlorines stored in fat are also released when that fat is metabolized by the seabird to provide energy for warmth, movement, egg production, or other physiological functions. This means that the stress on a seabird that is starving or exposed to oil is compounded by the organochlorines that enter its bloodstream at such times.

Seabirds have several methods of ridding themselves of organochlorine contaminants. One way is by breaking them down to less harmful substances by means of detoxifying enzymes in their livers. Direct excretion in the feces and the urine and through the uropygial gland are other processes. Females may also rid themselves of organochlorines in their eggs.



In normal circumstances, organochlorine levels in a seabird are in dynamic equilibrium: this means that input through the diet is balanced by elimination through excretion and metabolism, with the bulk of the contaminants stored in the fat acting as a reservoir. Factors that might affect this equilibrium include seasonal fluctuations in fat levels, changes in diet, migration from an uncontaminated area to a contaminated area, and other stress caused by factors such as prolonged flight, sickness, or exposure to oil.

Diet is obviously the most important factor, because that is how organochlorines enter the seabird's body. Diet varies among seasons, years, locations, and individuals, often according to sex or age. Although the diet of a seabird during all stages of its annual cycle is important, concentrations of organochlorines in eggs are most influenced by the diet in the month or two prior to egg-laying.

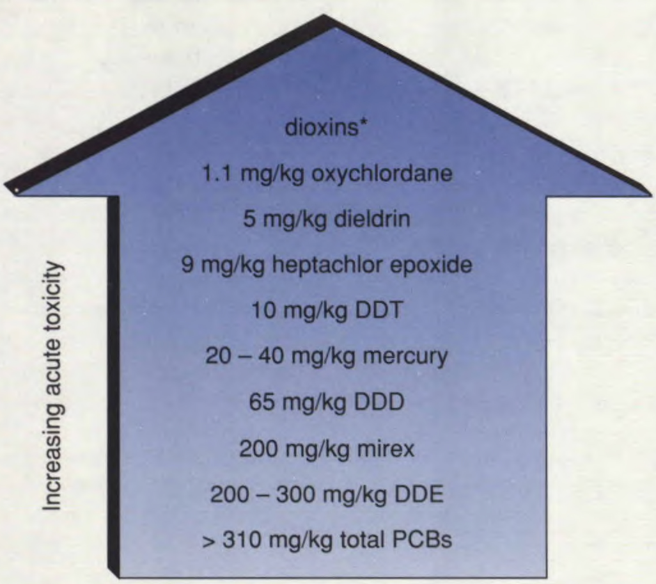
Chapter 4

Scientific evidence of health effects caused by contaminants

Organochlorines are contact poisons, designed to enter insects through the body wall or respiratory system (Carson 1962). In vertebrates, organochlorines have their greatest effect on the central nervous system. Direct exposure can be fatal to birds. Almost all experimental work on the acute toxicity of organochlorines to birds has been with species that are easy to keep in captivity (doves, quail, blackbirds, cowbirds, ducks, and starlings), rather than seabirds. Experimenters determined diagnostic lethal levels in the brain by comparing the concentrations of the chemical in the brains of the dead birds with those in the survivors.

Figure 7 lists the brain concentrations of commonly detected organochlorines that are hazardous to birds. The most toxic of these are dioxins, oxychlordane, heptachlor epoxide, dieldrin, and endrin (Stickel *et al.* 1969; Stickel *et al.* 1979; Ohlendorf *et al.* 1981). Oxychlordane may be hazardous at levels as low as 1.1 mg/kg (Stickel *et al.* 1979). DDT compounds are generally less toxic, with DDE (the main breakdown product of DDT) likely to cause death at brain levels greater than 200 mg/kg (Stickel 1973). Most PCBs are even less acutely toxic to birds, with lethal levels in brains often greater than 1 000 mg/kg (Heath *et al.* 1972). Stickel and co-workers (1984) later concluded that total PCB levels greater than 310 mg/kg were probably hazardous. As families of birds differ widely in their response to organochlorines, due to differences in biochemical pathways and physiology (Walker and Knight 1981), the levels that are hazardous to seabirds may differ from the values shown in Figure 7. Dioxins and furans and some PCB congeners are toxic at extremely low concentrations.

Figure 7
Comparison of minimum hazardous brain levels reported in birds



SOURCE: Heath and Spann 1973; Ohlendorf *et al.* 1981; Porter and Wiemeyer 1972; Scheuhammer 1988; Stickel *et al.* 1979; W.H. Stickel *et al.* 1969, 1970, 1984; Stickel and Stickel 1969.

* Compounds like 2,3,7,8 TCDD are known to have toxic effects at extremely low levels, but hazardous levels in brains of birds have not been determined.

Evidence of direct mortality of seabirds due to organochlorine pesticides

Although seabirds seldom come into direct contact with organochlorine pesticides, there have been a number of incidents where seabirds feeding on contaminated prey have accumulated concentrations high enough to kill them. Incidents attributed to pesticide poisoning include the 1964 die-off of terns and spoonbills in Holland (Koeman *et al.* 1968), the death of a Glaucous Gull on Bear Island in the Norwegian Sea (Bogan and Bourne 1972), deaths of gannets in Britain (Parslow *et al.* 1972), and seabird "wrecks" in Europe and North America (Holdgate 1971; Scott *et al.* 1975). However, in some of these cases of apparent pesticide poisoning, it was difficult to establish a cause-and-effect relationship. Sick or dying birds that cannot feed attempt to survive by metabolizing stored body fat. This significantly increases the amounts of contaminants reaching the brain. The starving birds may then be in danger of direct organochlorine poisoning.

This scenario is considered the likely explanation for some seabird wrecks, incidents that involve large-scale mortality of seabirds at sea, usually following severe weather. Dead birds are often washed ashore, typically emaciated and often containing high concentrations of environmental contaminants. Wrecks of gannets (Parslow *et al.* 1972), murres (Scott *et al.* 1975), Razorbills, puffins, Dovekies, petrels, and cormorants have all been reported.

In Canada, no seabird deaths can be definitely attributed to direct organochlorine pesticide poisoning. A number of seabirds found dead of unknown causes in the late 1960s and early 1970s were analyzed for organochlorines. The highest levels detected — 49 mg/kg DDE, 81 mg/kg PCBs, and 1.4 mg/kg dieldrin in the brain of a Northern Gannet — although extremely high, are not diagnostic of pesticide poisoning based on evidence from experimental work (see Figure 7).

Sublethal effects of organochlorine pesticides

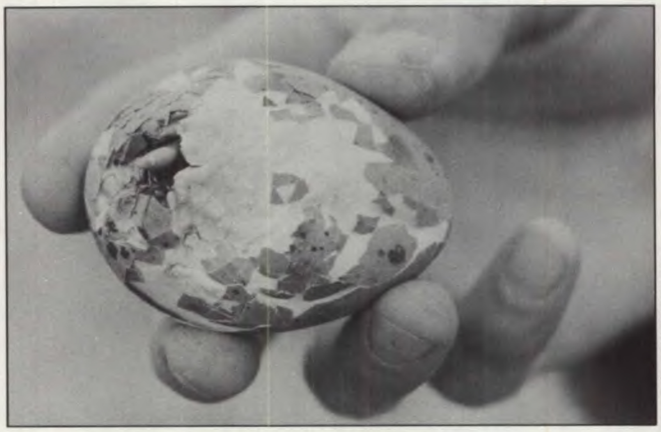
Most of the work on the effects of organochlorines and other pollutants on seabirds has focused on adverse effects on reproduction. High concentrations of an organochlorine in the body of a seabird may not kill it, but may interfere in biochemical pathways. Different contaminants have different effects.

Thinner eggshells and DDE

One of the common symptoms in most instances of reproductive failure was thin egg shells. Early reports of eggshell thinning involved fish-eating birds breeding in areas exposed to high levels of DDT. The contents of their eggs contained high levels of DDE. The initial reports were followed by others documenting eggshell thinning in a variety of predatory and fish-eating birds. By examining eggs in museum collections, scientists were able to track the onset of eggshell thinning (Anderson and Hickey 1972). In almost all cases, the initial decline of eggshell thickness started soon after 1947, when DDT was first widely used in North America. Thus, there appeared to be overwhelming circumstantial evidence that DDE (originating from DDT) was the cause of eggshell thinning.

The shell of the egg (mainly calcium carbonate) is formed just before laying. Experimental work on the effect of DDE on eggshell formation has suggested that DDE may interfere with the enzymes that react with carbonates or with other enzymes that take calcium from the blood (Cooke 1973). Whatever the process, less calcium carbonate is deposited, resulting in a thinner eggshell.

Eggshell thinning has been experimentally induced by dosing with DDE in experiments with American Kestrels (Wiemeyer and Porter 1970) and Mallards (Davison and Sell 1974), but much information has also been collected from the field. By plotting the concentrations of DDE against shell thickness, scientists were able to show a significant correlation in many species. The effect of DDE on eggshell thickness differs greatly among different groups of birds. The eggshells of chickens, quail, and songbirds are less affected by DDE than those of ducks, gulls, and pigeons, which in turn are less affected than those of pelicans, cormorants, hawks, and owls. Predatory and fish-eating species are among the most sensitive and, being at the top of the food chains, are also the most likely to be exposed to high levels in their prey.


Canadian Wildlife Service

The shell of this Lake Ontario Herring Gull egg was so thin that it was crushed during hatching. Eggshell thinning has affected some birds that breed in marine areas, in particular the Northern Gannets of Bonaventure Island in the Gulf of St. Lawrence.

Eggshell thinning reduces hatching success. Thin-shelled eggs are more likely to break or develop cracks fatal to the embryo inside. Seabird eggs often receive rough treatment because of the rocky surface of the nest site. Some species, like the Northern Gannet, incubate their egg under their feet. A general rule is that eggs with shells more than 20% thinner than normal are so likely to break that few birds laying these eggs will reproduce successfully. This does not mean that an egg with, for example, 30% eggshell thinning cannot hatch, but there is a low probability of the embryo surviving. Apart from the increased risk of breakage, thinner-shelled eggs may have structural abnormalities affecting gas exchange or temperature regulation, as was found in Common Terns (Fox 1976).

In Canada, a number of seabirds were found to be laying eggs with thin shells (Pearce *et al.* 1979). The Northern Gannets at Bonaventure Island exhibited eggshell thinning of more than 20% between 1968 and 1974, associated with high levels of DDE and other organochlorines in the eggs. Although not all nest failures could be attributed to shell breakage, egg loss rates were quite high. Other eggs failed to hatch. Breeding success was reduced from a normal level of 75% to as low as 29% in some years. This was the probable cause of the decline in

Highly toxic PCB congeners

PCBs are composed of complex mixtures of structurally similar compounds called congeners, which differ considerably in toxicity. Some congeners are as toxic as 2,3,7,8-TCDD, the most toxic dioxin. Until the mid-1980s, only some of the PCB congeners could be separated, so only estimates of the total amount of PCBs were reported. Many of the most toxic PCB congeners have now been detected in a wide variety of birds, fish, marine mammals, and terrestrial mammals in Japan and Canada (Tanabe *et al.* 1987; Norstrom *et al.* 1989). Current research on the toxicity of specific congeners should help to determine whether PCBs in the marine environment are having an impact on seabird health.

numbers at the colony (Chapdelaine *et al.* 1987; Elliott *et al.* 1988*b*).

Although eggshell thickness was not always recorded, eggs of Double-crested Cormorants from the St. Lawrence estuary and eggs of Fork-tailed Storm-Petrels from British Columbia contained DDE concentrations high enough to cause some eggshell thinning, based on evidence from field studies of related species. Nevertheless, there is little evidence that numbers of these species were seriously affected, although certain individuals may have failed to breed successfully.

Other adverse effects on reproduction

Investigations of the cause of eggshell thinning implicated DDE. Attempts to find out whether other organochlorines (dieldrin, heptachlor, HCB, PCBs) were affecting eggshell thickness were inconclusive. However, some of these compounds were found to have other adverse effects on reproduction.

Dieldrin reduces hatching success, mainly by killing the embryo. Although the sensitivity depends on the species, dieldrin concentrations as low as 1 mg/kg have been suspected of significantly reducing hatching success in some birds (Potts 1968; Wiemeyer *et al.* 1975). Dieldrin-related breeding failures have been reported in Shags (a type of cormorant) in Britain (Potts 1968) and Brown Pelicans in South Carolina (Blus *et al.* 1974).

In Canada, dieldrin levels in eggs of gannets in the late 1960s were high enough to have reduced reproductive success. In 1969, for example, the mean level in addled eggs (where the embryo had died) was considerably higher (1.17 mg/kg) than that in fresh eggs (0.64 mg/kg).

Canadian Wildlife Service

It is believed that deformities such as the crossed bill of this young Caspian Tern found in the Great Lakes in the early 1970s can be caused by high levels of organochlorines. Recently a small number of similar deformities have been reported in seabirds breeding in the Strait of Georgia.

There have been no studies on the effects of heptachlor, chlordane-related chemicals, mirex, or hexachlorocyclohexane (HCH) on seabird reproduction. Studies on kestrels suggest that heptachlor epoxide egg concentrations greater than 1.5 mg/kg might reduce breeding success (Henny *et al.* 1983).

In experiments with Herring Gull eggs, Boersma and co-workers (1986) found that HCB levels of more than 4.3 mg/kg caused 50% mortality of embryos. None of the eggs of Canadian seabirds contained nearly such high levels of HCB and heptachlor epoxide as these.

Effects of PCBs

PCBs are suspected of causing a variety of sublethal detrimental effects on fish-eating birds, including embryo mortality, interference with liver function, birth defects, tumours, skin lesions, and reduced growth rates (Gilbertson *et al.* 1976; Peakall 1987). Some of these effects have not been established in the field because other contaminants (such as dioxins) may also have been involved. It appears that the levels of total PCBs needed to cause many of these responses are quite high, greater than 50 mg/kg, although toxic effects due to particular congeners may occur at much lower concentrations. Elevated levels of PCBs and polychlorinated dioxins in eggs of Forster's Terns on the Great Lakes were associated with early embryonic death, crossed bills, and bone abnormalities (Hoffman *et al.* 1987). The average PCB level in the tern eggs was 22 mg/kg. High incidences of birth defects have not been reported in any Canadian seabirds, but no one has thoroughly investigated the possibility.

Effects of dioxins and furans

Because scientists have only recently been able to measure levels of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, we know little about their toxicity. However, one isomer, 2,3,7,8-TCDD, is known to be extremely toxic, and levels as low as 1 nanogram per kilogram (ng/kg, equivalent to a part per trillion) have been associated with a number of adverse effects in laboratory animals. Some of the furans are almost as toxic.

Dioxins were suspected of being a factor in chick edema disease in many fish-eating birds in the Great Lakes in the 1970s (Gilbertson 1988). Dioxins and furans were also implicated in reproductive failures of Great Blue Herons that were feeding in estuaries in the Strait of Georgia in 1987 and 1988 (Elliott *et al.* 1988*a*).

Effects of mercury

Mercury poisoning has been reported in many species of birds, including raptors that died as a result of eating prey that had fed on seeds treated with mercurial fungicides (Borg *et al.* 1969).

According to a review of metal toxicity to birds by Scheuhammer (1987), the critical lethal levels for mercury in a variety of bird species are 20–40 mg/kg in the liver and 15–20 mg/kg in the brain. The major toxic effects of mercury include impairment of the central nervous system, spinal cord degeneration, and brain lesions. The usual symptoms of methymercury intoxication in birds are weight loss, weakness, uncoordinated movement, and tremors. There is no conclusive evidence of mortality due to mercury poisoning in seabirds (Ohlendorf *et al.* 1978).

A number of sublethal effects have also been reported in birds. Mercury levels as low as 0.50–1.50 mg/kg in eggs of Ring-necked Pheasants were associated with early embryonic death in the eggs and an increased rate of infertility (Fimreite 1971). Mercury levels of 0.50 mg/kg in Mallard eggs resulted in an increased number of malformations, and levels of 4–5 mg/kg significantly increased embryonic mortality (Hoffman and Moore 1979). Concentrations causing reproductive effects are therefore considerably lower than those associated with adult mortality.

Effects of cadmium

Cadmium tends to accumulate in the kidney cortex of birds (Nicholson and Osborn 1983). In Britain, seabirds containing high levels of cadmium and mercury were found to have kidney lesions (Bull *et al.* 1977; Nicholson and Osborn 1983).

Minamata Disease

The most dramatic examples of mercury poisoning in the marine environment are two epidemics in Japan during the 1950s and 1960s (Takizawa 1979).

Since first reported in 1953, outbreaks of a disease (called Minamata Disease after the bay where it was reported) resulted in more than 2 000 confirmed cases of mercury poisoning, mainly Japanese fishermen and their families. The disease was often fatal, and 250 deaths were reported. The symptoms include impairment of sensory functions, uncoordinated movement, excessive salivation, sweating, and paralysis of limbs.

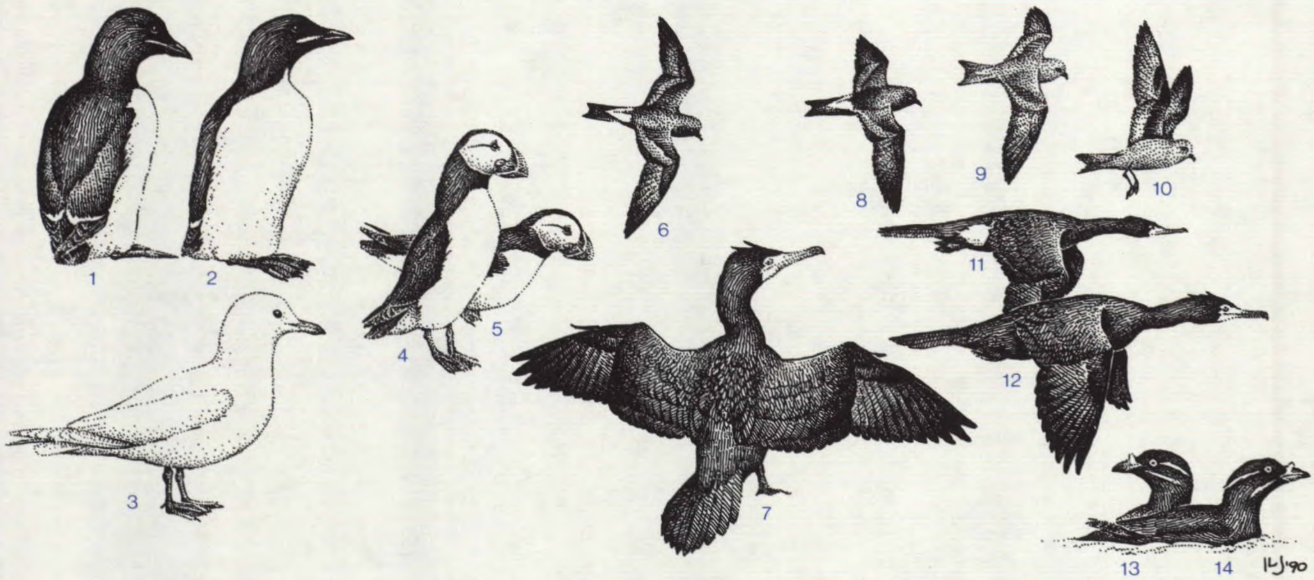
Although initial investigations of the cause of the epidemic had suggested mercury poisoning, several years passed before the link between the deaths and consumption of fish and shellfish from Minamata Bay was established. It turned out that most victims (being fisherfolk) consumed large quantities of local fish and shellfish. Marine organisms in the bay were accumulating mercury in their tissues, which was in turn accumulating in the tissues of humans. Despite the closing down of the factories in the bay using mercury and warnings about ingesting fish, the toll of the disease continued to rise until well into the 1970s.

