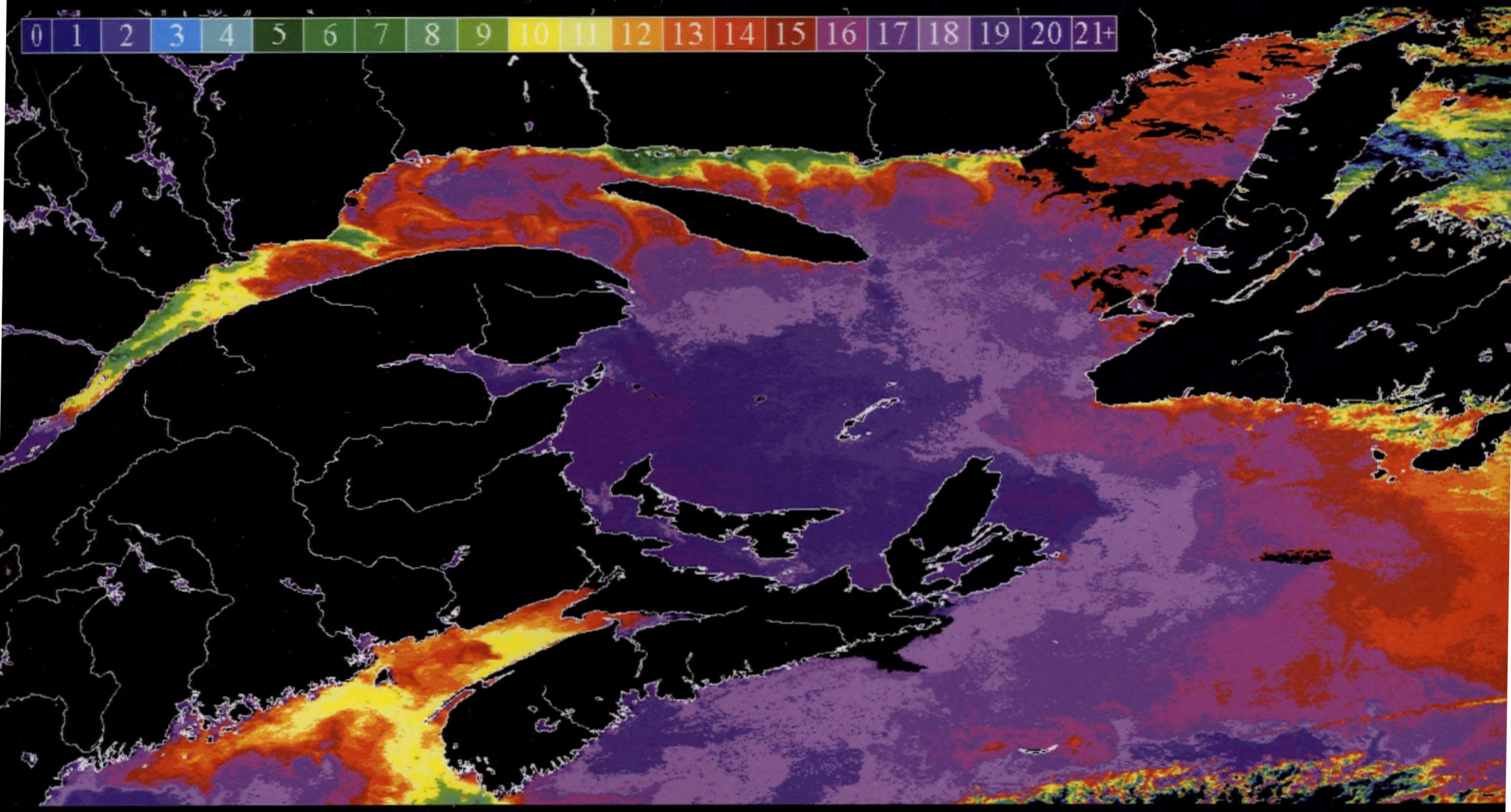
Marine Environmental Assessment of the Estuary and Gulf of St. Lawrence



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Marine Environmental Assessment of the Estuary and Gulf of St. Lawrence

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Baie des Anglais
Laurentian Channel
Les Méchins
Matane
Tadoussac
Saguenay Fjord
Rimouski
Gaspé Peninsula
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Île d' Orléans
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Bay of Fundy
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Halifax
Scotian Shelf

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Newfoundland
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Cabot Strait
St. John's
Avalon Peninsula
Cape North
St. Georges Bay
Cape Breton
Sydney
200 m
400 m
Laurentian Channel
Atlantic Ocean
200 m
400 m

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Sea surface temperatures in the Estuary and
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Executive Summary

Background

This assessment is a summary of the accumulated scientific understanding of the Estuary and Gulf of St. Lawrence. It discusses the extent of anthropogenic modifications to this marine environment, points out principal uncertainties that hinder our understanding, and identifies important regional environmental issues.

Many assessments attempt to provide easy-to-understand information to a wide, non-specialist audience. Others are directed more specifically to scientists, but include a conclusions section written for non-scientists. This document offers something of a middle approach: it is intended to be understood by a non-specialist audience, albeit one with a general knowledge of contemporary science. At the same time, it gives the professional scientist a broad-scale synthesis of current information.

The Estuary and Gulf of St. Lawrence marine system was chosen for a pilot Canadian marine environmental assessment because it

1) is one of the largest bodies of internal water within the Canadian marine environment,

2) has been extremely important to the development of the country because of its use for shipping and commercial fishing, and

3) continues to be the subject of considerable scientific and social study.

Sponsorship

The Estuary and Gulf assessment was prepared under the auspices of the Science Branch of Fisheries and Oceans Canada as a collaborative effort between the Maritimes Region (formerly Gulf and Scotia-Fundy Regions) and Laurentian Region (formerly Québec Region). It is the first assessment completed under the Toxic Chemicals initiative of the Green Plan. It follows the guidelines of the International Committee for the Exploration of the Sea (ICES 1989) and the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP 1994).

The information contained here will allow environmental conditions and human impacts in the Gulf to be compared with similar assessments prepared or being prepared for European coastal marine areas (e.g., North Sea, Irish Sea, Baltic Sea, Black Sea and Mediterranean Sea).

Organization

We discuss the Estuary and Gulf using three disciplines: physics (Chapter 1), biology (Chapters 2 and 3) and chemistry (Chapter 4). The chapter on physical oceanography describes the general physical characteristics of the system to which all organisms must adjust. Equally important are the biological characteristics of the system that define the living aspects of the region. Fisheries resources are discussed in more detail than other biological groups because of their commercial importance. Also, the commercial fisheries are regularly monitored and therefore provide the most quantitative information on emerging population trends of some marine biological species. Chapter 4 describes the sources and distribution of chemicals, both of natural and anthropogenic origin. The final chapter identifies and assesses the important issues of contaminants within and anthropogenic modifications to the marine environment. Recommendations are made for research that are required to resolve uncertainties.