Effects of lead

Lead poisoning has been reported in waterfowl and raptors (usually due to exposure to lead shot) but not in seabirds. However, chronic low levels of lead may lead to anemia, reduced growth rates, kidney and liver damage, and possibly some impairment of the nervous system (Scheuhammer 1987).

Chapter 5

Measuring contamination of seabirds and their environment



Two Arctic species being considered as monitors
1, 2 Thick-billed Murres
3 Ivory Gull

Atlantic coast monitors
4, 5 Atlantic Puffins
6 Leach's Storm-Petrel
7 Double-crested Cormorant

Pacific coast monitors
8 Leach's Storm-Petrel
9, 10 Fork-tailed Storm-Petrels
11 Pelagic Cormorant
12 Double-crested Cormorant
13, 14 Rhinoceros Auklets

Ian Jones

Investigating levels of environmental contaminants in Canadian seabirds began in the late 1960s and continues today. This investigation took the form of regular monitoring programs on the Atlantic and Pacific coasts and irregular surveys of contaminant levels in selected seabird eggs and tissues on the Atlantic, Pacific, and Arctic coasts.

The seabird monitoring programs, 1968 to the present

The Canadian Wildlife Service has regularly monitored chemicals in seabird eggs on the Atlantic coast since 1968, and on the Pacific coast since 1985. Figure 8 shows collection sites on the Atlantic coast, where every fourth year researchers visit two nesting colonies of each of the three species and collect 5–10 eggs at each site. The western program aims to collect and analyze eggs following the same pattern as the Atlantic coast program, but the egg collections are not as systematic on the Pacific coast because of the greater difficulties involved in arranging transportation to the remote seabird colonies. Figure 9 shows collection sites on the Pacific coast.

The success of any program that monitors marine pollution depends, in part, on the selection of appropriate monitors. The usefulness of seabird species as monitors depends, in turn, on the characteristics of the pollutants to be monitored and the oceanography of the area (Gilbertson *et al.* 1986). In order to monitor contamination of (*i*) coastal areas (which receive run-off from rivers and local industrial discharge) and also of (*ii*) the open ocean (which is most influenced by long-range transport of pollutants in the atmosphere and by ocean currents), scientists need to sample

Figure 8
Collection sites of seabird samples from the Atlantic coast

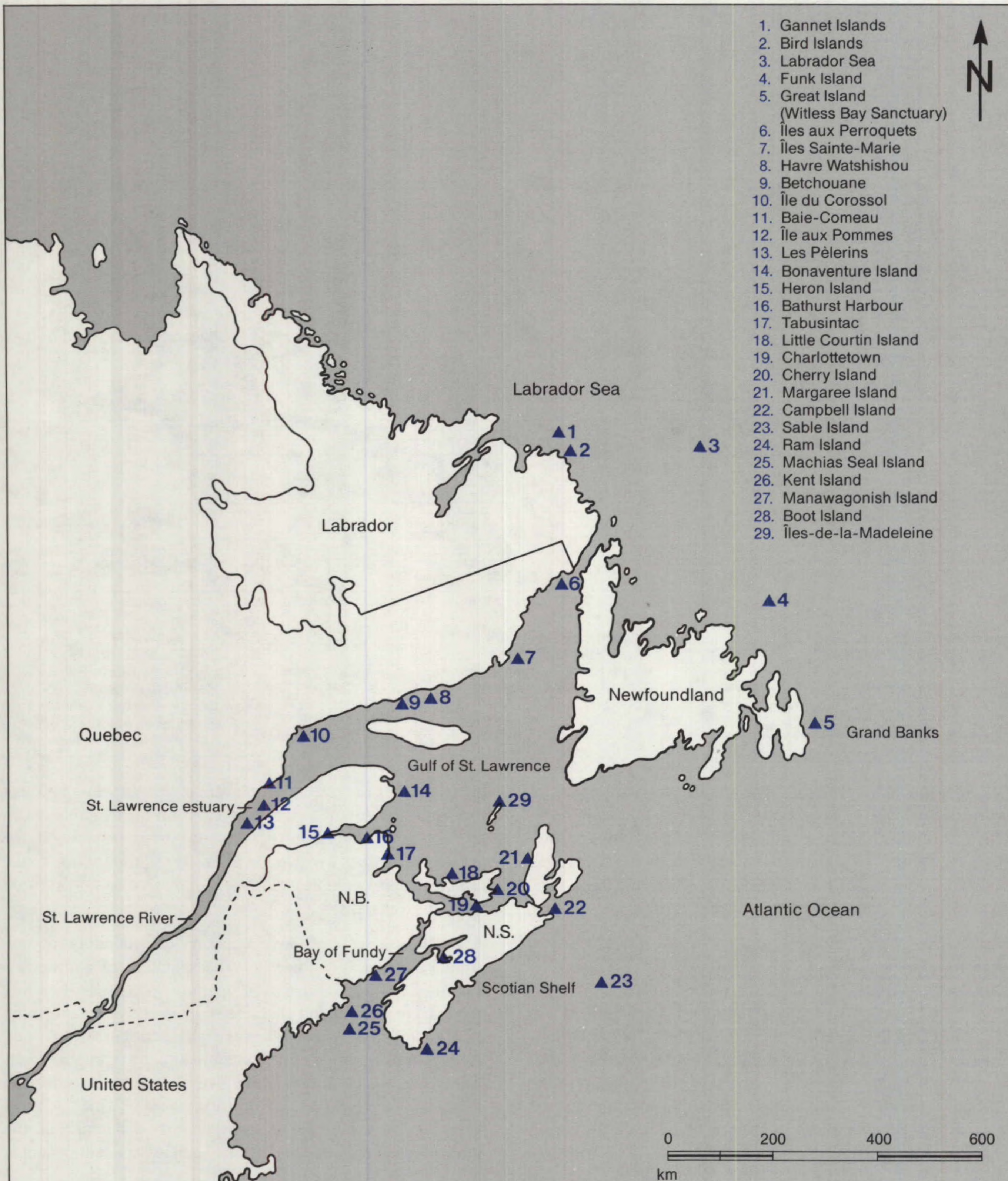


Figure 9
Collection sites of seabird samples from the Pacific coast

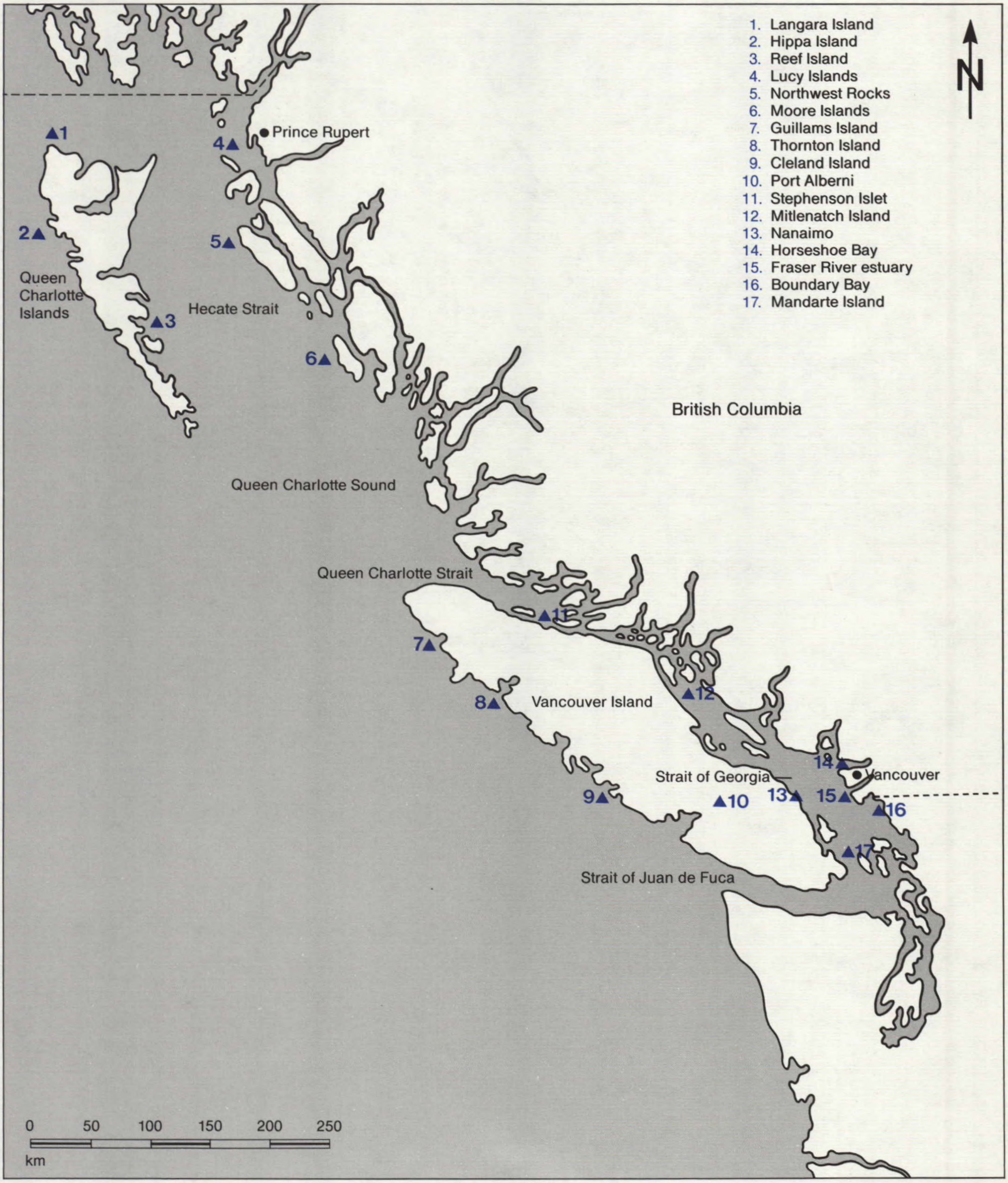


Figure 10
Collection sites of seabird samples from the Arctic

the species that feed in those different zones. Non-migratory species feeding on non-migratory prey would be ideal, but few such species exist in Canada. The wildlife biologists who designed the monitoring project also considered other factors, such as the principal components of the birds' diets, their habitat (surface or underwater, coastal or oceanic), their seasonal movements, and their sensitivity to pollutants (related to their physiology, reproductive strategy, and longevity). From the start, the researchers tried to pick species that inhabited both east and west coasts, so that when the west coast program started, it would be possible to measure differences between areas directly.

For the Atlantic coast monitoring program they selected three monitoring species: one inshore feeder (the Double-crested Cormorant) to detect pollutants in coastal run-off; one pelagic surface feeder (Leach's Storm-Petrel) to detect pollutants in atmospheric fall-out; and one offshore subsurface feeder (Atlantic Puffin) to monitor overall contaminant levels. For the Pacific coast program, they selected the Double-crested Cormorant, the Pelagic Cormorant, Leach's Storm-Petrel, and the Rhinoceros Auklet.

Double-crested Cormorants breed along most of the Atlantic coast and have recently expanded to Newfoundland. On the west coast the species is restricted to the Strait of Georgia; so Pelagic Cormorants are being used as an alternative in the Queen Charlotte Islands and western Vancouver Island. Leach's Storm-Petrels are abundant residents in the temperate regions of both coasts. Fork-tailed Storm-Petrels are also used as an alternative at sites on the west coast where Leach's Storm-Petrels do not breed. Atlantic Puffins breed throughout the Atlantic provinces, as far north as Labrador. On the Pacific coast, the Rhinoceros Auklet, which is puffin-like in size and feeding behaviour, makes a good substitute for the Atlantic Puffin. None of these species occur in the High Arctic, where the researchers have not yet selected "official" monitors.

Surveys for organochlorines and mercury, 1968 to the present

Any sampling of other seabird species or of monitor species outside the regular monitoring schedule is considered a survey. The surveys differ from the monitoring program in that they generally involve sampling in several locations and include a larger range of species.

During the late 1960s and early 1970s, scientists analyzed seabird eggs and tissues from both the Atlantic and Pacific coasts for organochlorines and mercury. They collected a few birds to analyze the tissues but in most cases were able to collect tissues of birds already dead. Analytical techniques available at the time allowed the quantification of DDT, DDE, DDD, dieldrin, heptachlor epoxide, PCBs (after 1968), and HCB. Noble and Elliott (1986), Pearce and co-workers (1979), and Ohlendorf and co-workers (1978) have reported data from those collections of seabirds eggs and tissues.

On the Atlantic coast, biologists collected eggs of Common Tern, Razorbill, Herring Gull, Black Guillemot, Common Murre, Northern Gannet, Double-crested Cormorant, Atlantic Puffin, and Leach's Storm-Petrel from colonies in the Bay of Fundy, on the Atlantic coast of Nova Scotia, on the coast of Prince Edward Island, in the St. Lawrence estuary and gulf, and in eastern Newfoundland (see Figure 8). They paid particular attention to colonies where reproductive problems were suspected, such as Bonaventure Island. Tissues of seabirds found dead in the Gulf of St. Lawrence (mainly gannets and cormorants) and others collected in southern Labrador (Northern Fulmars, Common Murres, Black Guillemots, Razorbills, and Atlantic Puffins) were also analyzed.

On the Pacific coast, preliminary sampling occurred in 1970 and again in the early 1980s. Biologists collected eggs of Leach's and Fork-tailed Storm-Petrels, Double-crested and Pelagic Cormorants, Glaucous-winged Gulls, Rhinoceros and Cassin's Auklets, Ancient Murrelets, Tufted Puffins, and Pigeon Guillemots from locations on Vancouver Island, in the Strait of Georgia, in Hecate Strait, and along the Queen Charlotte Islands (Figure 9). They took from 1 to 10 eggs of each species but often analyzed only one pooled sample. In addition, they collected some seabirds in the early 1970s and analyzed their tissues for mercury and organochlorines.

In 1975, Canadian Wildlife Service biologists first collected arctic seabird eggs for analysis (Figure 10). By then, analytical technology had developed so that HCH and the residues (nonachlors and chlordanes) and breakdown products (oxychlordane) of technical chlordane could also be measured reliably. Sampling of residues in arctic seabirds (Thick-billed Murre, Northern Fulmar, Black-legged Kittiwake, and Ivory Gull) has so far been limited to a series of samples in 1975–77 from Prince Leopold Island and in 1976 from Seymour Island, and another series of collections in 1987 and 1988 at Prince Leopold Island and Seymour Island.

Seabirds as indicators of environmental pollution

Definition of an indicator

The terms "indicator" and "monitor" are often used interchangeably, but in the context of this report they differ slightly in meaning. An indicator is an organism with a measurable characteristic (such as reproductive success, eggshell thickness, enzyme concentration, or pollutant level) that indicates something about the quality of the environment in which it lives. A monitor is an organism in which the same type of characteristic is repeatedly measured, such as in a series of samples over time. This makes it possible to follow changes in the selected measure over time, but does not necessarily involve any assessment of the quality of the environment.

The use of animals as indicators of some aspect of the quality of the surrounding environment is certainly not new. Coal miners used to take a canary with them into the mines. If dangerous fumes were released, the canary, more susceptible than the men, died, thereby warning the miners that they should return quickly to the surface.

In the same way, wild animals and plants have been used as indicators and monitors of the health of various environments, both terrestrial and aquatic. The biological information measured depends on the type of pollution to be detected. In assessing the health of a stream, for example, the presence of certain microorganisms indicates a high oxygen content, whereas the presence of others indicates anoxic conditions. Another example is the measurement of fecal coliform bacteria and contaminants such as cadmium and mercury in shellfish. If the concentrations are above those considered safe for human health, the area may be closed to shellfish harvesting.

The Herring Gull has been used successfully to *monitor* environmental contamination at a number of colonies in the Great Lakes. Herring Gulls are also used as an *indicator* — on the premise that healthy gulls mean healthy lakes and water that is safe to drink. However, a better *indicator* species in the Great Lakes might be the Bald Eagle. More sensitive to organochlorines than Herring Gulls, Bald Eagles have failed to re-establish themselves as a breeding species on the shores of the Great Lakes, despite efforts by biologists to re-introduce them. A breeding population of Bald Eagles would indicate very healthy lakes. Eagles, on the other hand, would not be a good monitor species.

Scientists use animals as monitors where direct measurements of contaminant levels in air or water are not practical. First of all, those levels are usually so low that only recently developed sophisticated chemical procedures can detect them. Moreover, those levels do not provide information about the bio-availability or toxicological significance of the contaminants detected.

Advantages of seabirds over other marine monitors

Seabirds fit the following criteria of a good monitor and have some advantages over other marine animals including mussels, cod, herring, eels, and Grey seals (Phillips 1980), which have also been used to assess pollution of marine ecosystems.

Seabirds feed at a variety of trophic levels — seabirds are generally considered to be "top predators" in the marine ecosystem, although their diet can vary from almost entirely zooplankton to carrion. They are, therefore, exposed to most of the persistent contaminants encountered by their prey.

Seabirds accumulate pollutants — Seabirds accumulate certain toxic substances (such as cadmium, mercury, lead, and organochlorines) in their tissues, where the rate of uptake through their diet exceeds the rate of elimination (by excretion, in eggs, or by metabolism).

Seabirds integrate pollutant levels — Because of their mobility, seabirds provide an indication of average exposure to pollutants over large areas (Boersma 1986).

Seabirds show health effects — At higher concentrations of certain pollutants, seabirds may show health effects. Some of the pathological and biochemical responses (such as changes in the multifunction oxidase enzyme systems of the liver) may also be seen in humans.