Approach

Our goal is to present a clear picture of the state of knowledge about the marine environment of the Gulf and Estuary. Unavoidably, we omit some detailed knowledge about the system. Thus, this assessment understates our knowledge of the Gulf and Estuary, but it does present our understanding of the region as a whole. We do not attempt to speculate on possible mechanisms or propose hypotheses.

Where possible, we have relied on reviews. However, primary scientific literature up to late 1995 was used to supplement the reviews with research results or when review papers were not available (e.g., benthic organisms and marine mammals).

We attempt to separate "natural" effects from "anthropogenic effects." Of course, human presence is part of the "natural" environment. Nevertheless, we feel this is an appropriate distinction to make because we need to distinguish changes clearly caused by human activities from those changes that occur independent of human activities.

The word "chemicals" is used in a neutral way to refer to the occurrence of either metals, elements, their complex compounds and organic substances regardless of their origin or the role of human activities in their distribution. "Contaminants" refers to the occurrence of chemicals at levels that are considered higher than what would ordinarily be expected from natural processes in a particular location. Infrequently, metal concentrations may be high enough in a small region for living organisms to be affected, but the sources of the metals are natural. Some chemicals are contaminants, by definition, because they do not occur in nature: PCB, DDT and pesticides, for example.

Summary

Physical Setting

The St. Lawrence Estuary and Gulf of St. Lawrence is a unique marine region. The Estuary in some ways displays processes more typical of a large sea and the Gulf in other ways displays processes more typical of estuaries. The St. Lawrence River supplies an enormous amount of fresh water to the entire region, and its effects are felt as far as the Scotian Shelf. The Laurentian Channel, a deep marine valley in the continental shelf, is a conduit into the Gulf and Estuary for Atlantic ocean waters that originate 1 300 km away at the Scotian Shelf. As a result, less saline waters on the surface move toward the ocean while deeper and more saline waters move towards the Estuary. Although the Gulf and Estuary can be considered as a single physical oceanographic unit, its structure is so complicated that no single approach or model can describe its behaviour and dynamics: nearly every known oceanographic process occurs in the region. Thus, there is fairly good understanding of the system on a broad geographic scale but much less on local variability.

Biology

The Estuary is characterized by generally low diversity of biological organisms, particularly for plankton, which have adapted to the rigorous physical conditions of the Estuary (large variations in salinity, turbidity and temperature). In the nutrient–rich waters of the Lower Estuary, many species (copepods, euphausiids and immature capelin) are very productive and this productivity is exported via the Gaspé Current to the Magdalen Shallows in the southern Gulf.

The Gulf, with its larger area and greater variety of habitats, has a greater diversity of species than the Estuary. However, many plankton and benthic species have not been described and their biology requires investigation, even in areas such as the Magdalen Shallows where many scientific studies already have taken place. Biological production in the northeastern Gulf has had little attention from the scientific community, but it was once presumed to be relatively unproductive for plankton. However, this is contradicted by the dense populations of breeding seabirds and migratory whales that gather there in the summer. There is probably a substantial effect from the four to five months of ice cover on the life history of biological species in the Gulf and Estuary, but few details are known.

Fisheries

Lobster, shrimp and crab populations are healthy and support thriving fisheries, in contrast to the groundfish fishery.

The collapse of the commercial groundfish industry, as indicated by the 1995 closures of the cod and redfish fisheries, is the clearest example of human impact on the Gulf ecosystem. The primary causes for the collapse in some fisheries are 1) environmental changes; 2) management policies that were not changed, in spite of evidence from indicators of adverse biological health; and 3) concurrent fishing practices that added further pressure on fishing stocks.

The main environmental changes that may have contributed to the collapse are decreased water temperatures and increased winter ice coverage. These changes may have resulted in

- altered distribution and migration patterns,
- reduced growth rates and food availability, and
- decreased survival of young fish.

Biological indicators of adverse health resulting from fisheries exploitation that were not incorporated into management decisions included

- the changing age structure of fish,
- alteration of the dominant genetic characteristics in the remaining population (i.e., larger and older fish were selected out leaving younger and smaller fish that are less fecund),
- loss of fish habitat due to alteration of the sea bottom by bottom trawlers and draggers,
- disruption of food web interactions, and
- mortality of non-target species.

Fishing practices that added to these problems were

- under-reporting and mis-reporting of catch by fishermen,
- exceeding of catch quotas, and
- increasing efficiency (due to technological advances) and overcapacity of the fishing fleet.

A solid understanding of fish biology, biological effects of exploitation, and environmental effects on fish recruitment needs to be fully incorporated in the future management of fish stocks. This understanding is necessary so that the commercial fishery is robust enough to survive any environmental changes such as alterations in water temperatures or ice coverage.

Chemical Contaminants

Collectively, studies of metals in the Gulf and Estuary indicate that metals are not a problem except in a few industrialized inshore areas. The occurrence of mercury, lead, cadmium, PCBs and DDT-group chemicals in living organisms has declined over recent decades. This is especially significant because PCBs and DDT-group chemicals together contribute almost 90% of the total amount of organochlorines found in seabird eggs and beluga blubber. Seabird data suggest that atmospheric inputs of organochlorines to the open ocean may currently be more important than river inputs to the marine environment. Some areas close to shore and enclosed bays near industrial complexes—Chaleur Bay, mouth of the Saguenay Fjord, and Baie des Anglais—have continuing high levels of both metallic and organochlorine contaminants.

Documentation of chemical occurrence in the region tends to be inconsistent, both geographically and over time. With the exception of the Estuary, few data are available in the same geographic area for contaminants in both the environment and throughout the food web. Few time trends are available because there have been few long-term monitoring programs.

It is important to understand that even if contaminant levels in biota are known, the less-than-lethal biological effects of these levels are not known. Given that qualification, the following are the clearest and most important trends available on chemical contamination in living organisms of the Gulf and Estuary.

Estuary

- Between 1972 and 1992, levels of PCBs and DDT-group chemicals significantly declined in eggs of Double-Crested Cormorants in the Estuary. Levels of dieldrin and HCH also declined while other pesticides (oxychlordane and mirex) appear to be as prevalent today as in the mid-1970s. In 1984, cormorants in the Estuary were the most contaminated birds of any coastal site in Canada, but current levels are comparable to those found in cormorants in the Bay of Fundy. Despite this overall decline, organochlorines such as PCBs and DDT-group chemicals are still a concern because 1) they persist for a long time in the environment and biota and 2) there remains continued low-level input into the environment, primarily from atmospheric deposition. At present, organochlorine levels do not appear to affect the reproduction of seabird populations. In many areas, seabird populations have been increasing in response to limits on illegal hunting and collecting of eggs.

- The St. Lawrence beluga population appears to be more highly contaminated (mercury, lead, DDT-group chemicals, PCBs and mirex) than beluga populations in the Canadian Arctic. Migratory eels from Lake Ontario are thought to be one of the principal sources of contaminants in the beluga diet. Between 1982 and 1994, PCBs, DDT-group chemicals and mirex levels in migratory eels declined by 69%, 77% and 56%, respectively. However, current contaminant concentrations in St. Lawrence beluga are representative of a lifetime (as much as 40 years) of accumulation. Some scientists have suggested that high organochlorine levels may be implicated in the lack of recovery of the beluga population.

Gulf

- Between 1977 and 1985, levels of mercury, copper and cadmium in the livers of Atlantic cod significantly increased but levels of PCBs and HCB significantly decreased in the same period.

- After an exponential decline in the early 1970s, PCB levels in plankton have remained relatively steady and at low levels between 1977 and 1993. PCB concentrations in plankton appear to be related to input from the atmosphere. Pelagic fish such as herring also show a consistent decline in PCB levels from the 1970s to the 1990s.

A major reason the Gulf is in better environmental condition than other semi-enclosed seas—such as the North Sea or Baltic Sea—is due to its relatively sparsely populated shoreline and to oceanographic and chemical processes in the Estuary that trap contaminants before they reach the Gulf. Local levels of chemicals in the Gulf are neither sufficiently severe nor widespread to have resulted in a major deterioration of marine resources.

Recommendations for Further Research

The actions needed to help protect the Gulf and Estuary from further degradation are mostly in the realm of scientific studies to eliminate areas of critical uncertainty. The lack of fundamental information hinders our ability to predict the effects of human activities such as coastal construction, commercial fishing and inputs of chemical contaminants.

- Dredging, raw sewage, and industrial activities can conflict with commercial fisheries and recreation in inshore areas. Therefore, inshore areas require more detailed studies by multidisciplinary teams of scientists: oceanographers, biologists, fish scientists and marine chemists. Such studies will expand our knowledge of local physical, biological and chemical oceanography and aid in resolving use conflicts in inshore areas. Important nursery areas for commercial fish (e.g., Belledune Harbour, Chaleur Bay and St. Georges Bay, NS) are potential candidates for studies.

- Mercury, PCBs and DDT-group contaminants are declining due to regulations and use restrictions beginning in the 1980s. However, new contaminants, such as chemical plasticizers and newer pesticides, are little studied and their effects need to be closely examined.

- Local sources of contaminants have declined in the region due to regulatory controls and, thus, long range atmospheric transport may now be the dominant source for some contaminants. Atmospheric transport is a much harder problem to solve because of transjurisdictional issues. More study is required, both by scientists and policy makers, to determine 1) the long-term effects of chronic, low-level contamination and 2) the appropriate regulatory response.

- Establishing ecological objectives for protecting marine life is hindered by lack of data on the marine toxicity of specific chemicals, particularly organochlorines. Thus, greater effort needs to be given to toxicological issues.

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Table of Contents

List of Discussion Boxes

Chapter 1 **Physical Oceanography**

Chapter 4 **Occurrence of Chemicals**

List Of Tables

Chapter 1 **Physical Oceanography**

Chapter 2 **Biological Status**

Chapter 3 **Commercial Fisheries**

Chapter 4 **Occurrence of Chemicals**

Chapter 5 **Overall Assessment**

List Of Figures

Chapter 1 **Physical Oceanography**

Chapter 2 **Biological Status**

Chapter 3 **Commercial Fisheries**

Chapter 4 **Occurrence of Chemical Contaminants**

Chapter 5 **Overall Assessment**

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Chapter 1

Physical Oceanography

Chapter 1 **Physical Oceanography**

THE GULF OF ST. LAWRENCE in some ways acts like a large estuary and the Estuary is unusual in that it has some characteristics more typical of enclosed seas. The forces that act on the marine waters of the Gulf and Estuary are the inflow of fresh water, exchanges of heat between the atmosphere and surface waters, winds and tides. These forces undergo daily, seasonal and annual fluctuations, and they determine the vertical and horizontal characteristics of the waters, the occurrence of sea ice and prevailing water currents.

The physical environment of the Gulf and Estuary is the backdrop against which biological and chemical processes occur—physical processes often control where certain biological processes happen and where chemical contaminants eventually reside. Physical processes in the Estuary remove much of the particle-bound contaminants that would otherwise have entered the Gulf. Within the Gulf, the large water mass dilutes many contaminants.

Overview

This assessment begins with a survey of the physical boundaries and bathymetric characteristics of the Estuary and Gulf. The major forces that govern the behaviour of the water masses are described. Finally we review the important characteristics of the water masses that are a result of the land boundaries, bathymetry and forces.

Physical Boundaries and Bathymetry

The St. Lawrence Estuary and the Gulf of St. Lawrence is a complex system receiving large inflows of both fresh water and sea water. The fresh water originates from the extensive drainage basin (Figure 1.1), which is nine times larger than the surface area of the Gulf. This ratio is larger than that for any other semi-enclosed sea (Dickie and Trites 1983). Sea water flows into the Gulf of St. Lawrence from the Atlantic Ocean through the Cabot Strait and, to a lesser extent, the Strait of Belle Isle (front map).

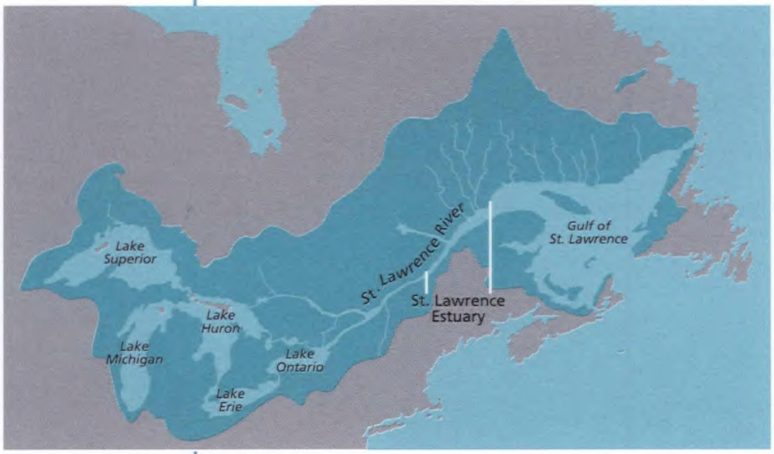

Figure 1.1
Drainage basin of the Great Lakes-St. Lawrence River-Gulf of St. Lawrence
Source: Adapted from Koutitonsky and Bugden 1991

Gulf

The Gulf itself has a surface area of 226 000 km^2, a volume of 34 500 km^3 and a mean depth of 152 m, although 25% of the Gulf is shallower than 75 m (Dickie and Trites 1983). The Gulf has two openings to the Atlantic:

- Strait of Belle Isle, with an average depth of 60 m, maximum width of 15 km and a cross sectional area of 1 km^2 and
- Cabot Strait, with a maximum depth of 480 m, maximum width of 104 km and a cross sectional area of 35 km^2.