Seabird eggs provide a standard sample — Studies on the variability of contaminant levels in different species found that levels in seabird eggs were less variable than those in fish or seals. The standardized size and composition of eggs make it easier to detect true changes over time, and between locations.

David Noble

A biologist collects eggs from a cliffside colony of Thick-billed Murres in the Arctic.

Seabirds are colonial — The eggs of abundant colonial seabirds are relatively easy to find and collect during the breeding season, with little effect on the population. At a colony, it is also possible to assess the biological effects of the pollutants by monitoring changes in reproductive success and total numbers, as well as biochemical changes in a sample of seabirds.

Of the other potential monitors, seals and other marine mammals are also predators, occupying the same trophic level as seabirds. However, they are more difficult to sample than seabird eggs and it is more difficult to assess sublethal effects. Moreover, collections of many species of marine mammals would be undesirable.

Some of the larger fish also occupy the same trophic level as seabirds. As many fish are harvested commercially, obtaining sufficient samples would be relatively easy. However, as in marine mammals, the variation in levels of contaminants in fish tissues was found to be much higher than in seabird eggs. The concentrations varied with size, age, sex, and species of fish and were often several magnitudes lower than in birds (Zitko *et al.* 1974). In comparison with knowledge of seabirds, relatively little is known of the seasonal movements of many fish.

Evaluation of the use of seabirds as monitors

The seabird monitoring program described in this report found ample evidence that seabirds accumulate organochlorines and heavy metals. Levels of contamination in the three seabird species monitored on the east coast are in general agreement with the position of their prey on the food chain. Health effects on seabirds were detected in a few species (for example, Northern Gannets on Bonaventure Island), where the levels of contamination were highest.

Concentrations in seabird eggs provide a method of assessing general levels of contamination within the area occupied by the sampled animals and over time. With some effort, regular collection of seabird eggs at selected colonies is logistically possible. However, because most of the seabird species sampled do move to other areas during the winter, it is difficult to say for certain where the contaminants in the eggs originated. This makes it important to know the seasonal movements of the seabirds being sampled.

Programs that use seabirds as monitors must take a number of other factors into consideration, for example:

(1) The capacity to metabolize toxic substances differs among species (Walker and Knight 1981) and may also vary with age and condition of the individual.

(2) Ideally, the analytical techniques used (see Appendix 2) should be comprehensive enough to detect the presence of new contaminants, which are continually entering the marine ecosystem.

(3) Not all toxic substances are readily accumulated in the food chain, and not all are necessarily transferred to eggs. Lead, for example, is more likely to accumulate in the liver, kidney, or bones. Cadmium tends to accumulate in the kidney.

The monitoring programs reported here are not the first to use seabirds to assess contamination in the marine environment. In Europe, Common Murres were used to monitor pollutant levels in the Baltic Sea (Olsson 1977), and the Shag was used to assess local coastal contamination in the North Sea (Coulson *et al.* 1972). Penguins have been used as indicators of pollution in the remote Antarctic (Ballschmiter *et al.* 1981). Comparisons of levels in tissues of shearwaters at either end of their trans-equatorial migration have been used to compare the relative contamination of the northern and southern hemispheres (Tanaka *et al.* 1986). Levels of contaminants in Common Terns were used to assess differences between urban and rural run-off in Massachusetts (Nisbet and Reynolds 1984), and regurgitations of storm-petrels were recently sampled for the presence of petroleum hydrocarbons (Boersma 1986).

Chapter 6

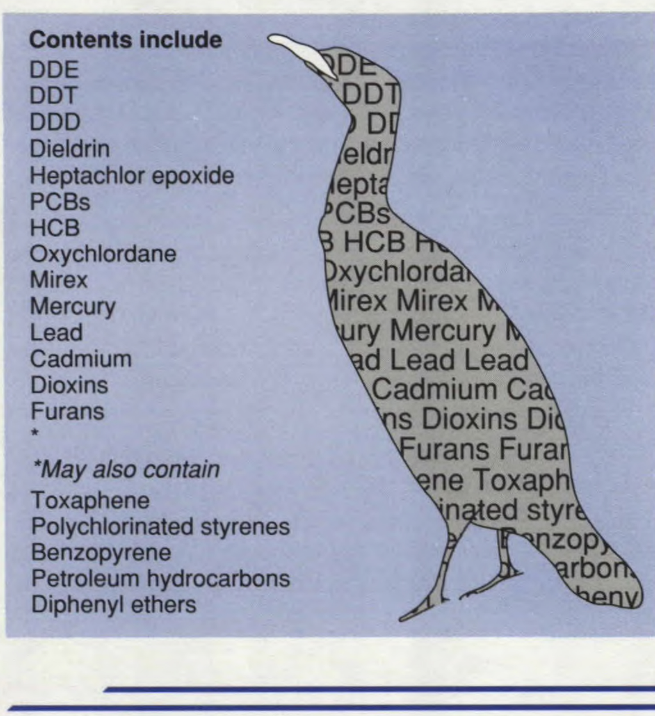
The extent of contamination revealed by surveys and monitoring

More than 40 species of seabirds breed in Canadian coastal waters, and another 10 species are regular visitors. They are a diverse group, ranging in size from swallow-sized storm-petrels to albatrosses with wingspans in excess of 2.4 m. All of these seabirds, as a rule, spend most of their life at sea and depend on marine food sources. Gulls, terns, or cormorants breeding in fresh water, i.e. the Great Lakes or Lake Manitoba, are not included.

Of the 50 or more species of seabirds that occur in Canada, only 24 have ever been sampled for environmental contaminants, and only 15 species have been sampled enough for us to meaningfully assess the levels of contaminants in different areas, over time, or the impact on their health (Noble and Elliott 1986).

Initial surveys, 1968 to 1972

None of the birds examined in early surveys contained lethal residues, but eggs of a number of species exhibited high levels of contamination, particularly in the Bay of Fundy, the Strait of Georgia, and in the estuary and gulf of the St. Lawrence. DDE and PCBs were the dominant chemicals in eggs (generally 0.20–20 mg/kg, on a wet weight basis); dieldrin and HCB were less prevalent (0.1–1.0 mg/kg); heptachlor epoxide, mirex, DDT, and DDD even less (usually less than 0.1 mg/kg).



Mercury in livers of seabirds from Chaleur Bay, New Brunswick, and the Strait of Georgia, British Columbia, ranged from 2 to 11 mg/kg, with the highest residues occurring in cormorants collected in Bathurst Harbour. Mercury levels in eggs were all less than 0.50 mg/kg.

Geographic patterns of contamination on the Atlantic coast

St. Lawrence River estuary

The St. Lawrence estuary (the 550-km stretch of the St. Lawrence River between the Island of Orléans and Anticosti Island where fresh water mixes with the salt water of the gulf) receives outflow from the Great Lakes and several large rivers via the St. Lawrence River. This river is one of Canada's major shipping routes, and its shores are heavily industrialized and densely populated.

Levels — Researchers collected eggs of three common breeding species (Double-crested Cormorant, Herring Gull, and Razorbill) from Les Pèlerins Islands, Île aux Pommes, and North-east and South-west Rasade Islands (Figure 8).

Considering its industrialization, it is not suprising that the highest levels of organochlorines reported in this study were in eggs from the St. Lawrence estuary. DDE concentration in all species averaged between 1 and 3 mg/kg, with the highest level (12.8 mg/kg) in a single Double-crested Cormorant egg. PCBs were the dominant organochlorine, with average values between 5 and 20 mg/kg in eggs of all three species, and as high as 58 mg/kg in a single Herring Gull egg. The other contaminants were detected at much lower concentrations, with average values for dieldrin typically between 0.03 and 0.13 mg/kg, heptachlor epoxide between 0.01 and 0.10 mg/kg, HCB between 0.01 and 0.08 mg/kg, and oxychlordane between 0.01 and 0.11 mg/kg. Mirex was detected at significant levels only in the eggs of Herring Gulls.

Despite differences in diet and migratory patterns, eggs of all three species in the estuary were similarly contaminated, suggesting that local conditions — namely the outflow from the heavily industrialized Great Lakes and St. Lawrence River watershed — were primarily responsible. However, these levels are half those that have been detected in cormorant and gull eggs collected in the lower Great Lakes at about the same time (Vermeer and Peakall 1977).

Despite the presence of significant concentrations of a number of contaminants, Chapdelaine and Laporte (1982) were unable to find evidence of adverse reproductive effects in Razorbills. The contaminant residues detected in the eggs of seabirds were considerably higher than those in fish and invertebrates collected from the estuary (Figure 4), but not as high as levels of DDT compounds and PCBs in the blubber of beluga whale (Masse *et al.* 1986).

Trends — Information on changes in contaminant levels over time is available for two species: Double-crested Cormorants from Île aux Pommes, and Herring Gulls from Îles aux Pommes and some nearby colonies (Figure 11). In eggs of Double-crested Cormorants collected every four years between 1972 and 1988, none of the organochlorines showed statistically significant declines, although DDE and dieldrin are much lower now than in 1972. HCB increased significantly between 1972 and 1976, and heptachlor epoxide increased dramatically between 1976 and 1980, although it then declined somewhat by 1984. In eggs of Herring Gulls, collected in 1974, 1976, and 1977, there were no consistent changes in any of the organochlorines detected. Oxychlordane and perhaps heptachlor epoxide appeared to be increasing at some colonies, but the major contaminants (DDE, dieldrin, and PCBs) did not seem to be changing.

The lack of decline in organochlorine contamination in the St. Lawrence estuary suggests that pollutants continue to enter it via the St. Lawrence River system. Although levels of most organochlorines have declined significantly in Double-crested Cormorants breeding in the Great Lakes between 1972–73 and 1980–81, the decline appears to have reached a plateau (Weseloh *et al.* 1983). Continuing atmospheric input, mobilization of pollutants from sediments, and leaching of pollutants from the soil along the industrialized shores of the watershed are also likely sources. The lack of adequate controls (until recently) on sewage and wastes entering the St. Lawrence River has undoubtedly contributed to the problem.

Gulf of St. Lawrence

The Gulf of St. Lawrence takes in a much larger area than the estuary. It is bounded by Newfoundland to the east, Quebec to the north and west, and New Brunswick, Prince Edward Island, and Nova Scotia to the south. Smelters, mines, and numerous pulp and paper mills are located along the coast of New Brunswick; on Prince Edward Island and Nova Scotia, agriculture predominates; along the north shore of Quebec, forestry and fishing are most important. Although influenced by the St. Lawrence River outflow, the gulf is fed by the cold Labrador Current in the north and by components of the warm Gulf Stream from the south. Shipping traffic and industrialization (particularly in the southern gulf) are relatively heavy, and, most importantly with regard to pesticides, the gulf receives runoff from an area of extensive historic DDT aerial spraying.

Levels — In the early 1970s, researchers collected eggs of Double-crested Cormorants, Herring Gulls, and Atlantic Puffins from colonies along the north shore and in the middle of the gulf; eggs of Common Terns from the New Brunswick and Prince Edward Island coasts; eggs of Razorbills, Common Murres, and Black Guillemots from the north shore of Quebec; and Northern Gannet eggs from Bonaventure Island in Gaspé.

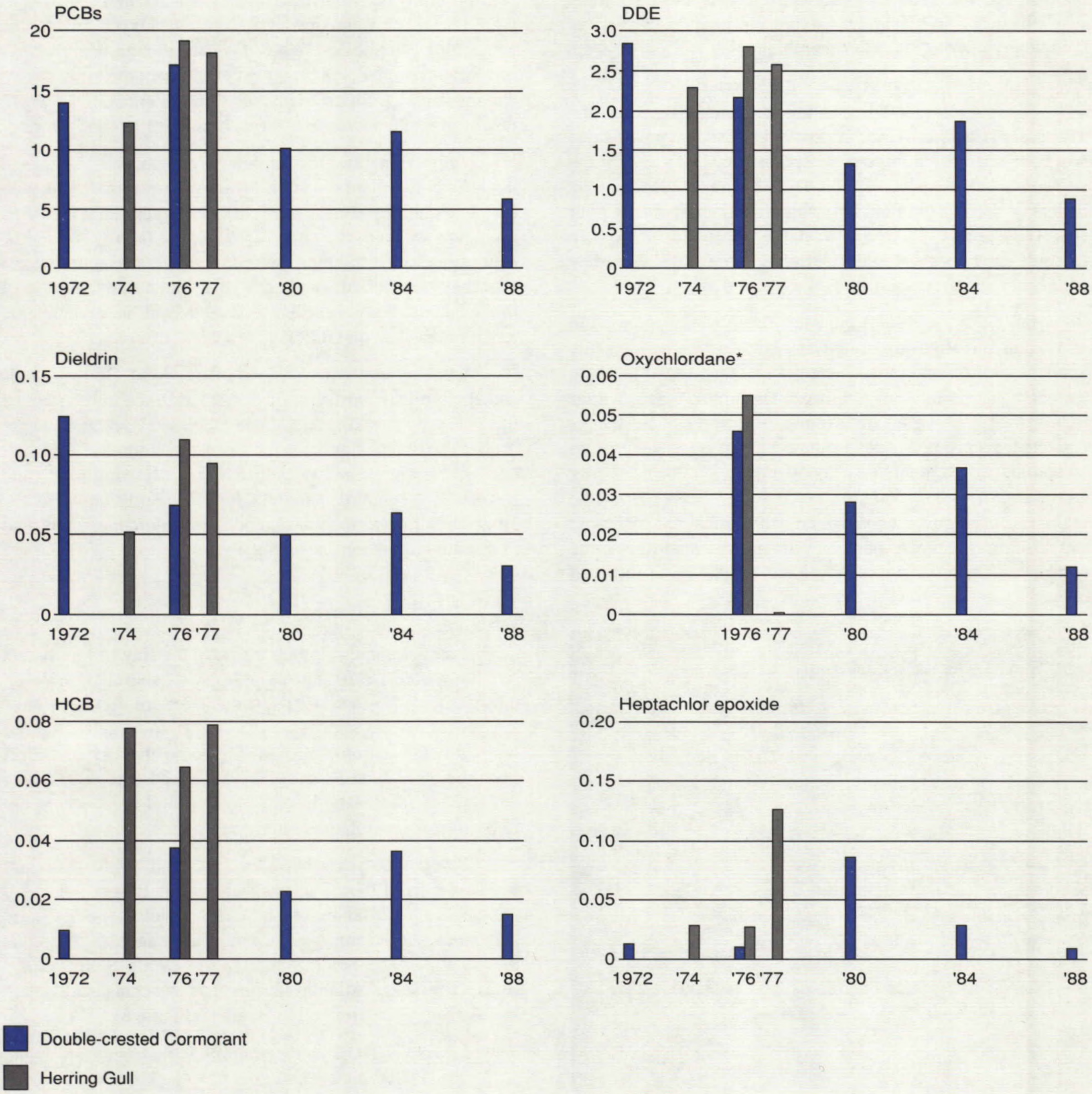
Reflecting the diverse local environmental influences, organochlorine contamination, which is lower overall than in the estuary, differed among sampling locations (Figure 8). Average DDE content ranged between 1 and 15 mg/kg and PCBs between 1 and 25 mg/kg. Dieldrin concentrations in eggs were generally less than 0.2 mg/kg, except in gannets, where concentrations were as high as 1.5 mg/kg. Oxychlordane, HCB, and heptachlor epoxide were detected at levels near 0.10 mg/kg or less.

During the 1970s, the ranking of species in order of level of contamination was Northern Gannet, Double-crested Cormorant, Razorbill, Herring Gull, Atlantic Puffin, Common Murre, Black Guillemot, and Common Tern. The differences in contamination among species appeared to roughly reflect their diets (Appendix 3). The gannets, which feed on large schooling fish such as mackerel and herring, contained the most contaminants. Terns, which feed on very small fish and pelagic zooplankton, were the least contaminated.

In the 1980s, only eggs of gannets from Bonaventure Island and Herring Gulls from the north shore of the gulf were analyzed. Organochlorine levels were similar in the two species and comparable with levels found at the same time in eggs of Double-crested Cormorants from the St. Lawrence estuary.

Trends as shown by the eggs of Northern Gannets from Bonaventure Island — The most comprehensive series of data on historical pollutant levels in the gulf comes from analyses of gannet eggs from Bonaventure Island. The large breeding colony of Northern Gannets at the eastern tip of the

Figure 11
Changes in contaminant levels in eggs of seabirds breeding in the St. Lawrence estuary, 1972–88. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.

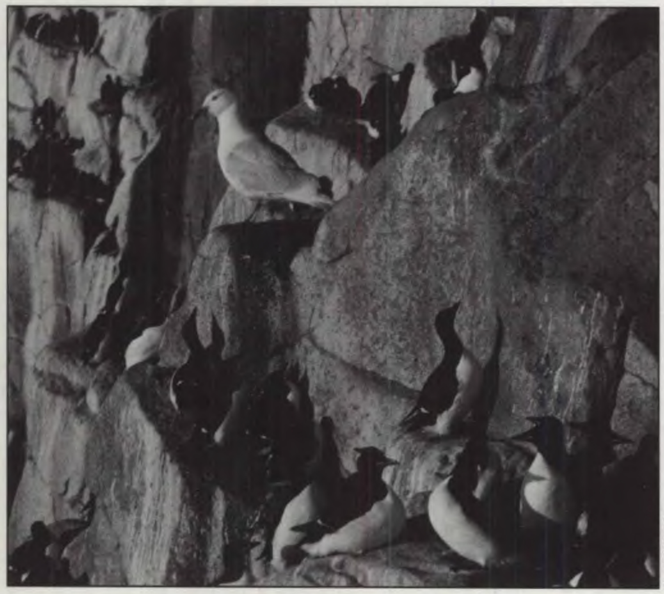


* Eggs were not analyzed for oxychlordane in 1972.

Gaspé peninsula has been studied for more than 20 years. During the late 1960s, less than 30% of the eggs were hatching and many eggs were found broken. Among the many contaminants detected in those eggs, DDE was particularly high. The suspicions of shell thinning were confirmed, with sampled eggs considerably (29%) thinner than the pre-1947 samples. In 1969 many eggs were completely missing the outer membrane that normally covers a gannet's egg.

The source of DDE was not hard to find. Since the 1950s, most of the Maritime provinces, Quebec, and Maine had been engaged in large-scale spraying of DDT against the spruce budworm. Much of this DDT eventually reached the waters of the gulf through atmospheric transport and in river runoff. Feeding exclusively on relatively large fat-rich fish in the gulf, gannets were soon taking in more DDT than they could excrete or metabolize.

DDT use on New Brunswick's forests was stopped in 1969, and further restrictions were imposed in the next few years. Figure 12 shows the response of contaminant levels in gannet eggs to the ban on organochlorines. The values plotted are the average values found in a sample of fresh eggs collected in any one year. (Some addled eggs were more contaminated, containing up to 60 mg/kg PCBs, 57 mg/kg DDE, and 1.5 mg/kg dieldrin.) These data come from the reanalysis of archived eggs, which had been stored frozen at -40°C in a specimen bank. This means that the same techniques were used to analyze all of the eggs collected between 1968 and 1984 (Elliott *et al.* 1988*b*).



David Noble

A Glaucous Gull on the lookout for eggs (or chicks) of Thick-billed Murres, at a colony in northern Hudson Bay. Gulls whose diet includes a large proportion of eggs or chicks may be at risk from contaminants.

Almost all contaminants appeared to decline between 1968 and 1984. DDE, dieldrin, and PCBs declined significantly. DDE shows the most dramatic decline, probably reflecting the abrupt elimination of DDT from the forest spray programs. HCB and PCBs, which originate mainly from industrial processes, declined more slowly as these chemicals were slowly phased out. Oxychlordane and heptachlor epoxide levels did not change significantly over the period sampled. Chlordane, the main source of these two chemicals, was not restricted in Canada until 1978, which may explain the increase in levels between 1969 and 1976.

Improvements in reproductive success, eggshell thickness, and numbers at the colony correspond well with the declining levels of DDE, dieldrin, and PCBs. Most biologists believe that the reproductive failures were the result of eggshell thinning caused by DDE, although dieldrin also may have killed some embryos. The current success of the gannet colony at Bonaventure Island is undoubtedly related to the ban on DDT.

Contaminant concentrations in eggs of Herring Gulls and Razorbills from the Gulf of St. Lawrence have changed little over the past 20 years. Only DDE levels show a general decline. Heptachlor epoxide and oxychlordane did not decline anywhere, and they increased in Herring Gulls and Razorbills at seabird colonies along the north shore of the gulf. Dieldrin, heptachlor epoxide, oxychlordane, HCB, and PCBs showed no consistent pattern.

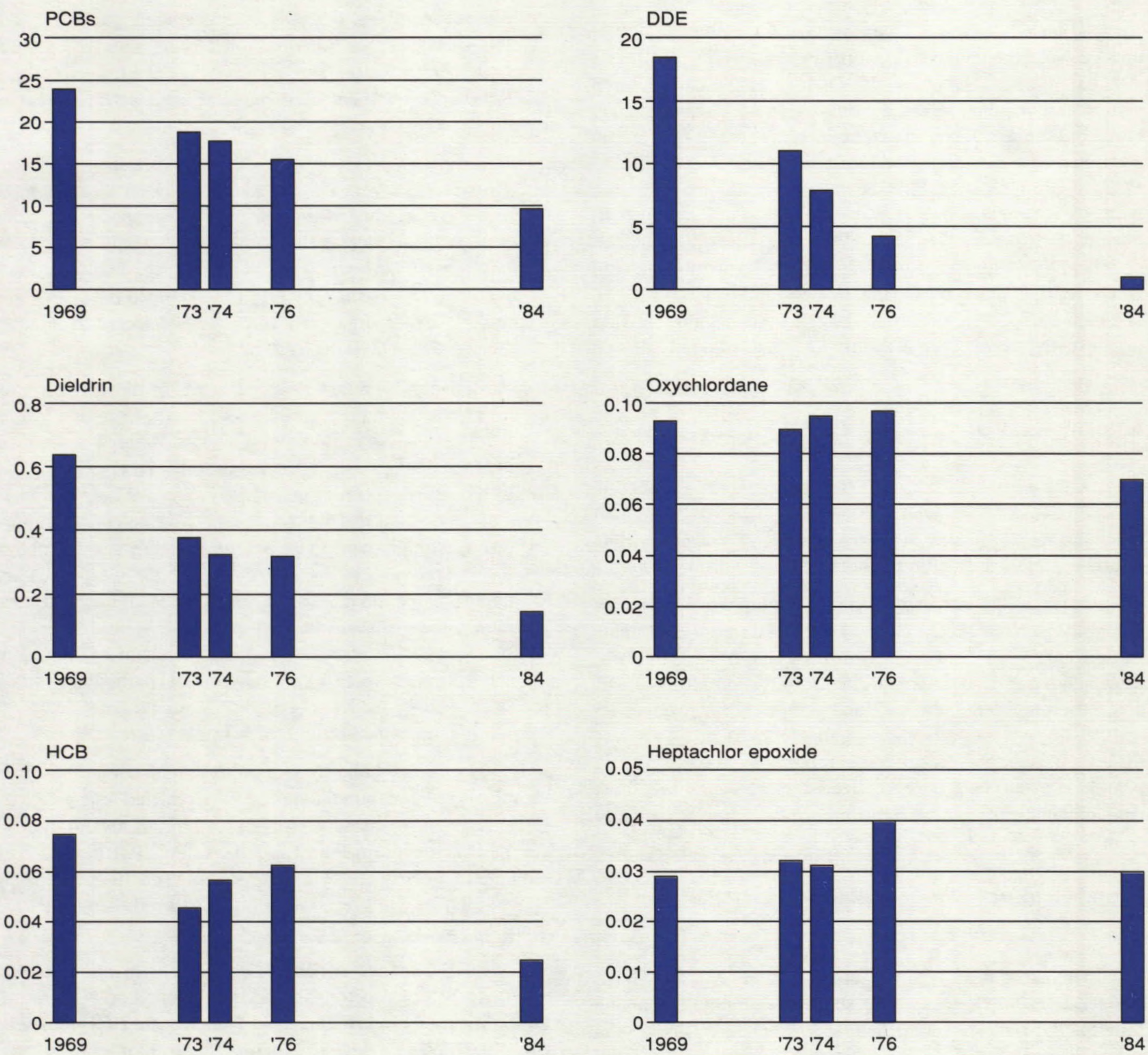
Bay of Fundy

There is some shipping traffic in the Bay of Fundy, but relatively little industrialization along its shores. However, during the 1950s and 1960s, large tracts of forest in New Brunswick were sprayed with DDT to combat spruce budworm infestations, and DDT entered the bay as runoff from the Saint John River. This watershed drained not only the sprayed forest land but also agricultural areas where use of pesticides was relatively high.

Every four years between 1972 and 1988, biologists sampled eggs of four seabird species in the Bay of Fundy for organochlorine contamination. The monitor species were Double-crested Cormorants from Manawagonish Island at the mouth of the Saint John River, Leach's Storm-Petrels from Kent Island, Atlantic Puffins from Machias Seal Island, and Herring Gulls from all three areas (Figure 8).

Levels — DDE concentrations varied between 1 and 7 mg/kg, PCBs between 2 and 20 mg/kg, oxychlordane between 0.02 and 0.13 mg/kg, dieldrin between 0.02 and 0.34 mg/kg (in a Herring Gull egg), and HCB between 0.01 and 0.20 mg/kg. Heptachlor epoxide was always at levels less than 0.10 mg/kg.

Figure 12
Changes in contaminant levels in fresh eggs of Northern Gannets at Bonaventure Island in the Gulf of St. Lawrence, 1969–84. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.



The oceanic storm-petrels and puffins were similar in overall contamination. The inshore-feeding cormorants contained some of the highest levels of DDE and PCBs, but were low in the other contaminants. Herring Gull eggs showed the most variability. Overall levels were lower than in the St. Lawrence estuary or gulf.

Trends — In all four species monitored (Double-crested Cormorant, Leach's Storm-Petrel, Herring Gull, and Atlantic Puffin), residues of DDE and PCBs declined significantly (Figure 13) as did dieldrin in the eggs of puffins and cormorants. The dramatic decline in DDT can be attributed to the cessation of forest spraying. The decline in PCBs suggests that local pollution had been the major source of this contaminant in the past. Oxychlordane declined in puffins between 1976 and 1988, but did not change significantly in the other three species. Heptachlor epoxide levels reached their maximum in cormorant eggs in 1980, and then declined significantly. Levels of heptachlor epoxide in the other three species were low and did not change significantly.

Scotian Shelf

The continental shelf zone extending along the southern coast of Nova Scotia, although rich in fish populations, lacks large seabird colonies. Land use in this region is mainly agricultural, with one major port, Halifax.

Levels — The only seabird eggs sampled from colonies along the Scotian Shelf were Double-crested Cormorants from Campbell Island and Herring Gulls from Campbell, Ram, and Sable Islands, all in 1976 (Figure 8). DDE concentrations were between 1 and 2 mg/kg, PCBs between 5 and 15 mg/kg, and all other organochlorines at levels less than 0.10 mg/kg. Despite the remote location of Sable Island, Herring Gull eggs collected there were the most contaminated, although the difference was not statistically significant.

Grand Banks of Newfoundland and southern Labrador

The continental shelf area, which extends from southeastern Newfoundland to southern Labrador, contains some of the richest seabird habitat in Canada. This area is more oceanic than those described previously, more influenced by ocean currents than river runoff. Fishing is the mainstay of most of the people and there is a moderate amount of industrial shipping, mainly to the major port at St. John's. On land there is virtually no farming, but there are several forest-product industries.

Large seabird colonies are located in the Witless Bay area, Cape St. Mary's, Baccalieu Island, and Funk Island and further to the north on the Gannet and Bird Islands near Cartwright, Labrador (Brown 1986). The main species are Atlantic Puffins, Common Murres, Razorbills, Black-legged Kittiwakes, and Leach's Storm-Petrels, but there are also significant numbers of gulls, fulmars, and gannets. The Grand Banks are an important wintering area of seabirds from the Arctic, Greenland, and the Gulf of St. Lawrence, as well as large numbers of shearwaters and petrels from the southern hemisphere.

Levels — Eggs of Leach's Storm-Petrel and Atlantic Puffin collected from Great Island (southeast of St. John's) were less contaminated than eggs of those species from the Gulf of St. Lawrence or the Bay of Fundy (Figure 8). DDE values ranged between 0.30 and 3 mg/kg, PCBs between 1 and 4 mg/kg. Toxaphene residues averaged between 1 and 2 mg/kg. Other organochlorines were detected at concentrations less than 0.10 mg/kg.

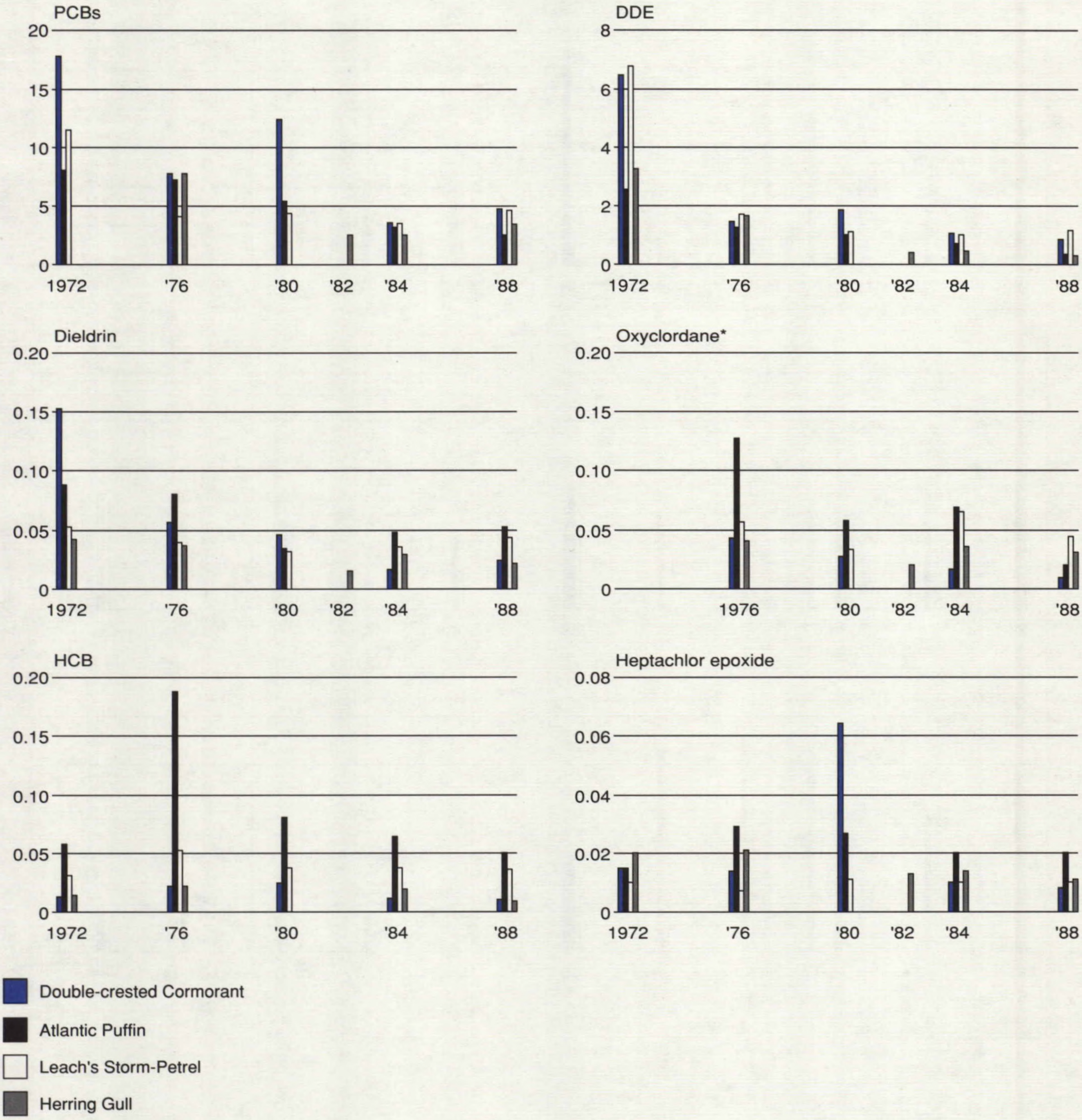
Between 1968 and 1970, carcasses of five alcid species (Dovekie, Atlantic Puffin, Black Guillemot, Common Murre, and Razorbill) and Northern Fulmars were collected in southern Labrador, or farther north in Davis Strait, and analyzed for organochlorines and mercury. Whole bodies of fulmars contained the highest organochlorine concentrations detected, with an average of 2.6 mg/kg DDE and 7.2 mg/kg PCBs. The muscle tissue of Razorbills was the most contaminated of the alcids. Dovekies were significantly less contaminated than any other species. Mercury residues ranged from 0.16 to 0.32 mg/kg. The levels of contaminants in the muscle tissue of murres are of particular interest because many residents of Newfoundland and Labrador regularly hunt and consume Thick-billed Murres.

Trends — Long-term monitoring of contaminants in seabirds in Newfoundland has been carried out at Great Island. Of the many species that breed in this area, only eggs of the Leach's Storm-Petrel and the Atlantic Puffin have been sampled regularly, every four years between 1968 and 1988. Some Herring Gull eggs were also analyzed, between 1975 and 1988.

DDE residues declined significantly in eggs of both puffins and storm-petrels, but PCBs declined only in puffins and only after 1980 (Figure 14). Dieldrin and HCB remained at fairly constant levels, whereas heptachlor epoxide and oxychlordane appear to have increased between the late 1960s and the late 1970s, although not significantly. By 1988, levels of heptachlor epoxide and oxychlordane were generally as low as in the late 1960s (Figure 14).

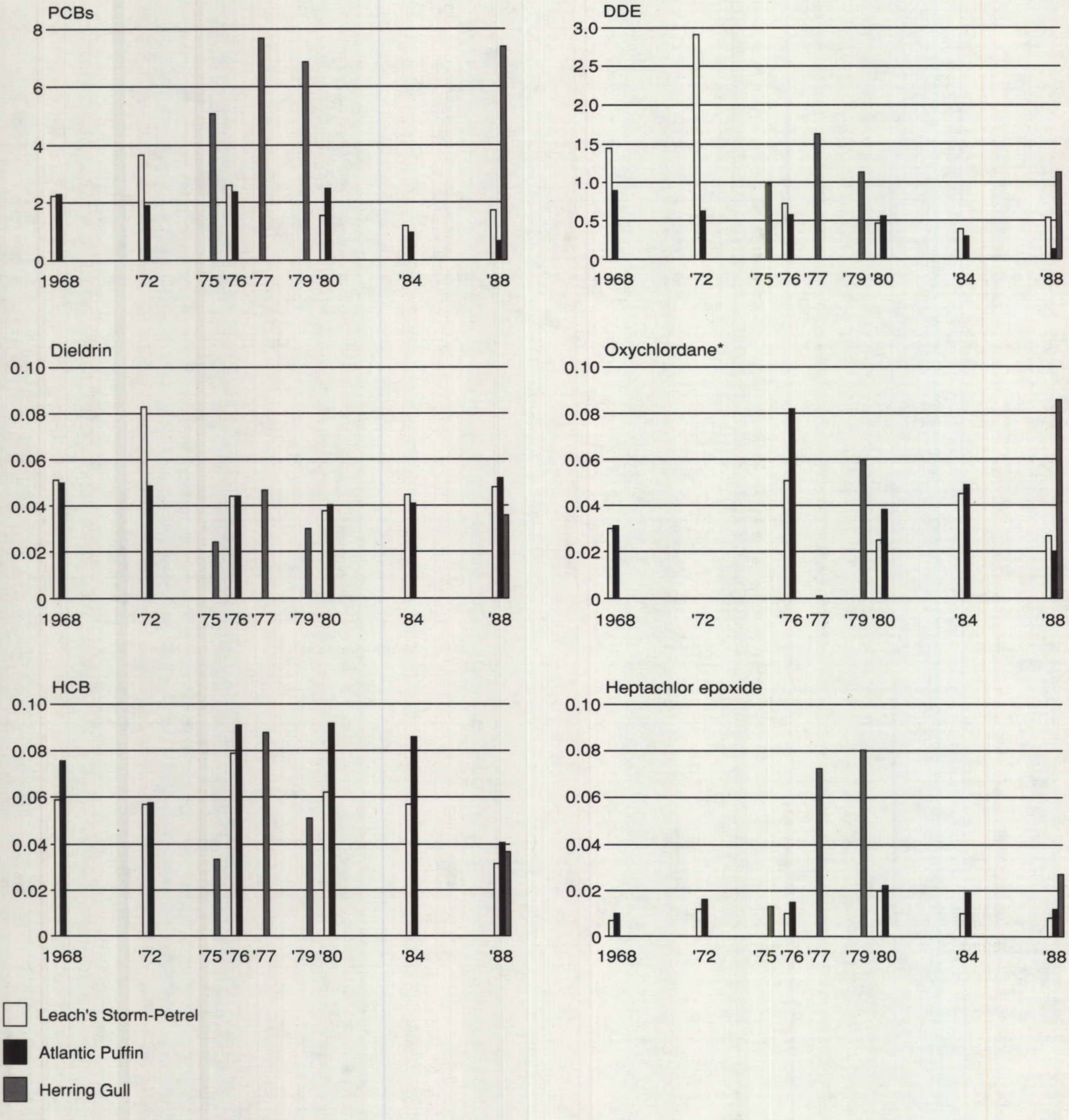
Seabirds breeding along the continental shelf of Newfoundland are comparatively remote from major sources

Figure 13
Changes in contaminant levels in eggs of seabirds breeding in the Bay of Fundy, 1972–88. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.