(Until the construction of the Canso Causeway in 1952, between the island of Cape Breton and mainland Nova Scotia, there was a third, though very small, opening to the Atlantic: Canso Strait.)

The dominant feature of the bottom topography of the Gulf and Lower Estuary is the Laurentian Channel (front map) which begins in the deep ocean beyond the Scotian Shelf and ends at Tadoussac in the Estuary, a distance of over 1 300 km. It has a maximum depth of 535 m. There are also two side branches of the Laurentian Channel within the Gulf: the Esquiman Channel and the Anticosti Channel. The maximum depths of these branches are 345 m and 296 m, respectively (Loring and Nota 1973).

The remaining marine feature of importance in the Gulf is the Magdalen Shallows, a plateau in the southern Gulf (front map), with a water depth that rarely exceeds 80 m and a surface area of 50 000 km^2.

There are three major land outcrops in the Gulf: Prince Edward Island, Île d'Anticosti and Îles-de-la-Madeleine. Prince Edward Island has an area of 5 660 km^2. Much of its land is under cultivation, and it has a population of about 130 000. Île d'Anticosti, by contrast, has an area of 7 940 km^2, is heavily forested, and has only one village (Port-Menier) with a population of 300. The only industries it supports are tourism and sport hunting, primarily of deer. Îles-de-la-Madeleine is a chain of 16 islands, and the 9 inhabited ones have a total population of about 15 000. The residents depend heavily on the fisheries and tourism for their livelihood. It has a total surface area of 230 km^2.

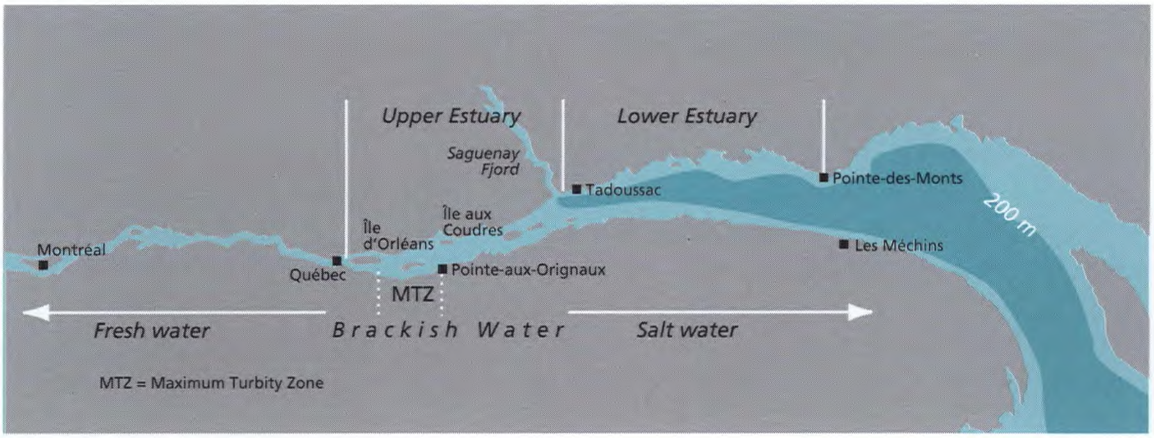

Figure 1.2
The Estuary
Source: Government of Canada 1991

Estuary

The Estuary has two main subregions, the Lower Estuary and the Upper Estuary (Figure 1.2). The Upper Estuary lies between Tadoussac and Québec City, and is 2–24 km wide with typical depths of 20–50 m. The boundary region of fresh water and salt water, called the maximum turbidity zone (MTZ), is between the seaward end of Île d' Orléans and Île aux Coudres / Pointe-aux-Orignaux. There, the water is brackish (salinities of 0–15), suspended particulate matter concentrations are greater than upstream or downstream, water tends to recirculate, intense mixing occurs throughout the water depth and there is enhanced deposition of mud and silt (GESAMP 1987). These properties are common to the boundary of fresh water and salt water in most estuaries.

The boundary between the Lower Estuary and the Upper Estuary is the head of the Laurentian Channel, near Tadoussac at the mouth of the Saguenay Fjord. The head of the Laurentian Channel is the site of intense mixing of three water masses: the Saguenay Fjord brackish water, the Upper Estuary surface water and the cold, deep, saline waters of the Laurentian Channel. These deep waters, rich in nutrients, move to the surface by tidal action in a narrow zone where the bottom rises from 300 m to 50 m over a distance of 10–20 km (Figure 1.6, page 9).

The Lower Estuary's width varies between 30 and 50 km and its length is 200 km, the distance from Tadoussac to the boundary between the Lower Estuary and the Gulf. The boundary is the area between Pointe-des-Monts and Les Méchins (Figure 1.2).

Summary of Physical Characteristics

The physical oceanographic features of the St. Lawrence Estuary and Gulf system are unique for several reasons:

- The Lower Estuary has oceanic characteristics because water from the Atlantic Ocean flows in through the Laurentian Channel.
- There are two areas of intense mixing, the MTZ and at the head of the Laurentian Channel.
- The St. Lawrence Estuary empties into a semi-enclosed sea (the Gulf), in contrast to most estuaries which flow directly onto continental shelves.
- The influence of the high water volumes that exit the Estuary are felt as far as the Scotian Shelf, over 400 km beyond Cabot Strait; thus, the Gulf acts in some ways as an extended estuary.

Dominant Forces

The following discussion focuses primarily on the Gulf of St. Lawrence rather than Estuary, for the sake of brevity. However, the Lower Estuary does share some characteristics with the Gulf: currents are affected by the Earth's rotation, formation of gyres is common, there are large surface tides as well as internal tides, and some sections have highly saline waters.

Fresh Water Flow

Fresh water comes into the Gulf from two main sources: the St. Lawrence River and the combined rivers of the Gulf and Estuary north shore. The contribution of the fresh water outflow from the Estuary is estimated by adding the fresh water discharges of the St. Lawrence River (as measured at Québec City) and the Saguenay, Betsiamites, Outardes and Manicouagan rivers in the Lower Estuary, a sum referred to as RIVSUM. An alternate calculation of RIVSUM, which gives somewhat smaller values, uses the fresh water contributions of the St. Lawrence River (as measured at Cornwall, 100 km upstream of Montréal) and Ottawa and Saguenay rivers.