* Eggs were not analyzed for oxychlordane in 1972.

Figure 14
Changes in contaminant levels in eggs of seabirds breeding in Newfoundland, 1968–88.
Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.



* Eggs were not analyzed for oxychlordane in 1972. Data for 1968 is from re-analysis of stored samples.

of pesticides and industrial chemicals. This is reflected in the generally low levels in their eggs. The decline in DDE is probably due to the stopping of DDT use on forests in Atlantic Canada as well as general North American restrictions on use. The continuing presence of oxychlordane, heptachlor epoxide, and HCB in some Great Island seabirds may be due to atmospheric transport to mid-ocean regions, where the puffins and storm-petrels habitually feed.

Contamination in the Arctic

The High Arctic, the area north of 70 degrees latitude, is an immense archipelago of islands. Although there is virtually no industry in the Arctic — only a few mines — there has been extensive oil exploration during the past two decades. Lancaster Sound, for example, a very biologically productive area with a rich diversity of seabirds and marine mammals, has been proposed as a route for oil tankers transporting oil south from the Arctic (Gaston and Nettleship 1981).

Seabird colonies in the High Arctic tend to be large, dominated mainly by Thick-billed Murres, Northern Fulmars, and Black-legged Kittiwakes, with smaller numbers of other gulls (Brown 1986). Sites of major colonies include Cape Vera and Hobhouse Inlet (Devon Island), Coburg Island, Prince Leopold Island (at the western end of Lancaster Sound), Cape Hay (Bylot Island), Cape Searle, and Reid Bay (Baffin Island). In the Low Arctic, major colonies of mainly Thick-billed Murres occur on Hantzsch Island, Akpatok Island, Digges Sound, and Coats Island, all in the Hudson Strait area. A major Ivory Gull colony is located on Seymour Island, north of Bathurst Island (MacDonald 1978).

Levels — The arctic seabird samples analyzed include eggs or livers of four seabird species from Prince Leopold Island and Seymour Island (Figure 10), collected in the mid-1970s and in 1987–88. With the exception of PCBs, organochlorine residues in eggs were relatively low, with DDE levels less than 0.50 mg/kg, and other compounds at levels less than 0.10 mg/kg. Organochlorine concentrations in livers were similar to those in eggs.

There were few differences in contaminant levels in eggs among the species sampled (Thick-billed Murre, Black-legged Kittiwake, and Ivory Gull), with the exception of high concentrations of PCBs (up to 6 mg/kg in one egg) in the kittiwakes (Figure 15). The resident Ivory Gulls, surprisingly, were as contaminated as migratory species, providing evidence of long-range transport to the Arctic.

The similarities in residue levels are probably due to similarities in their diets during the early part of the breeding season. Ivory Gulls, fulmars, and kittiwakes habitually feed at the ocean surface on amphipods and associated arctic cod. The murres, although feeding on prey captured below the surface, are also largely dependent on ice-associated amphipods (and arctic cod) early in the season when eggs are being laid.

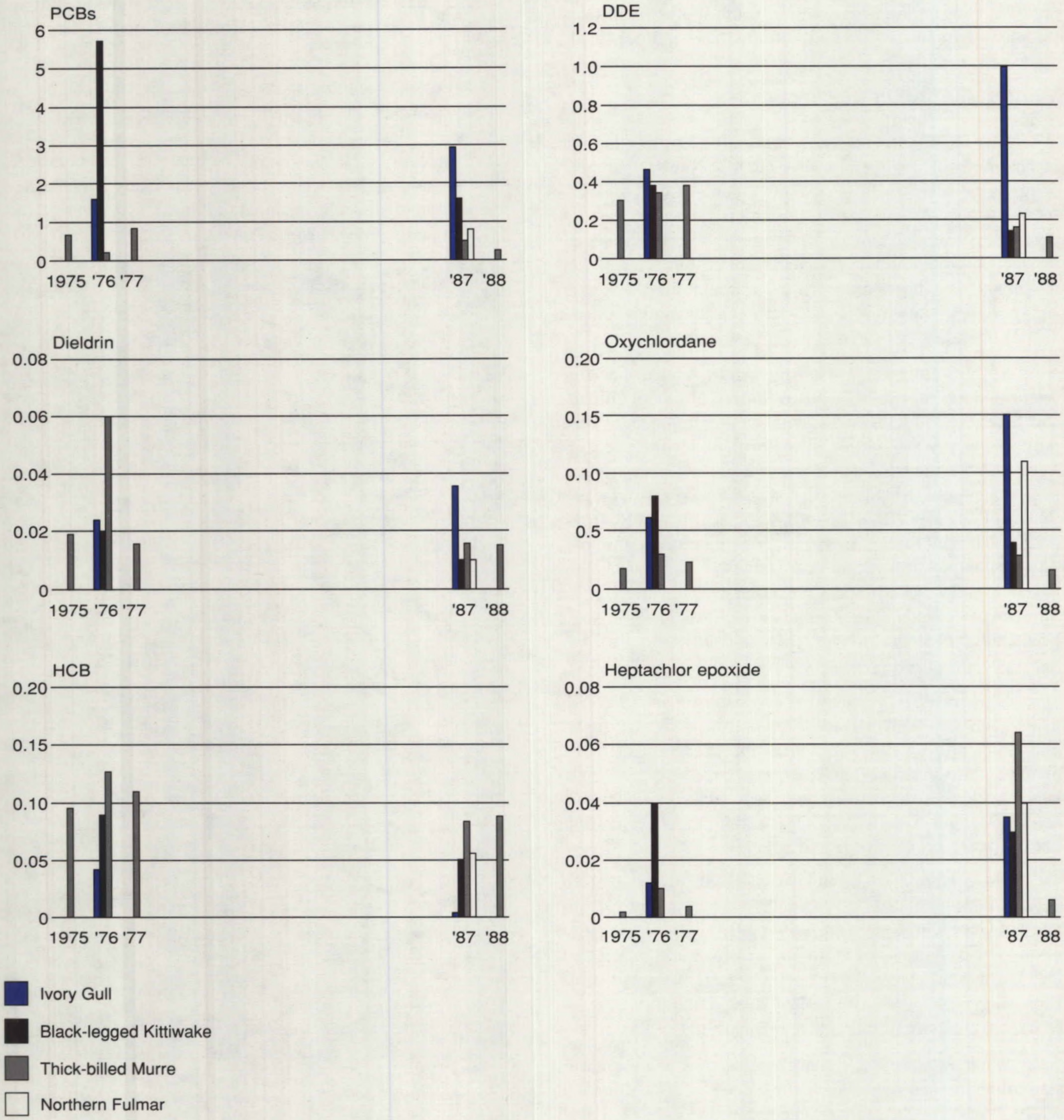
Fulmar livers were the most contaminated. This species may be further exposed to contaminants through occasional scavenging from carcasses of marine mammals (Appendix 3).

Long-range transport is the major source of organochlorines in the Arctic (contamination from D.E.W. line sites is another), and Norstrom and co-workers (1988) were able to relate the detected levels to the amount of precipitation an area received. It seems likely that much of the current organochlorine input to the Arctic originates from continuing use outside North America.

Canadian Wildlife Service

A Black-legged Kittiwake. Because these birds feed on the surface of the ocean the levels of contaminants in their eggs tend to reflect the amount of pollution transported by the atmosphere to their breeding areas.

Figure 15
Levels of major contaminants in eggs of Arctic seabirds, 1975–88. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.



Trends — It was possible to compare levels of contaminants in eggs of Thick-billed Murres, Ivory Gulls, and Black-legged Kittiwakes and in livers of Northern Fulmars in the mid-1970s to those measured in 1987 and 1988. At Prince Leopold Island, most organochlorines (DDE, PCBs, dieldrin, and HCB) appear to have declined (Figure 15). Heptachlor epoxide and oxychlordane, however, showed no signs of declining and even increased in some species. In eggs of Ivory Gulls, DDE, PCBs, oxychlordane, dieldrin, and heptachlor epoxide all increased between 1976 and 1987. The declining levels of organochlorines in the migratory species may reflect an overall reduction in organochlorine levels of the North Atlantic, whereas increased levels in the resident Ivory Gulls suggest an increased atmospheric flow to the Arctic.

Geographic patterns of contamination on the Pacific coast

Strait of Georgia

The Strait of Georgia lies between mainland British Columbia and Vancouver Island. Instead of the steel manufacturing/chemical plants found in other contaminated areas such as Lake Ontario and the upper St. Lawrence River, the main industries in the Strait of Georgia are those associated with forest products. These include pulp and paper mills, wood-product industries, and log storage areas. There are some metal mines and considerable shipping traffic (Waldichuk 1983). The Fraser River, which drains most of industrial and agricultural southern British Columbia, contributes 75% of the fresh water that flows into the strait.

Most of the seabird colonies in the strait are relatively small, with cormorants and Glaucous-winged Gulls dominating. Pigeon Guillemots, Marbled Murrelets, and many other fish-eating birds, such as Great Blue Herons, mergansers and scoters, also breed in the area (Vermeer *et al.* 1983).

Levels — Biologists collected eggs of Pigeon Guillemots, Glaucous-winged Gulls, and Double-crested and Pelagic Cormorants from several colonies (Figure 9) in the Strait of Georgia, between 1970 and 1985.

In spite of the number of forest-product industries in the strait, most organochlorine pesticide levels were surprisingly low. (The recent findings of high levels of chlorinated dioxins and furans in eggs of cormorants are discussed at the end of this chapter.) DDE was detected at concentrations less than 1 mg/kg in all eggs, except in those of cormorants in the early 1970s. In all four species, dieldrin, heptachlor epoxide, and oxychlordane were at levels of 0.05 mg/kg or less, and HCB ranged up to 0.30 mg/kg in Double-crested Cormorants. PCBs averaged between 1 and 15 mg/kg, with the highest residues detected in the cormorants. Although the data were extremely variable, the Double-crested Cormorant appeared to be the most contaminated species sampled.

None of these species are particularly migratory, although some may disperse outside the strait during the winter. Although gulls often obtain food from terrestrial sources such as garbage dumps, this source of food does not appear to be particularly contaminated. In fact, gulls that forage at dumps may be in less danger than those that do not, because the discarded "human food" eaten has been more strictly monitored for contaminants (according to human health standards) than food obtained from the marine environment.

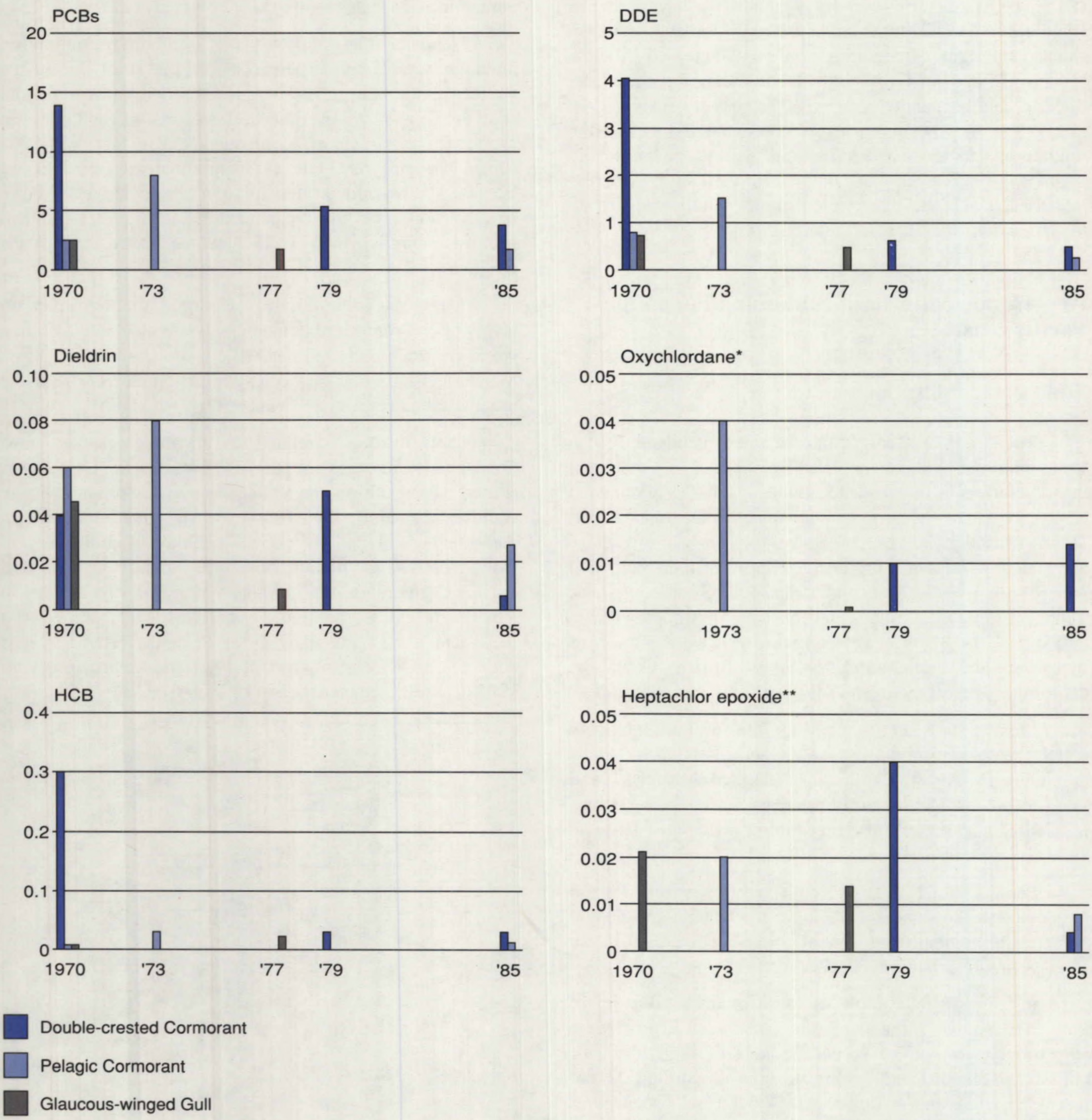
Trends — In the Strait of Georgia, long-term data on levels of environmental contaminants are available for three species: Double-crested and Pelagic Cormorants from Mandarte Island and Glaucous-winged Gulls from near the mouth of the Fraser River (Vancouver).

DDE residues declined in all three species, most dramatically in eggs of the Double-crested Cormorants (Figure 16). Dieldrin and heptachlor epoxide did not change significantly until the 1980s, when they declined in cormorants and gulls. PCBs declined significantly in Double-crested Cormorants, but only slightly in gulls and Pelagic Cormorants. Oxychlordane increased slightly only in Double-crested Cormorants, and HCB levels showed no consistent trend. Re-analyses of Pelagic Cormorant eggs collected at Mandarte Island in 1973 and comparison with 1985 data revealed increases in HCH and HCB.

Canadian Wildlife Service

A Double-crested Cormorant. The eggs of this species appeared to be the most contaminated of any seabird sampled in the Strait of Georgia.

Figure 16
Changes in contaminant levels in eggs of seabirds breeding in the Strait of Georgia, 1970–85. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.



* Prior to 1973, eggs were not analyzed for oxychlordane.

** None of the 1970 samples were analyzed for heptachlor epoxide.

Western and northern Vancouver Island

Compared with the strait, the western coast of Vancouver Island is relatively clean. It is largely unindustrialized, with only a few ports and little agriculture except in the south. This coastline supports a large population of seabirds, including Leach's Storm-Petrels, Glaucous-winged Gulls, Tufted Puffins, Cassin's and Rhinoceros Auklets, Marbled Murrelets, and three species of cormorants. Triangle Island, just north of Vancouver Island, is the site of the largest seabird colony, including a large population of Common Murres.

Levels — In 1970, researchers sampled four species (Leach's Storm-Petrel, Glaucous-winged Gull, Pigeon Guillemot, and Tufted Puffin) from Cleland Island (near Tofino) for organochlorines. In 1985, they collected eggs of Leach's Storm-Petrel, Glaucous-winged Gull, and Pelagic Cormorant from several colonies at the northwest end of Vancouver Island (Figure 9).

Analyses of the 1970 samples revealed relatively low levels of most organochlorines, with DDE and PCBs between 1 and 3 mg/kg, and dieldrin and HCB less than 0.05 mg/kg. The Leach's Storm-Petrels, which are oceanic surface-feeders, were the most contaminated. Glaucous-winged Gulls contained the highest levels of PCBs.

In the 1985 samples from farther north, organochlorine levels were uniformly lower, with DDE averaging about 0.50 mg/kg in eggs, PCBs up to about 1.0 mg/kg, and all other contaminants virtually undetectable. The ranking of species was similar to the 1970 rankings, with Leach's Storm-Petrels most contaminated, particularly with DDE, DDT, and DDD. Glaucous-winged Gull eggs contained the most PCBs, oxychlordane, and heptachlor epoxide.

Trends — Analyses of eggs of Leach's Storm-Petrels and Glaucous-winged Gulls collected at Cleland Island in 1970 and at the northwest tip of Vancouver Island in the mid-1980s give some idea of temporal trends in pollution along the west coast of Vancouver Island.

In both species, egg concentrations of DDE and dieldrin were considerably lower in the 1980s (Figure 17). PCBs declined significantly in the gull eggs, but only slightly in those of storm-petrels. However, these differencies may be due to the fact that different colonies were sampled in those two time periods.

Hecate Strait and the Queen Charlotte Islands

Apart from Prince Rupert, there are no major ports in Hecate Strait or on the Queen Charlotte Islands, but the area is an important route for logs (from northern British Columbia) and oil tankers, mainly from Alaska. The Queen Charlotte Islands archipelago contains many small seabird colonies, mainly storm-petrels, Ancient Murrelets, and Cassin's Auklets. Rhinoceros Auklets and Glaucous-winged Gulls are more common in Hecate Strait.

Large numbers of shearwaters, kittiwakes, murres, auklets, loons, and phalaropes migrate through Hecate Strait in spring and fall, making it one of the most important areas of the west coast in terms of biomass of seabirds, as well as marine mammals.