The flow of the St. Lawrence River alone (424 km^3/y) exceeds the runoff (353 km^3/y) from the entire east coast of the U.S., from Canada to southern Florida (Sutcliffe et al. 1976). Table 1.1 lists the sources of fresh water into the Gulf. The rate of fresh water flow from the St. Lawrence varies widely over the year, with the maximum occurring during the spring runoff and the minimum in the winter (Figure 1.3). Besides this seasonal variation, there is also a very strong variation of as much as 50% from year to year (Koutitonsky and Bugden 1991).

Another important contribution to the fresh water cycle comes from the formation and melting of ice. As ice forms in the winter, salt is expelled into the water, resulting in the formation of high salinity brines, which then sink into the deeper waters. In the spring, ice melt is a significant fresh water source at the surface.

Table 1.1 Fresh water supply to the Gulf of St. Lawrence

Source of Fresh Water	*Per Cent Contribution to Total Fresh Water Entering the Gulf*
St. Lawrence Estuary[a]	84%
Rivers of north shore of the Gulf	14%
Other Rivers	2%
Total	100%
	(represents 19 000 m^3/s)

Source: Koutitonsky and Bugden 1991

[a] the estimate of the flow of the St. Lawrence Estuary into the Gulf is called RIVSUM, defined as the sum of the discharges of St. Lawrence River (at Québec City) and the Saguenay, Betsiamites, Outardes and Manicouagan rivers.

Box 1.1: Coastal Modifications, Dams and Reservoirs

Although dams and reservoirs are generally inland features, they do influence fresh water flow to the coastal environments. Fresh water discharge is key to Gulf circulation and physical processes. Therefore, any changes in the timing and extent of discharge have the potential to alter the relative importance of different physical, biological and chemical processes. The installation of hydroelectric dams, which alter and regulate river flow, is the main agent of anthropogenic changes to fresh water flow. Neu (1975), using data from 1964 to 1970, noted increases in flows in mid-winter and decreases in the spring, as measured at Pointe-des-Monts. The flow of fresh water induces deep and nutrient-rich water to be brought to the surface. These additional nutrients can change the biological cycles that depend on the availability of nutrients. Any change in the ratio of winter flow to flow in the remainder of the year could modify the primary productivity of the Gulf through a shift in timing of nutrient availability (Neu 1975).

Figure 1.4 depicts the horizontal variation of surface salinity in the Gulf. In the Estuary, salinity varies from zero, at Québec City where the St. Lawrence River flows into the Estuary proper, to 29 at the mouth of the Estuary near Point-des-Monts. The low and high averages for salinity values in winter (when fresh water flow is relatively low) show consistently higher values than the low and high averages for salinity in the spring when the fresh water runoff is high.

Petrie (1990) calculated monthly vertical averages for temperature and salinity at 14 depths for 17 subdivisions of the Gulf and Estuary. Figure 1.5 shows the seasonal averages for the Lower Estuary and Cabot Strait. The salinity minimum of the Estuary surface waters in the spring is caused by the spring melt, but the deeper waters are relatively unaffected. Summer heating of the surface waters of the Estuary is highest from May to June.The deeper waters are less affected. The surface waters of the Cabot Strait show a salinity minimum in late summer when the spring runoff from the Estuary finally reaches there.

Heat Exchanges

Heat budget estimates for the Gulf show that solar radiation is the major source of heat during the spring and summer, while evaporation and conduction account for autumn and winter heat losses (Koutitonsky and Bugden 1991).

Heat from the sun in the spring and summer causes a shallow layer of warm water to develop on the surface throughout the Gulf and the Lower Estuary, overlying cooler, deeper waters. Cooler air temperatures and stronger winds in fall and winter cause the upper layers to lose heat to the atmosphere and to mix with deeper waters below.

In the summer, surface temperatures decrease markedly from the Upper Estuary toward Cabot Strait: from 20 °C in the Upper Estuary to 16 °C in the Cabot Strait and 11 °C in the northeastern Gulf. In the winter, temperatures decrease slightly from the Estuary toward Cabot Strait: 1 °C to 0 °C.

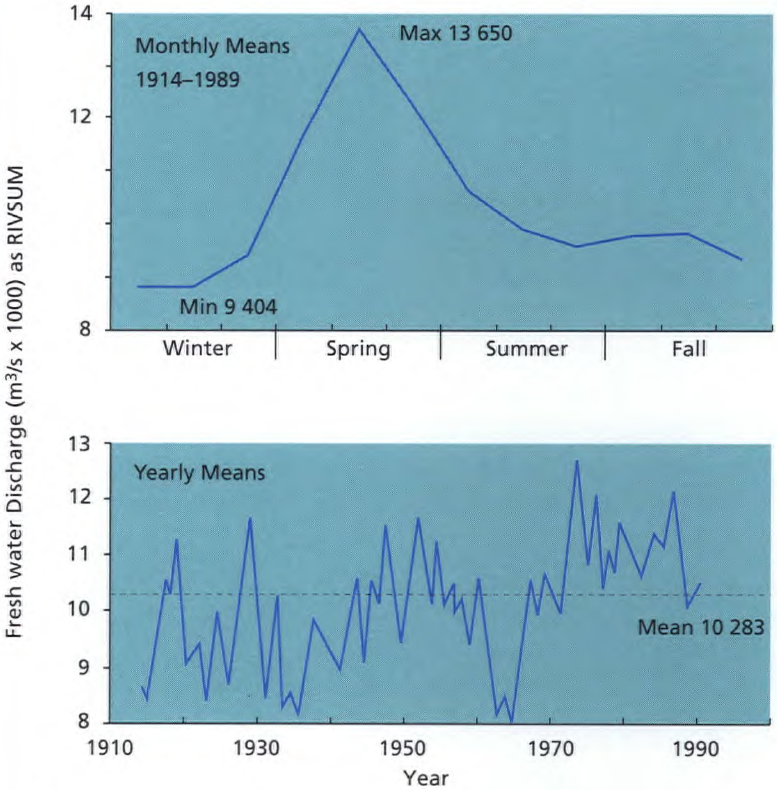

Figure 1.3
Variations in the fresh water flow of the Estuary to the Gulf
Source: B. Petrie, personal communication
Note: RIVSUM is here defined as the sum of the discharges from the St. Lawrence River (at Cornwall) and the Ottawa and Saguenay rivers.

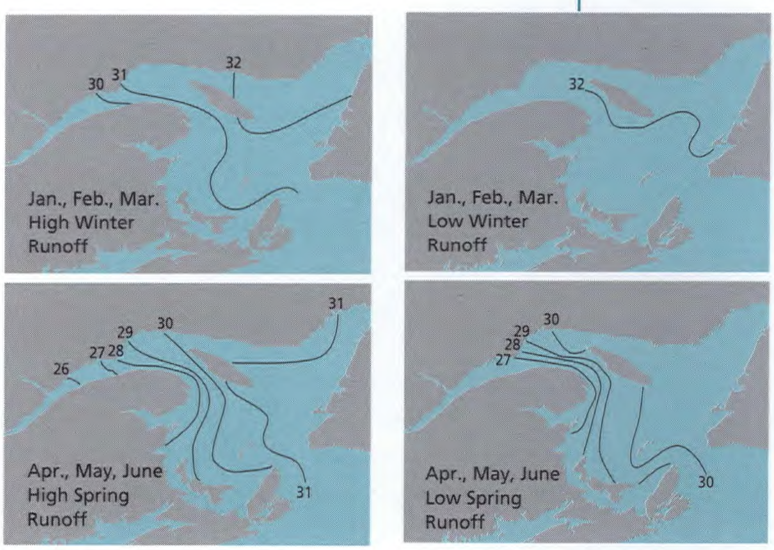

Figure 1.4
Median salinity of the surface waters of the Gulf and Lower Estuary, 1900–1982
Source: Koutitonsky and Bugden 1991

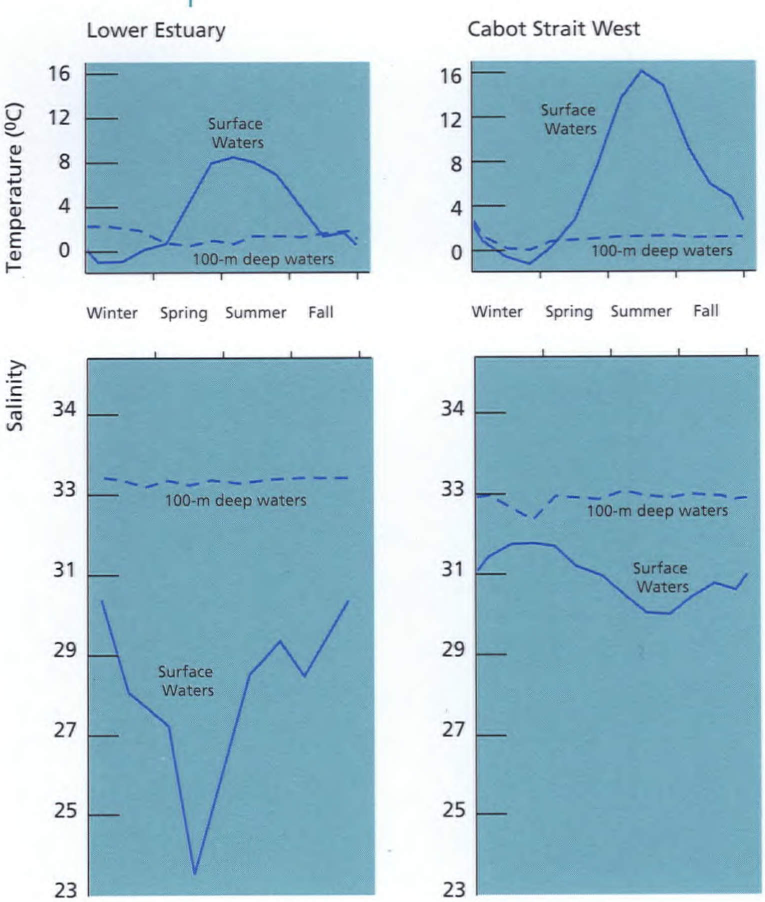

Figure 1.5
Seasonal variations of temperature and salinity in the Gulf and Lower Estuary
Source: Adapted from Petrie 1990

Winds

Strong winds are more frequent in the Gulf in the winter and spring than anywhere else on the continental shelf—from Georgia (USA) to the Strait of Belle Isle (Saunders 1977). Only two other regions are equivalent, but they are small in area: east of the Avalon Peninsula of Newfoundland in the winter and, in the spring, where the Laurentian Channel intersects with the continental shelf break. The Gulf winter and spring winds are generally from the northwest to the southeast (mouth of the Estuary to Cabot Strait). The spring winds are about half the strength of those in winter. The summer winds are generally from the southwest to northeast (PEI to Gulf north shore) and are about one-sixth the strength of winter winds. The winds in fall blow almost easterly (Gaspé to Newfoundland) and are one-third the strength of winter winds (Saunders 1977).

Storms in the Gulf tend to be quite large, covering the entire region. As a result, for the period of their duration, they impose a common circulation on the surface water throughout the Gulf (El-Sabh et al. 1982; Koutitonsky and Bugden 1991).

Tides

Tides are governed by gravitational forces arising from the relative positions of the sun and moon with respect to the earth. These relative positions are referred to as different phases of the sun and moon. The influences of the sun and moon alone can be classified into seven principal tidal constituents, each of which has its distinctive amplitude and speed. The local characteristics of a particular body of water—its physical boundaries, bathymetry and location on the earth—determine the relative importance of the different tidal constituents. Tidal highs and lows increase near the full and new moons when the sun and moon are nearly aligned; the tides during these times are called spring tides. Tidal highs and lows decrease near the first and third quarters of the moon when the influences of the sun and moon tend to cancel each other out; the tides during these times are called neap tides. Generally, neap tidal heights are one-third lower than spring tides (Groves 1992).

Tides reach the Gulf through the Cabot Strait (and to a lesser extent through the Strait of Belle Isle) and circulate in a counterclockwise direction around the Gulf. The most important tidal component in the Estuary and in the northwest and northeast corners of the Gulf is the semidiurnal (two low and two high tides per day) principal lunar constituent. In the southern Gulf, the tides are dominated by the diurnal (one low and one high tide per day) lunar-solar constituent. Both semidiurnal and diurnal components are strong in the northern and central Gulf (Koutitonsky and Bugden 1991). Tidal amplitudes vary between 0.2 and 0.5 m in the Gulf and increase considerably in the Estuary, due to the changing shape and topography of the bottom of the Estuary, to greater than 2 m near Québec City (Koutitonsky and Bugden 1991).

Oceanic Influences

The deep waters in the Laurentian Channel are made up of a mixture of Labrador Current and North Atlantic waters. The temperature and salinity of the deep waters of the Laurentian Channel are primarily influenced by the oceanic waters that enter the Laurentian Channel. These properties change over periods from months to decades, but only those larger variations that occur once in a decade or longer are strong enough to be evident farther up the Laurentian Channel because local factors within the Gulf mask normal monthly and yearly variations (Koutitonsky and Bugden 1991; Bugden 1991).