Levels — In the late 1960s and early 1970s, wildlife biologists collected eggs of Leach's and Fork-tailed Storm-Petrels, Glaucous-winged Gulls, Pigeon Guillemots, Rhinoceros and Cassin's Auklets, and Ancient Murrelets from sites in the Queen Charlotte Islands and Hecate Strait (Figure 9).

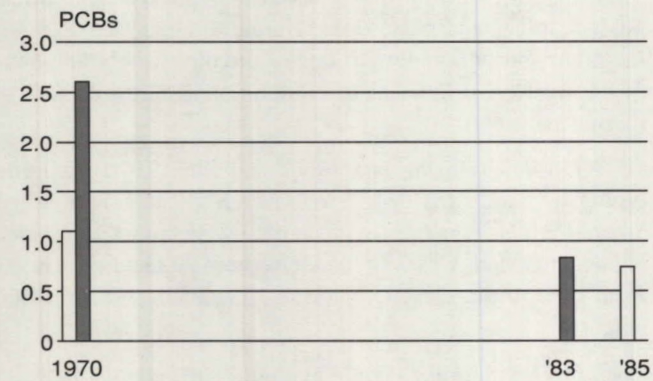
Organochlorine contamination of this relatively unindustrialized region then appeared to be minor (Noble and Elliott 1986). DDE varied between 0.50 mg/kg (in gulls and guillemots) and 3 mg/kg (in auklets and storm-petrels). This suggests that DDE was most prevalent in the more oceanic zooplankton prey of the storm-petrels and auklets and was not originating from local coastal areas, where the guillemots and gulls were feeding. Dieldrin, heptachlor epoxide, and HCB levels were uniformly low.

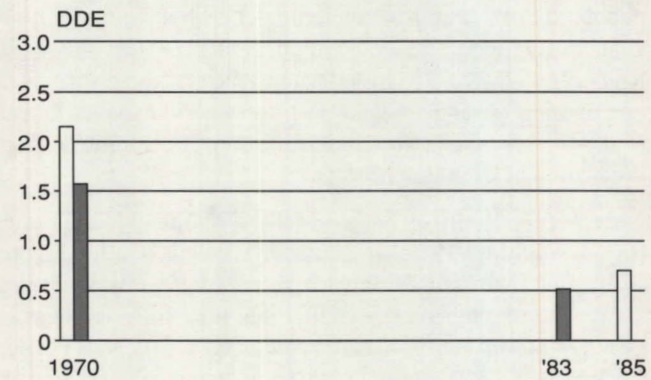
In addition to eggs, a number of adult alcids were collected between 1968 and 1972. Rhinoceros Auklets were the most contaminated (DDE averaging 5.9 mg/kg in whole bodies). Common Murres and Tufted Puffins were the least contaminated.

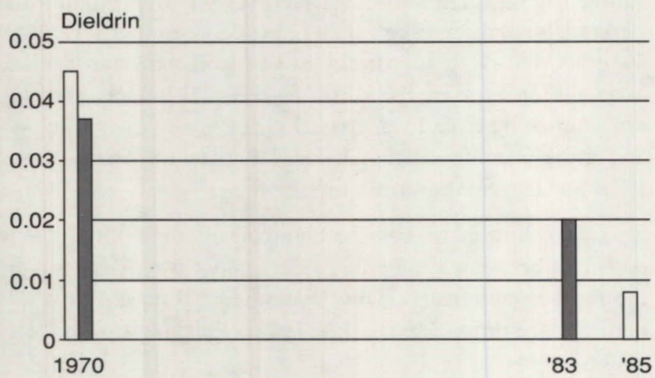
In the mid-1980s, eggs of Leach's and Fork-tailed Storm-Petrels from Hippa Island (on the west coast of the Queen Charlotte Islands) and eggs of Rhinoceros Auklets and Ancient Murrelets from Hecate Strait were analyzed for organochlorine content. DDE ranged up to 3 mg/kg, and PCBs up to 4 mg/kg. Oxychlordane levels were highest (0.15 mg/kg) in eggs of Fork-tailed Storm-Petrels. Organochlorine levels in the other three species were very similar. The generally higher levels of organochlorines in Fork-tailed than in Leach's Storm-Petrel may be due to the former's occasional scavenging on the carcasses of marine mammals or to its preference for foraging areas closer inshore (Vermeer and Devito 1987). Overall, levels were comparable with those in seabirds in the Strait of Georgia.

The most surprising find was the high concentrations of HCH (0.67 mg/kg) in eggs of Ancient Murrelets from Reef Island in western Hecate Strait, the highest recorded in any natural bird populations to date (Elliott *et al.* 1989). Ancient Murrelets forage in the offshore zone for zooplankton and small fish and probably winter offshore south of the Queen

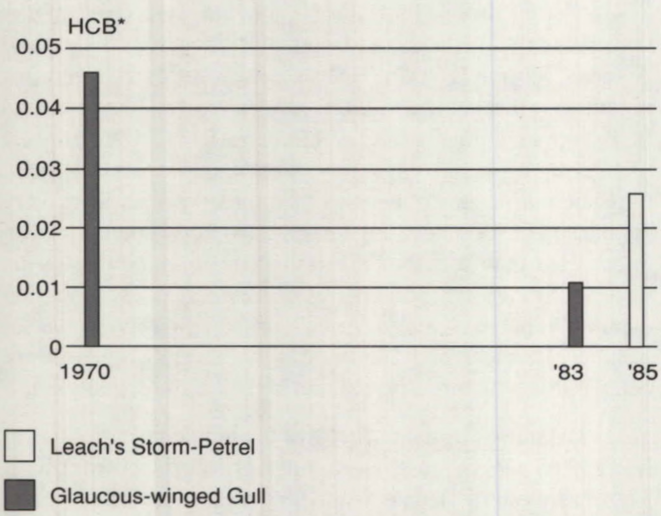
Figure 17
Changes in contaminant levels in eggs of seabirds breeding on the west coast of Vancouver Island, 1970–85. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.







Trends could not be determined for oxychlordane because the 1970 samples were not analyzed for this compound.



Trends could not be determined for heptachlor epoxide because the 1970 samples were not analyzed for this compound.

* The 1970 Leach's Storm-Petrel eggs were not analyzed for HCB.

Charlottes. The HCH isomers probably originated from continuing use of the pesticide BHC in Asian countries.

Trends — Species for which long-term data are available include Ancient Murrelets, Rhinoceros Auklets, and Leach's and Fork-tailed Storm-Petrels. Although only the auklet eggs were collected at the same colony (Lucy Island in Hecate Strait near Prince Rupert) throughout the sampling period, some general comparisons are possible for the other species.

In the Rhinoceros Auklet eggs, DDE and PCBs declined considerably, but HCB levels remained about the same (Figure 18). In eggs of both storm-petrel species, DDE and PCBs also declined, and so did HCB. DDE levels in eggs of Ancient Murrelets were only slightly lower in 1985 than in 1968. Dieldrin increased considerably in Fork-tailed Storm-Petrel eggs, but declined in Leach's Storm-Petrels and in Ancient Murrelets. Heptachlor epoxide declined in Ancient Murrelets, but increased in Leach's Storm-Petrels.

Summary of overall levels and trends

PCBs, DDE, toxaphene, dieldrin, mercury, HCB, oxychlordane, DDT, DDD, heptachlor epoxide, alpha and beta HCH, mirex, cis-chlordane, and nonachlors were detected in most of the samples that were analyzed for those particular contaminants.

The overall pattern of change in contaminant levels was quite consistent among all of the coastal regions for which long-term data were available (Figures 11–18). DDT compounds have declined significantly everywhere since the early 1970s. On the Atlantic coast, PCBs and dieldrin have declined in eggs of most species, but not always significantly. HCB, HCH, oxychlordane, and heptachlor epoxide levels were variable, but are basically just as high now as in the mid-1970s. On the Pacific coast, PCBs have declined only slightly along the west coast of Vancouver Island. HCB, oxychlordane, dieldrin, and heptachlor epoxide trends were inconsistent, increasing in some species and declining in others. In the Arctic, although most organochlorines show little change since the mid-1970s, heptachlor epoxide and oxychlordane have increased.

A national perspective

With respect to organochlorine pesticides and PCBs, the St. Lawrence estuary was, and continues to be, one of the most polluted marine areas in Canada, followed by the Bay of Fundy, the Strait of Georgia, and the west coast of Vancouver Island. Residues in the Arctic Islands, off Newfoundland, and along the coast of northern British Columbia were relatively low. Nevertheless, concentrations of contaminants in the eggs of seabirds from the St. Lawrence estuary are considerably less than in eggs of the same species breeding in colonies on the Great Lakes (Gilman *et al.* 1977; Weseloh *et al.* 1983; Noble and Elliott 1986). Pollution in the St. Lawrence estuary seems mainly to originate along the industrialized St. Lawrence Seaway and surrounding agricultural land, so is probably less affected by the outflow from the Great Lakes than it is by local sources in Quebec. This supposition is supported by Laporte's (1982) findings of high levels of many organochlorines in eggs of Great Blue Herons collected along the tributaries of the St. Lawrence River system.

A global perspective

On a global scale, residue levels in the St. Lawrence estuary are slightly lower than organochlorine levels in seabirds from industrialized western Europe (Parslow *et al.* 1972; Dyck and Kraul 1984), with the exception of the extremely high levels detected in Canadian gannets. Pollutant levels in alcids and gulls from Newfoundland are equivalent to levels found in seabirds breeding in Norway and other parts of northern Europe (Barrett *et al.* 1985).

The highest organochlorine levels found in seabirds in Canada — those in seabirds breeding in the St. Lawrence estuary — were comparable with levels in Common Terns and Brown Pelicans from the Atlantic coast of the United States (Blus *et al.* 1979; Nisbet and Reynolds 1984).

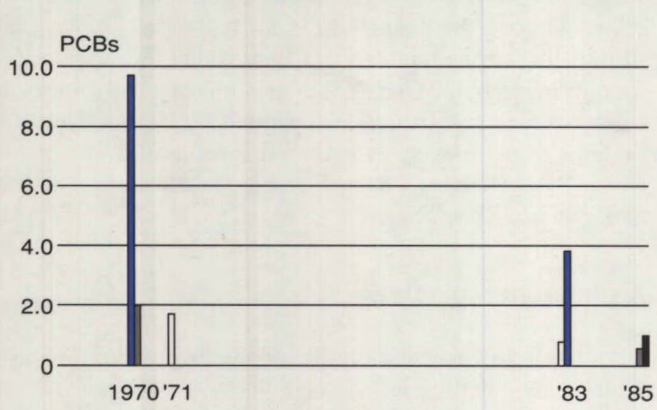
The concentrations of organochlorines in the eggs and tissues of arctic seabirds (Figure 15) were equivalent to levels detected in seabirds from arctic areas in Europe (Barrett *et al.* 1985).

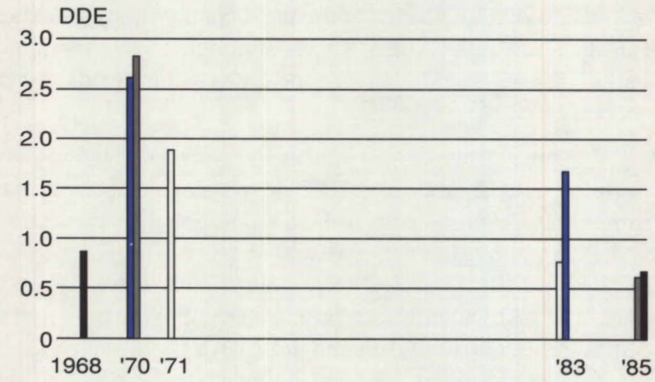
Organochlorine concentrations in seabirds on the British Columbian coast were intermediate between lower levels found in seabirds from Alaska (Ohlendorf *et al.* 1982) and higher levels to the south in Oregon (Henny *et al.* 1982) and California (Risebrough *et al.* 1967; Gress *et al.* 1971; Coulter and Risebrough 1973).

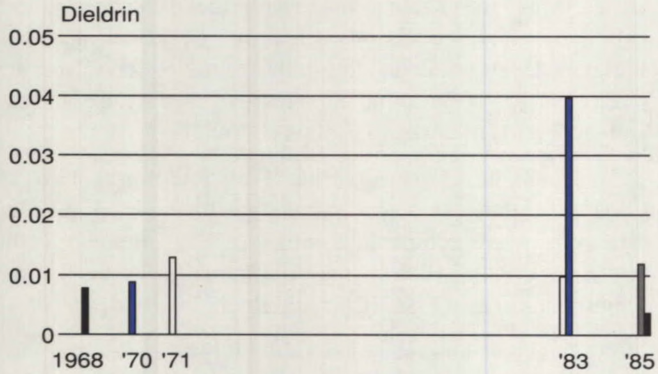
Contamination by dioxins and furans

Some recent analyses revealed the presence of an array of chlorinated dioxins and furans in the eggs of Pelagic and Double-crested Cormorants from the Strait of Georgia. Although levels were below acutely toxic levels, there may have been sublethal effects similar to those found in Great Blue Herons feeding in the same areas. Elevated levels of 2,3,7,8-TCDD in eggs of the herons were associated with reproductive failures in 1987 (Elliott *et al.* 1988*c*) and sublethal effects in the embryos in 1988 (Bellward *et al.* 1990).

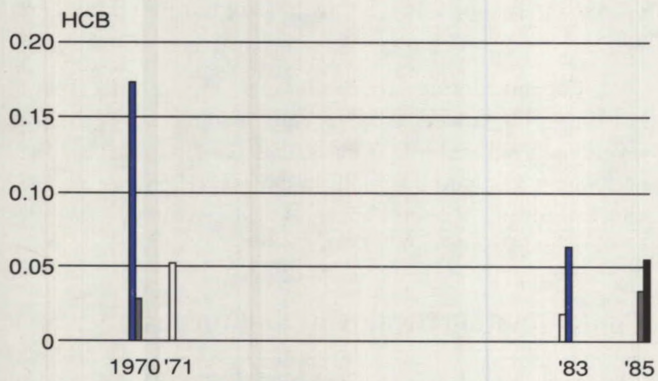
Figure 18
Changes in contaminant levels in eggs of seabirds breeding in the Queen Charlotte Islands and Hecate Strait, 1968–85. Contaminants were measured in milligrams per kilogram (mg/kg), wet weight.

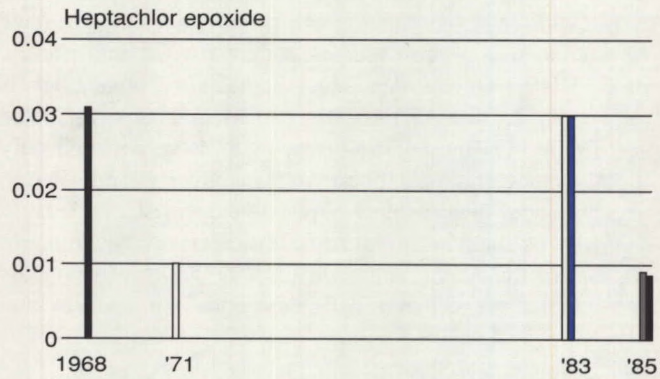






Trends could not be determined for oxychlordane because the samples collected in 1968, 1970, and 1971 were not analyzed for this compound.

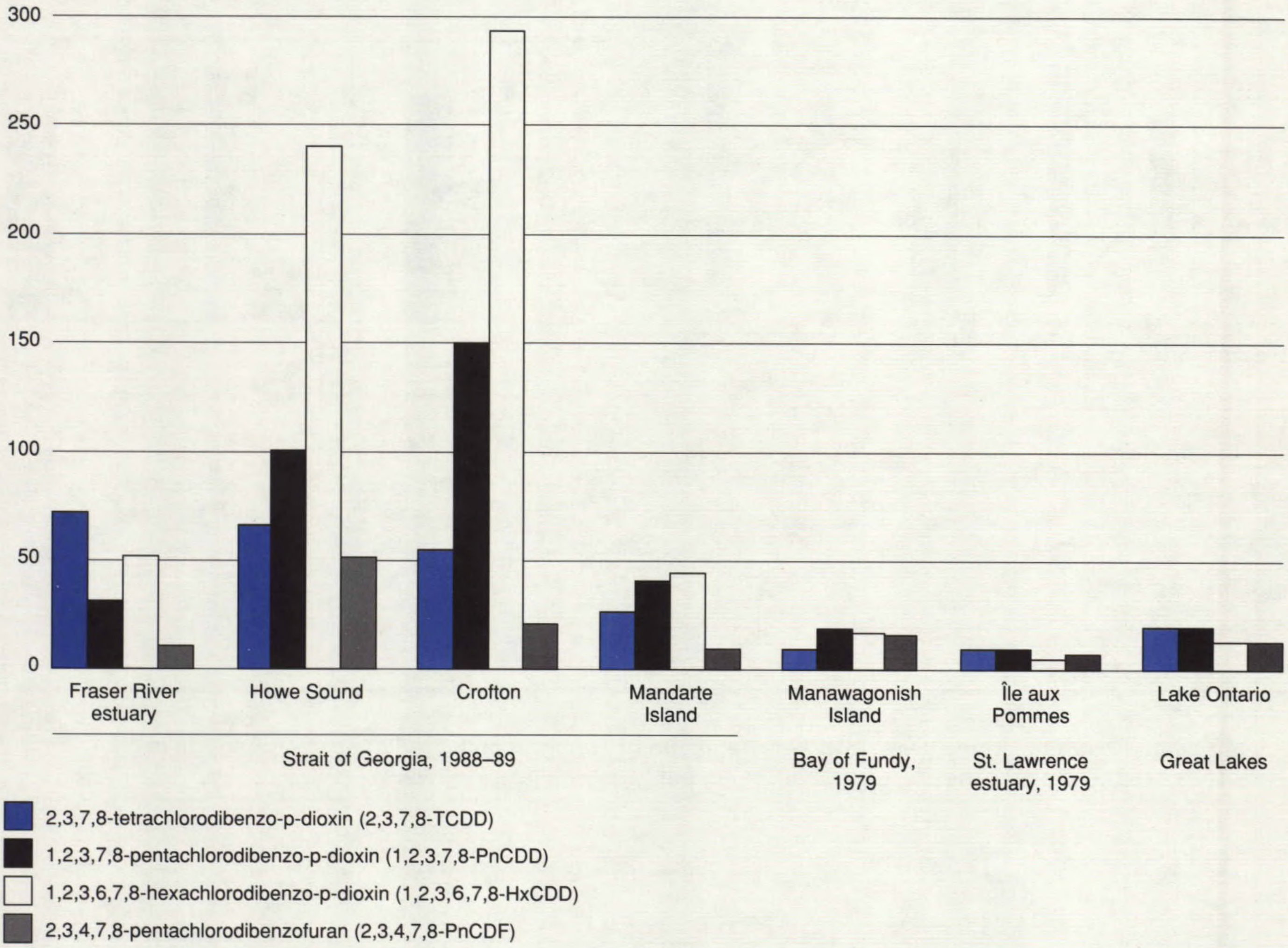




Leach's Storm-Petrel
Fork-tailed Storm-Petrel
Rhinoceros Auklet*
Ancient Murrelet**

* Rhinoceros Auklet eggs from 1970 were analyzed for DDE, PCBs, and HCB only.
** Ancient Murrelet eggs from 1968 were analyzed for DDE, dieldrin, and heptachlor epoxide only.

Figure 19
Geographic pattern of contamination of the major dioxins and furans in eggs of Double-crested Cormorants during the 1980s. Contaminants were measured in nanograms per kilogram (ng/kg, equivalent to parts per trillon), wet weight.



Levels found in Double-crested Cormorants breeding in the Strait of Georgia were high, compared with levels detected elsewhere: in the Great Lakes, the St. Lawrence estuary, and the Bay of Fundy (Figure 19). Within British Columbia, Pelagic Cormorants and Great Blue Herons show the same geographical pattern as the Double-crested Cormorants.

There appeared to be no consistent trend in dioxin levels over time in eggs of Double-crested Cormorants collected at Mandarte Island, British Columbia, in 1973, 1979, 1985, and 1989, although there was considerable yearly variation.

Levels of heavy metals

Mercury levels in seabirds eggs were generally low, between 0.10 and 0.50 mg/kg wet weight. There were few differences between species or among locations (Figure 20).

Figure 20
Levels of mercury in eggs of monitor species of seabirds in 1971–72. Mercury was measured in milligrams per kilogram (mg/kg), wet weight.

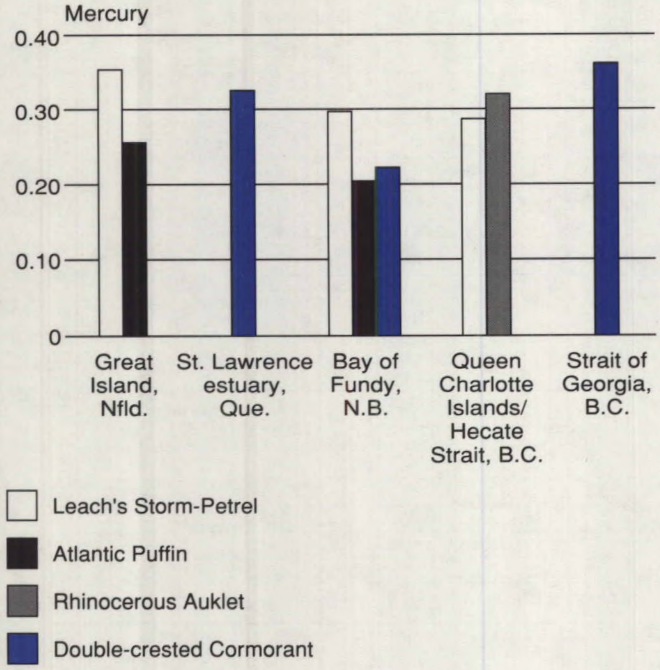


Figure 21
Changes in mercury levels in eggs of three seabird species from the east coast of Canada. Mecury was measured in milligrams per kilogram (mg/kg), wet weight.

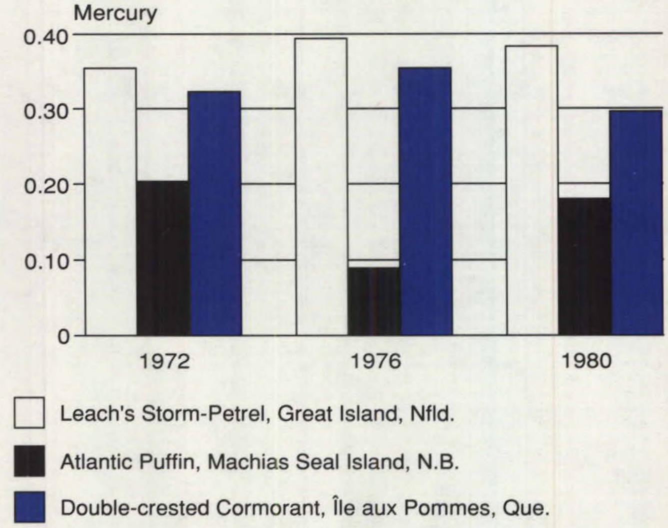


Figure 22
Levels of cadmium in kidney, liver, and muscle tissue of seabirds collected in eastern Canada in 1970 and 1971. Cadmium was measured in milligrams per kilogram (mg/kg), wet weight.

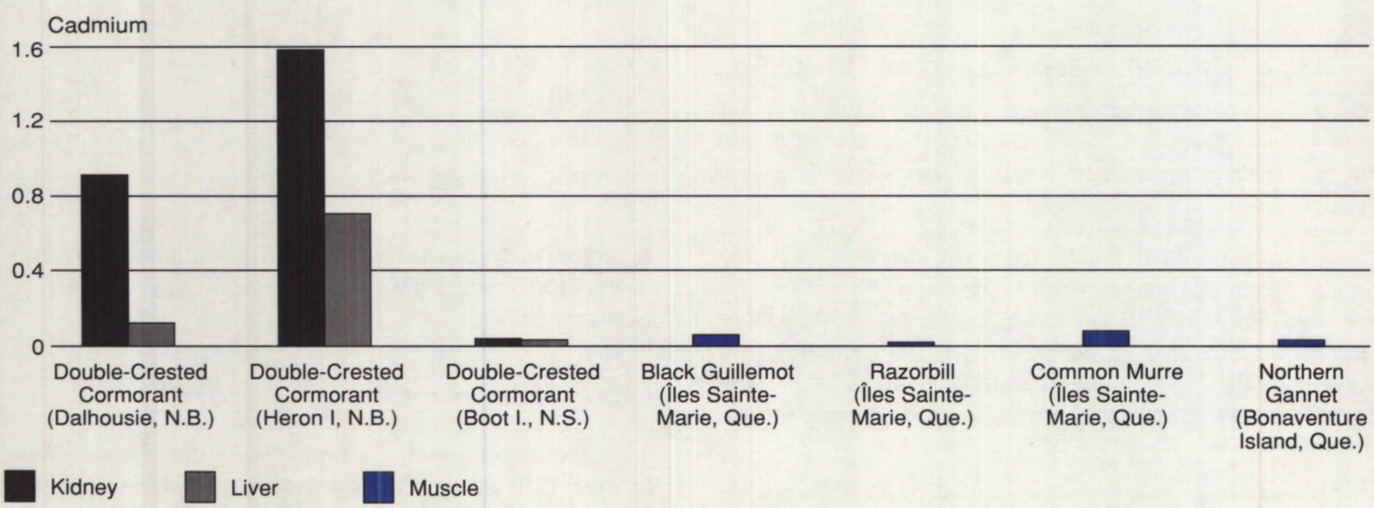
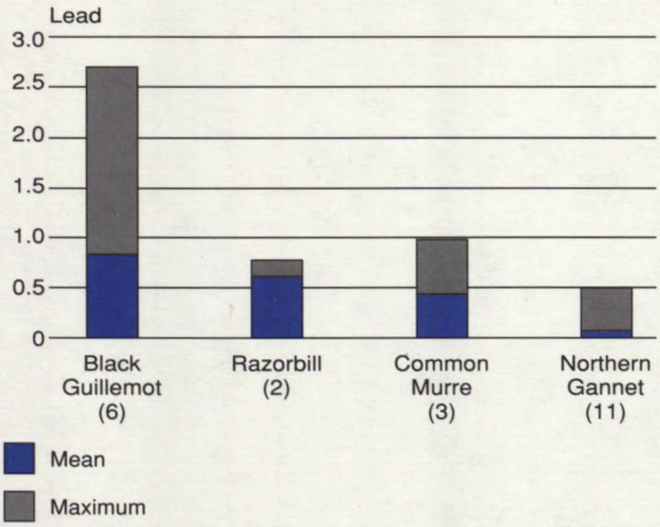


Figure 23
Levels of lead in breast muscle of seabirds collected from the east coast of Canada in 1971 (mean and maximum value recorded). Lead was measured in milligrams per kilogram (mg/kg), wet weight.



However, elevated levels of mercury were found in the livers of Double-crested Cormorants collected in Chaleur Bay, N.B., in 1969. Mercury did not show any obvious trends between 1972 and 1980 (Figure 21) in any species sampled. We lack data to determine whether levels have declined since that time.

Cadmium was detected at low levels in most east coast seabirds (Figure 22). The highest levels were found in the kidneys of Double-crested Cormorants at Heron Island in Chaleur Bay. In 1980, parts of the bay were closed to lobster fishing because of high concentrations of cadmium in the lobsters (Uthe *et al.* 1986). Discharge from a local lead smelter was found to be the source. Once waste treatment was improved, cadmium levels declined, and the lobster fishery was re-opened in 1985. The cormorants have not yet been re-tested.

Lead was measured in the muscle of four species of seabird in eastern Canada (Figure 23). The elevated levels found in some Black Guillemots suggest exposure to lead. Contamination from lead shot used by hunters is a possibility.

Chapter 7
Health of seabirds and status of Canadian seabird populations

Health of seabirds

None of the organochlorine contaminants currently detected in the eggs and tissues of Canadian seabirds were at levels high enough to kill birds that had fledged, according to information from laboratory studies. Many of the poisoning incidents reported in other countries were due to direct exposure from chemical spills or from the untreated effluent from pesticide manufacturing plants. Seabird deaths related to exposure to oil, on the other hand, are probably considerable, in Canada as well as elsewhere.

However, there were adverse effects on reproduction in some Canadian seabirds. During the late 1960s and early 1970s, eggs of Northern Gannets from Bonaventure Island, Quebec, contained an average of 30 mg/kg DDE. Reproductive success was greatly reduced during this period, with less than one-third of the eggs producing chicks that survived to fledging.

During the early 1970s, 20% of the Double-crested Cormorant eggs laid in eastern Canada contained more than 15 mg/kg DDE, theoretically enough to cause a 20% reduction in eggshell thickness in these species. No information is available on the reproductive success at those colonies, but the population in the Gulf of St. Lawrence declined during this period.

Small amounts of eggshell thinning probably occurred in a number of other species, including Leach's Storm-Petrels from the Bay of Fundy, in the early 1970s.

Status of Canadian seabird populations

Recent seabird studies

Determining the status of seabird populations, in Canada or elsewhere, is a complex problem. Many colonies are on remote islands, and nest sites are often hidden or inaccessible to humans. This chapter summarizes what evidence we do have for changes in status, based on both historical and recent studies.

Information about the seabirds that inhabit Canadian coastal waters spans several centuries. The earliest accounts are from Canada's native peoples — on both coasts and in the Arctic — who have traditionally depended on seabirds and their eggs for food during part of the year. The sheer magnitude of many colonies impressed early explorers and settlers, who appreciated this rich source of fresh meat. Many species were later also exploited for their plumage. This exploitation led to the extermination of the flightless Great Auk from its only breeding area off the coast of Newfoundland.

Throughout the 19th century, explorers and naturalists continued to visit seabird colonies, often collecting eggs and specimens for museums and recording the natural history of the birds. In 1916, the Migratory Birds Convention was signed with the United States, committing the government of Canada to the job of protecting and managing migratory birds. Since that time, agencies such as the Canadian Wildlife Service have acted to protect some species by outlawing trade in feathers and attempting to prohibit egg collections. This fight continues today, with the help of such groups as the Quebec-Labrador Foundation, which runs education programs and promotes conservation, mainly in communities along the north shore of the Gulf of St. Lawrence.

In the 1970s, officials assessing the potential environmental effects of proposed oil development in the North and along both coasts needed accurate data about the state of wildlife populations. Consequently, oil companies and government agencies funded a number of studies on the breeding ecology of arctic seabirds.

Seabirds on the Atlantic coast of Canada — Seabirds breeding on islands in migratory bird sanctuaries along the north shore of the Gulf of St. Lawrence have been censused every five years since the 1920s and this provides one of the most useful series of population numbers. Regular censuses of the Northern Gannet colony at Bonaventure Island began in the 1950s.

In Newfoundland, little was known before the 1950s when Leslie Tuck initiated banding operations of alcids, particularly Common Murres. During the past 15 years, scientists in the Canadian Wildlife Service have visited most of the breeding colonies in Newfoundland. Great Island in the Witless Bay Sanctuary has been the focus of considerable research on the breeding biology and diet of the Atlantic Puffin. More recently, censuses of breeding seabirds in Newfoundland have been continued, with an attempt to determine the population status of the Leach's Storm-Petrel, a burrow-nesting species notoriously difficult to count.

Seabirds in Arctic Canada — Most arctic seabird colonies are well known to the local native people, many of whom have traditionally depended on them for food during the summer. Attempts by explorer-naturalists since the nineteenth century to census colonies give us some idea about historical status, but some of the most comparable estimates come from visits by Tuck in the 1950s.

Since oil exploration began in the Arctic, the number of visits to seabird colonies has increased. Banding and reproductive assessment studies have been completed at Cape Hay, Coburg Island, Digges Island, Akpatok Island, the Minarets, and Hantzsch Island, where Thick-billed Murres, Black-legged Kittiwakes, and Northern Fulmars are the dominant species. Long-term studies are continuing at Thick-billed Murre colonies in Hudson Bay and at Prince Leopold Island in Lancaster Sound.

The Canadian Museum of Nature, represented in particular by Stuart MacDonald, has also been involved in basic ornithological surveys in the Arctic and is the main source of information on Ivory Gulls.

Seabirds on the Pacific coast of Canada — Less is known historically of the seabirds of the Pacific coast of Canada, mainly because most of the species are nocturnal burrow-nesters and more difficult to census. The Royal British Columbia museum has collected data on the status of many species since the 1940s.

Triangle Island, the largest seabird colony in British Columbia, has been the site of several studies during the past 15 years, focusing on the reproductive biology of Tufted Puffins and Rhinoceros Auklets. In the 1980s, the Canadian Wildlife Service conducted a census of burrow-nesting seabirds over the entire British Columbia coastline and, since 1984, has been operating a long-term study on Ancient Murrelets near the South Moresby National Park.

Current status of seabird populations

Despite the studies currently underway or recently carried out, our knowledge of the status of most seabird populations is incomplete because we lack reliable historical data. Survey techniques have varied considerably over the years, and the resultant biases make it difficult to detect real changes in numbers. In the case of the burrow-nesting storm-petrels and many Pacific coast alcids, there are no earlier surveys to compare with current estimates. Where possible, earlier "rough" estimates are considered, and any detectable indications of historical levels (such as unoccupied ledges covered with guano) are used to infer population changes. Based on the population estimates available, the current status of seabird populations in Canada is shown in Table 1, arranged by geographic area. It is limited to species for which contaminant data are available.

Organochlorine and industrial contamination is highest in the St. Lawrence estuary and adjacent areas of the gulf. Fluctuations of Northern Gannet populations at Bonaventure Island clearly demonstrate the relationship between elevated DDE levels in eggs, eggshell thinning, reduced productivity, and declines in numbers. By 1984, DDE levels were significantly reduced and gannet numbers had increased to previous levels.

Although Double-crested Cormorant eggs were among the most contaminated of those sampled, particularly during the late 1960s, this species is currently flourishing all over its range. A short-lived decline in numbers of Double-crested Cormorants along the north shore of the Gulf of St. Lawrence in the early 1970s may have been related to high levels of pollutants, such as DDE.

There is insufficient evidence to attribute the current declines in Common Terns or Atlantic Puffins at many locations in eastern Canada and the United States to organochlorine contamination. Terns are known to be adversely affected by habitat changes and disturbance at many of their colony sites; however, as eggshell thinning (Fox 1976), congenital abnormalities (Hays and Risebrough 1972), and reduced hatchability (Hoffman *et al.* 1987) have all been documented in terns, it may be that they are particularly sensitive to organochlorines. The frequent breeding failures of Tufted Puffins and Rhinoceros Auklets at Triangle Island and the occasional poor years of Atlantic Puffins at Great Island have been attributed to lack of available food during the breeding season. There is no evidence that organochlorines have reduced the food supply, but it is possible that high levels of organochlorines may have contributed to the mortality of fat-depleted chicks.

Numbers of Razorbills in the estuary declined during the late 1960s and early 1970s. Razorbills in the St. Lawrence contained contaminants at concentrations high enough to be associated with reductions in reproductive success, although previous investigations of the breeding success of this species revealed no evidence of problems (Chapdelaine and Laporte 1982).

Table 1
Status of seabird populations in Canada

Atlantic coast	
Leach's Storm-Petrel	- status unknown
Northern Fulmar	- increasing in Newfoundland/Labrador
Double-crested Cormorant	- increasing in Nova Scotia and the St. Lawrence estuary - declined along the north shore of Gulf of St. Lawrence in the early 1970s, but is now increasing again
Northern Gannet	- declined at Bonaventure in the late 1960s and early 1970s, but has increased since 1975
Herring Gull	- stable since expansion in the 1970s
Black-legged Kittiwake	- increasing in the Gulf of St. Lawrence and Newfoundland
Common Tern	- declining in Nova Scotia and in the Gulf of St. Lawrence
Common Murre	- was declining in the Gulf of St. Lawrence - stable in Newfoundland
Razorbill	- declining in the Gulf of St. Lawrence - increasing in the St. Lawrence estuary
Black Guillemot	- status stable/unknown
Atlantic Puffin	- declining at some colonies in Newfoundland - probably stable elsewhere
Pacific coast	
Fork-tailed Storm-Petrel	- status unknown
Leach's Storm-Petrel	- status unknown
Double-crested Cormorant	- increasing in the Strait of Georgia
Pelagic Cormorant	- stable in Strait of Georgia and Vancouver Island - declining in Queen Charlotte Islands and Hecate Strait
Glaucous-winged Gull	- increasing on Vancouver Island and in the Queen Charlotte Islands
Common Murre	- status unknown
Pigeon Guillemot	- status unknown
Tufted Puffin	- declining in British Columbia
Rhinoceros Auklet	- probably stable
Cassin's Auklet	- probably stable
Ancient Murrelet	- probably declining in the Queen Charlotte Islands
Marbled Murrelet	- status unknown
Arctic	
Northern Fulmar	- probably stable
Black-legged Kittiwake	- status unknown
Ivory Gull	- status unknown
Thick-billed Murre	- probably stable
Dovekie	- status unknown

Threats to seabird populations

Most of the observed declines in seabird populations can be attributed to causes other than organochlorine pollution. Oil spills have caused the deaths of thousands of seabirds on both coasts recently and may threaten breeding colonies (see Appendix 1). Mammalian predators, such as rats and raccoons, have been blamed for declines and disappearances of populations of Ancient Murrelets and other alcids in the Queen Charlotte Islands. Logging has probably destroyed much of the nesting habitat of Marbled Murrelets in British Columbia. Along the north shore of the Gulf of St. Lawrence, hunting of seabirds and egg collecting at the colonies have caused substantial decreases in the past. On both coasts, significant numbers of seabirds are accidently caught and drowned in both inshore and offshore fishing nets every year, and in Newfoundland and Labrador very large numbers of murres are shot for food every winter.