Main Features Of Water Masses

The previous section discusses the main forces acting on the waters of the Gulf and Estuary. This section summarizes how the waters respond to these forces.

Stratification

The Upper Estuary is vertically well mixed with little stratification, except at times of neap tides. Two-layer stratification begins to appear at Île-aux-Coudres. The Lower Estuary waters are strongly stratified beginning at the Laurentian Channel (Silverberg and El-Sabh 1990).

Figure 1.6 shows the water circulation in and along the Laurentian Channel during the summer. The circulation is similar to that of estuaries where deep water flows inward from the ocean and surface water flows outward to the ocean. The water is stratified into three layers: a

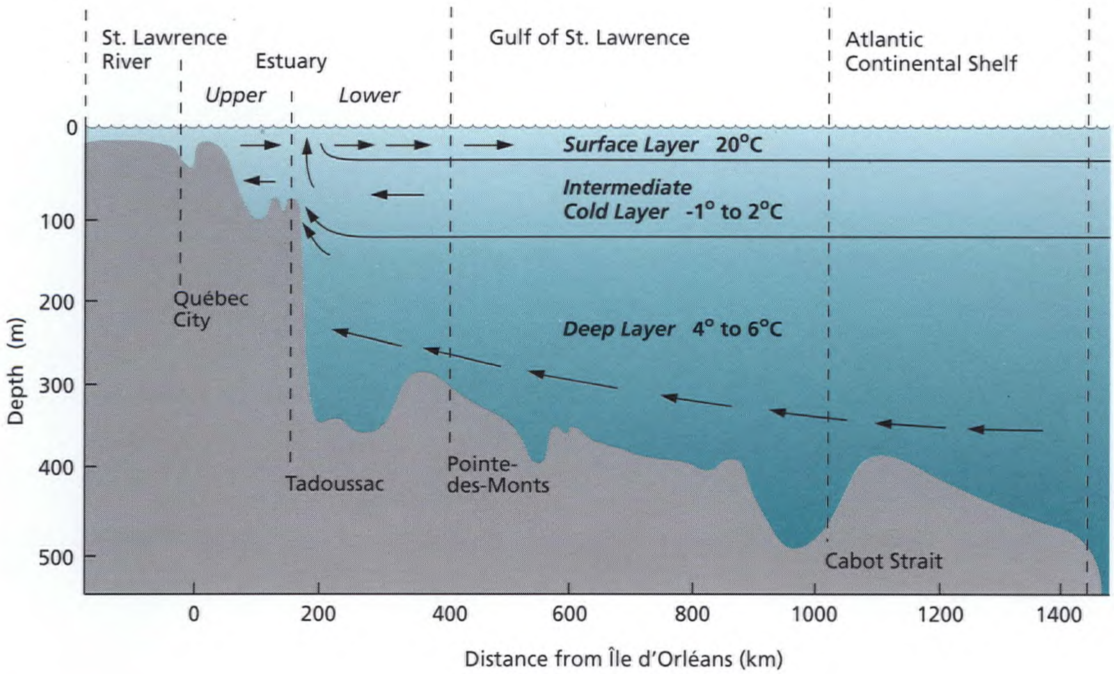

Figure 1.6
Water column stratification and circulation along the Laurentian Channel during the summer
Source: Adapted from Koutitonsky and Bugden 1991

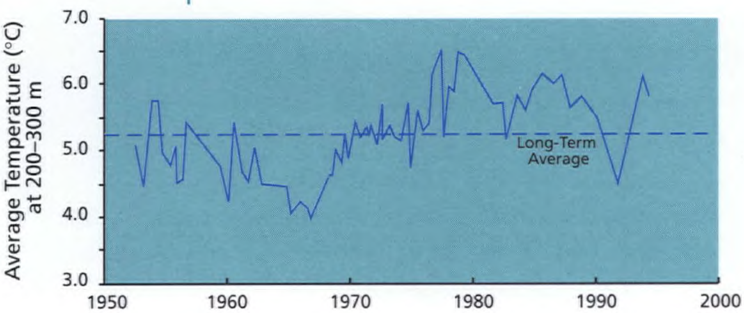

Figure 1.7
Deep water temperature trends at Cabot Strait
Source: Adapted from Petrie 1990; Gilbert et al. 1995

thin and warm surface layer, an intermediate cold layer and a deep oceanic layer. The shallow surface layer extends 10–30 m, has a salinity of 27–32 and flows towards the Atlantic Ocean. The intermediate layer has a temperature that averages less than 0 °C, a salinity of 31.5–33 and a depth of 80–150 m (Gratton et al. 1994; Drinkwater 1993; Drinkwater et al. 1992). Up to 35% of the cold intermediate layer comes from Labrador Shelf waters that enter the Gulf through the Strait of Belle Isle (Petrie et al. 1988).

The deep layer begins at about 125 m and continues to the bottom. This layer has temperatures between 4 °C and 6 °C and salinities between 33 and 34.6. Summer-winter differences in the water properties are not significant at these depths. The deep layer contains about 45% of the volume of the Gulf (Trites 1972). Labrador Current waters also contribute to the formation of the bottom water (Bugden 1991). The temperature of the deep layer has been observed to fluctuate over a range of 2 °C over the past several decades. Figure 1.7 shows the temperature measurements at the 200–300 m depth at the Cabot Strait over the past 40 years.

During fall and winter the three-layered summer stratification is modified. Local cooling and mixing by strong winds causes the cold intermediate layer to extend to the surface, resulting in a two-layered stratification. The monthly-averaged interannual variability in surface temperature can be from 1°C to 5 °C (Koutitonsky and Bugden 1991).

Water Movement

Water Exchange

In the Upper Estuary, fresh water moves seaward along the southern portion, while the compensatory landward flow of more saline water is primarily in the deeper waters (Silverberg and El-Sabh 1990).