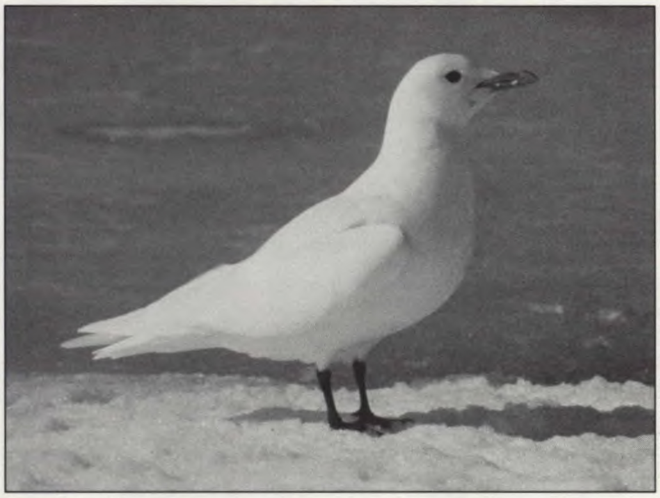
Some species are obviously in no danger: Black-legged Kittiwakes, Herring Gulls, Ring-billed Gulls, Northern Fulmars, and Glaucous-winged Gulls are increasing dramatically over much of their range. Some of the reasons suggested to explain these increases include the increased availability of human-derived sources of food such as fish offal and "natural" expansion of their range due to climate changes.

It seems unlikely that any populations of Canadian seabirds are currently adversely affected by organochlorine contamination, although a few species suffered pesticide-induced declines in the past. The main current threats to Canadian seabirds are oil, drift nets, habitat destruction, introduced mammals, overfishing, and overhunting.

Chapter 8
Contaminant research

Although there do not appear to be any drastic problems with seabird health at the moment, biologists conducting research are alert for any potential problems. The high organochlorine levels that have been found in beluga in the St. Lawrence estuary (Masse *et al.* 1986) suggest that seabirds living there may also be at risk. In areas where organochlorine contamination is considered high, further investigation of reproductive and biochemical effects is recommended. The most efficient policy is to integrate contaminant monitoring with reproductive studies and population monitoring for other conservation purposes, as is now being done. Two areas that warrant further investigation at present are the St. Lawrence estuary and the Strait of Georgia.

One of the new areas of research is detection of the deadly microcontaminants, the chlorinated dioxins and furans. First detected by new analytical techniques in Herring Gulls from the Great Lakes, these chemicals were recently found in the eggs of Great Blue Herons and Pelagic and Double-crested Cormorants feeding in the Strait of Georgia (Elliott *et al.* 1988*a*). This work was one of the first signals of widespread contamination by dioxins from the forest industry. Although scientists have not yet established for certain whether these compounds are affecting reproductive performance of the herons, there is cause for concern about the levels in other marine birds feeding in the strait. Retrospective analyses of samples stored in the Canadian Wildlife Service's National Specimen Bank revealed the presence of these compounds as early as 1973 (Elliott *et al.* 1988*c*).



Canadian Wildlife Service

Eggs of the Ivory Gull are being considered for regular monitoring in the Arctic. As the species does not usually winter south of the pack ice, scientists can be sure that all the contaminants it contains are reaching it through the Arctic food chain.

Related to this research is work on the environmental chemistry of specific PCB congeners. PCB congeners differ in toxicity, and the proportion of each isomer in the environment depends on the source of the PCBs. Many scientists believe that PCB pollution will continue to increase in the environment over the next decade or two (Tanabe 1988) because of the high proportion of PCBs still present in electrical equipment, in sediments, and in the immense reservoirs of the world's oceans.

The future of the seabird monitoring program

The seabird monitoring program will continue more or less as originally planned, with some minor modifications in sampling design. The main emphasis is on developing a strategy for the Arctic coast similar to the ones in place on the Atlantic and Pacific coasts. Where possible, samples of several species will be collected every four or five years from at least one colony. To this end, eggs of Thick-billed Murres, Black-legged Kittiwakes, and Northern Fulmars were collected in 1987 and 1988 from the original collection site on Prince Leopold Island in Lancaster Sound. Another species, the Ivory Gull, which is resident in the north, is also being considered as a potential indicator of contamination of the High Arctic.

In order to improve our knowledge of exposure and accumulation of heavy metals in marine birds, preliminary surveys are planned. Tissues of selected seabirds from both coasts will be analyzed for mercury, lead, and cadmium and will be examined for biochemical and histological effects of metal exposure. The species selected will represent both oceanic feeders (such as storm-petrels) and inshore feeders (such as cormorants).

New techniques

The use of feathers to measure mercury is a promising line of research. Braune (1987) was able to demonstrate changes in mercury levels in Bonaparte's Gulls and other marine birds in the Bay of Fundy over the season by measurement of mercury in moulted feathers.

Recent developments in the use of biochemical markers may prove to be valuable tools in assessing the effects of pollutants on birds. Certain physiological functions of birds (and mammals) are affected by the presence of foreign substances such as organochlorines or petroleum hydrocarbons. The alien chemicals may invoke responses from enzyme systems such as the MFO (multifunction oxidase) system (Walker and Knight 1981; Peakall *et al.* 1986; Rattner *et al.* 1989).

For example, it is possible to take livers from seabirds and measure the amount of the activated form of the enzyme called aryl hydrocarbon hydroxylase (AHH) in the liver. This can indicate exposure to AHH inducers such as organochlorines and petroleum hydrocarbons (Peakall *et al.* 1986).

Exposure to lead can be assessed by measuring the activity of blood amino levulinic acid dehydratase (ALA-d), an enzyme involved in heme synthesis (Scheuhammer 1989). A decline in the activity of blood ALA-d is the most sensitive known indicator of lead exposure.

Blood samples have been used to monitor organochlorines in migrating raptors. However, for seabirds, this technique offers no advantages over the collection of eggs.

As mentioned earlier, monitoring of contaminants is best carried out in conjunction with biological monitoring. To this end, the choice of locations for monitoring pollutants in seabirds has been partially based on the presence of ongoing ecological research, particularly breeding studies. At the same time, collection procedures have been modified in order to maximize the information obtained from the analyses. Collection sites may be visited several times in order to assess breeding performance at nests from which eggs were collected or to obtain an average breeding success rate for the colony.

Outlook

Although levels of most organochlorine contaminants appear to be declining in eggs of Canadian seabirds, their continuing presence more than 20 years after restrictions were imposed suggests that large amounts remain in the marine environment. Current research on the environmental effects of specific PCB congeners and other industrial chemicals such as dioxins and furans suggests that some fish-eating birds may still be adversely affected. For those chemicals (such as DDT) that we have stopped releasing we have reversed the buildup of dangerous concentrations near sources. Instead, the contaminants are now spread more thinly throughout our environment and ourselves. No one knows how long it will take for all the contaminants to break down into harmless substances. Thus, the rapid declines in contamination that followed restrictions are giving way to much slower declines in background levels. Continued monitoring of seabirds is necessary not only to keep track of the declines, but also to discover whether any new toxic substances created by our industrial society are bioaccumulating.

Seabirds and their eggs constitute a significant part of the diet of many Native people (particularly in the North) and non-Native inhabitants of Newfoundland, Labrador, and the north shore of the Gulf of St. Lawrence. These groups are justifiably concerned about contamination of their traditional foods, which further supports the need for continued monitoring of contaminant levels.

Although no Canadian seabird populations appear to be currently declining because of toxic chemicals, the additive effects of oil pollution, habitat destruction, hunting, disturbance of breeding colonies, and reduction of fish stocks have resulted in the decline of several seabird species. The dramatic decline in most of the North American gannet population during the 1960s due to the presence of organochlorine contaminants shows the need for continued vigilance. The recovery of the gannet population on Bonaventure Island when DDT was banned demonstrates that prohibiting the use of chemicals that bioaccumulate can successfully halt dangerous local accumulations.

Chapter 9

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Appendix 1

Other major groups of marine pollutants

Petroleum hydrocarbons

Since the late 1960s, accidents involving oil tankers or offshore drilling rigs have resulted in several major oil spills each year. In addition to these accidents, oil tankers and other vessels often dump waste oil and contaminated water before docking. Depending on its consistency, oil on water rapidly spreads into a thin layer. Some of its component hydrocarbons evaporate, whereas others remain and are very slow to degrade. Crude oil tends to coagulate into a sticky mass.

The immediate physical effects of oil exposure at sea are most noticeable in seabirds and marine mammals, because they encounter it at the ocean surface. Oil penetrates the feathers of seabirds, displacing air and reducing buoyancy and insulation. The water-logged birds are usually unable to forage or keep warm, and may die once their fat stores have been used up. This was the probable cause of death of thousands of Alaskan seabirds in 1989 when the Exxon Valdez spilled hundreds of thousands of litres of oil into Prince William Sound.

Ingested oil may also be toxic. Oil is a complex substance, composed mainly of saturated and aromatic hydrocarbons, as well as naphthenic acids, phenols, and nitrogen- and sulphur-containing cyclic compounds (Holmes 1984). A certain fraction of oil, such as some polycyclic aromatic hydrocarbons (PAHs), is highly toxic to seabirds. The effects include embryo mortality, stunted growth, osmo-regulatory changes, endocrine disfunction (Holmes 1984) as well as anemia, and liver and kidney damage (Fry and Lowenstine 1985).

Even minor exposure to oil may have detrimental effects. Application of very small amounts of oil (externally and internally) to Leach's Storm-Petrels reduced their reproductive success, apparently due to temporary parental abandonment of the nest site (Butler *et al.*, 1988). We know little about the effects of oil on the fish and invertebrate prey of seabirds.

Plastics and nonbiodegradables

Plastics, styrofoam, and other nonbiodegradable materials also pose hazards to seabirds (Ryan 1987). These substances (which are dumped at sea as garbage) tend to build up in areas of ocean current convergences, also the richest feeding areas for seabirds. Morris (1980) reported that plastic particles were present at average densities of 1000 to 4000 per square kilometre on the surface of both the Atlantic and Pacific Oceans.

There have been numerous reports of seabird stomachs being filled with plastic particles (Furness 1987). The adverse effects to ingestion include increased exposure to PCBs and reduced capacity to digest food (because so much of the gizzard is full of plastic particles). It appears that seabirds often mistake small particles of plastics and other material for food.

Radionuclides

Like heavy metals, most radionuclides occur naturally at very low concentrations, but incidents such as the 1986 Chernobyl accident reveal how easily contamination of a wide area can occur. Very little work has been done on the effects of nuclear power plants on local marine life, but sea birds may be useful as monitors of exposure to radionuclides. Long-lived species may accumulate detrimental levels of these substances.

Appendix 2

How organochlorines are measured

The levels of pollutants in seabirds are measured by chemically analyzing homogenized mixtures of a known amount of tissue or eggs and determining the proportion by weight of each identifiable chemical. This process involves careful sample preparation and sophisticated analytical instruments and therefore most wildlife samples are analyzed by laboratories specializing in this work. The development of gas-liquid chromatography and the electron capture detector in the 1970s revolutionized this field and allowed the detection of miniscule (i.e., less than one part per million) concentrations, previously undetectable.

Collection of egg samples

Whether sampling is part of a monitoring program or part of a study on the effects of a certain chemical, the samples must be collected in a standardized way.

Most of the monitoring programs involve the collection of eggs. Organochlorine levels in eggs are considered to represent levels in the female prior to egg-laying. Eggs are usually collected fresh, early in the season to encourage re-laying, and only one egg per clutch is collected. These procedures minimize the effects of the research on breeding success of the population. Where reproductive problems are suspected, both fresh and unhatched eggs are of interest, because failure to hatch might be associated with higher concentrations of the pollutant. Unhatched eggs (addled or with dead embryos) are taken opportunistically at the end of the season.

Tissue collections

Now that more sophisticated analytical instrumentation has been developed, it is possible to measure organochlorines in very small samples, such as a millilitre sample of blood. Although some seabirds were killed in order to measure pollutant levels, most were found dead by the public and sent to the Canadian Wildlife Service. If the specimen was relatively fresh, and if contamination of that species was of interest, selected tissues were analyzed.

Storage

To minimize decomposition (and possible degradation of the chemical residues) all samples have to be refrigerated as soon as possible and transferred to sterile containers. Eggs can be stored refrigerated for a few weeks, but tissue samples should be frozen within a few hours. Before chemical analysis, each sample is homogenized in a blender.

Chemical analysis

High resolution gas capilliary chromatography coupled with electron capture detectors is the technique in current use by most chemical laboratories to measure the levels of organochlorines. The chlorinated hydrocarbons currently detected and reported are DDE, DDD, DDT, dieldrin, heptachlor epoxide, mirex, oxychlordane, cis and trans non-achlor, cis and trans chlordane, HCB and other chlorinated benzenes, alpha, beta, and gamma HCH, and PCBs.

Nowadays, most laboratories also analyze a control sample whose composition is known, although often not by the analytical chemist. These controls serve as a quality control check on the data generated by the laboratory, and are meant to detect errors at any point in the procedure.

Because of the differences in both analytical techniques not all analyses from the 1960s can be directly compared to levels detected today. If the techniques available today had been used to analyze those samples from the 1960s, the result might have been quite different. Therefore, the Canadian Wildlife Service stores all samples in its National Specimen Bank (Turle and Norstrom 1987) to be re-analyzed when needed.

Another important feature of chemical analyses is their cost. In 1986, a chemical analysis of a single sample cost about $300, because of the expensive equipment and the experience of the technicians required. For financial reasons, biologists cannot analyze specimens indiscriminately, but must decide which are the most important. One option is to analyze several samples mixed together (pooled samples) in order to measure the average contamination of a particular species. Although useful, pooled samples do not reveal the true range of levels normally found in wild populations, and they make it more difficult to statistically analyze for changes between sampling periods. However, the unanalyzed specimens are stored, and, if potentially harmful levels are detected in the pooled sample, it is possible to retrieve the individual samples from storage in the specimen bank and analyze them separately.

Analyses for metals

Biological samples are initially treated with digestive acids in order to isolate the heavy metals. Total mercury is determined by cold vapour atomic absorption spectrometry, by techniques first described by Hatch and Ott (1968) and later modified by the Ontario Research Foundation. Cadmium, lead, and other heavy metals are determined by atomic absorption spectrometry.

Appendix 3
Diets of Canadian seabirds

Most species have a fairly wide range of preferred foods, depending on the season and their physiological requirement at the time. The "typical" diet includes both fish and zooplankton, with the most abundant prey types (arctic cod, capelin, sandlance, amphipods, copepods, euphausids or squid) predominating (Table 3.1).

A few species are more specialized. The gannet, for example, feeds almost exclusively on large-bodied schooling fish such as mackerel and herring, as well as squid (Kirkham *et al.* 1985). Cormorants feed on both benthic and pelagic fish, depending on availability (Robertson 1974). Some of the smaller auklets, such as Cassin's Auklet and the Dovekie, feed almost exclusively on pelagic zooplankton (Vermeer 1981; Bradstreet 1982). Most of the larger alcids (murres, Razorbills, and puffins) are fish-eaters, but forage at different depths (Bradstreet 1983; Gaston and Nettleship 1981; Cairns 1981; Vermeer *et al.* 1979).

Storm-petrels feed at the surface on a variety of zooplankton and small fish (Linton 1978). Fulmars, gulls, and some storm-petrels will feed on offal (from fishing boats) or carrion (floating marine mammal carcasses) (Gill 1977; Haley 1984). These sources of food are potentially the most contaminated due to the age and trophic level of the dead animal. Large gulls are often predatory and will take the eggs or young of other seabirds, even adults if they are injured or dead.

Diet may also vary with season. Thick-billed Murres are omnivorous for most of the year, feeding mainly on zooplankton, fish, squid, and other invertebrates. During the chick-rearing stage, however, they provide the offspring almost exclusively with fish (Gaston and Nettleship 1981).

In most cases, little is known of diets during the winter, when most species are well offshore. Generally, a greater

Table 3.1
Diets of Canadian seabirds

Species	Foraging habitat	Main prey
Leach's Storm-Petrel Fork-tailed Storm-Petrel	oceanic, surface feeder	zooplankton and myctophid fish
Northern Fulmar	oceanic, surface feeder	zooplankton, squid, arctic cod and carrion
Northern Gannet	offshore, plunge-diver	mackerel, herring, squid and capelin
Double-crested Cormorant Pelagic Cormorant	inshore, underwater diver	mainly fish (herring, sandlance, capelin)
Herring Gull Glaucous-winged Gull	inshore, opportunistic	fish, shellfish, seabird eggs, carrion and garbage
Black-legged Kittiwake	offshore, surface feeder	zooplankton, fish (arctic cod, capelin)
Common Tern	inshore, shallow plunge-diver	small fish and invertebrates
Common Murre Thick-billed Murre Razorbill Atlantic Puffin Rhinoceros Auklet	mainly offshore, underwater diver	mainly fish (arctic cod, herring, sandlance and capelin) zooplankton (euphausids, amphipods)
Black Guillemot Pigeon Guillemot	coastal, underwater diver	mainly benthic fish (blennies, etc.)
Cassin's Auklet Ancient Murrelet	inshore and offshore, underwater diver	mainly zooplankton (crustaceans) and larval fish

prevalence of pelagic zooplankton and other marine invertebrates would be expected, whatever the diet during the breeding season. The importance of a single prey species to the seabird community is most evident where immense feeding assemblages of many seabird species congregrate (Ainley and Sanger 1979). In Hecate Strait, for example, huge numbers of Sooty Shearwaters, Northern Fulmars, Kittiwakes, Glaucous-winged Gulls, Rhinoceros and Cassin's Auklets, Common Murres, and Sabine's Gulls may be seen in proximity, feeding on swarms of euphausids and the associated herring.

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