Figure 1.8 shows the currents through the Cabot Strait. Most of the outflow of Gulf waters

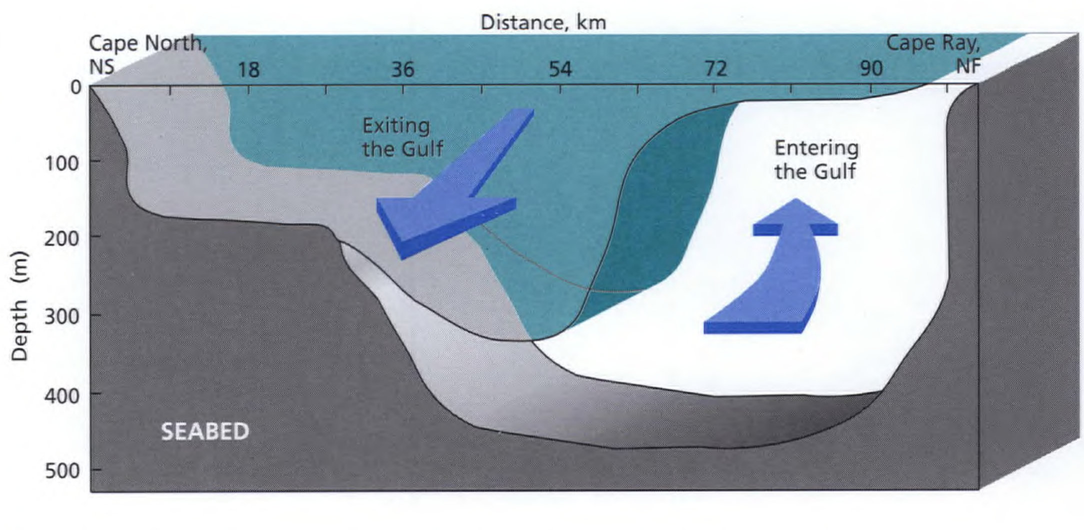

Figure 1.8
Water flow at Cabot Strait
Source: Adapted from Koutitonsky and Bugden 1991

occurs on the western side and is balanced by the inflow of generally saltier water at depth, which reaches the surface on the eastern side of the Strait. Annually averaged outflow is estimated at 4–6 x 10^5 m^3/s (El-Sabh 1977), 20–30 times the fresh water flow into the Gulf. Thus, fresh water flow is 3–5% of the total outflow. The balance (95–97%) of the outflow originally entered the Gulf from the Atlantic Ocean. The residence time of water in the Gulf is about one year (Bugden et al. 1982).

The net inflow for the Strait of Belle Isle ranges from 1.3 x 10^5 m^3/s in the summer to 3 x 10^5 m^3/s in the winter (Petrie et al. 1988).

Horizontal Circulation

Figure 1.9 shows the relative strengths of horizontal surface currents in the Gulf. Seaward flow in the Estuary divides into two branches near Rimouski. One branch flows along the south shore and becomes the Gaspé Current (Benoît et al. 1985). The other, much weaker, branch flows across the Estuary to the north and subdivides into two additional branches: one turns west and moves upstream while the other moves seaward along the north shore. This latter current is deflected at the mouth of the Estuary to join with the Gaspé Current (El-Sabh 1979; Ardisson and Bourget 1992). This surface circulation pattern causes two gyres to form in the Lower Estuary. The first is centred between the mouth of the Estuary and Baie-Comeau. The second is between Rimouski and the mouth of the Saguenay Fjord (El-Sabh et al. 1982; Ardisson and Bourget 1992).

In the Gulf, the strong Gaspé Current is reinforced by a southward current at the mouth of the Estuary and intensifies around the Gaspé Peninsula. As the current moves downstream it is confined to the south shore of the Lower Estuary by 1) the action of winds and 2) the Coriolis force arising from the Earth's rotation. It reaches its maximum strength as it leaves the Estuary and is strengthened by the Anticosti counterclockwise

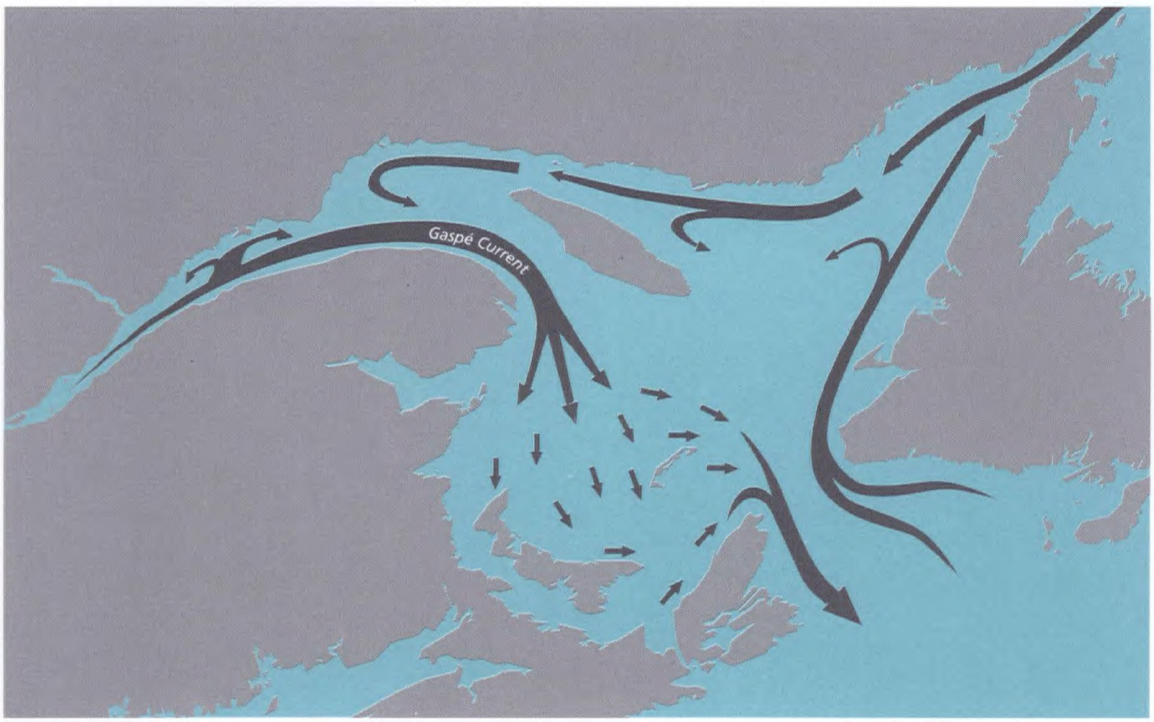

Figure 1.9
Dominant horizontal surface circulation in the Gulf and Estuary
Source: P. Smith, B. Petrie and G. Bugden, personal communication; Ardisson and Bourget 1992

gyre in the northwestern Gulf.

The Gaspé Current has a maximum speed of about 1 m/s, a width of 15–20 km, a length of over 400 km and is restricted to the first 40–50 m of the water column (Benoît et al. 1985). Its seasonal variability depends upon fresh water discharge, prevailing winds and tides. For example, between June and November its salinity increases as its speed decreases from its maximum value to 0.6 m/s (Ingram and El-Sabh 1990).

The overall circulation is counterclockwise in the Gulf. Over the Magdalen Shallows, the currents weaken between the Laurentian Channel and Prince Edward Island before leaving through the Cabot Strait. Surface drifter studies during the summer (Boudreault and Héritier 1971; Messieh 1974) suggest that a portion of the surface waters recirculate around the Gulf, rather than leaving through the Cabot Strait. The horizontal currents that circulate in the Gulf create continuous gradients in important properties of the waters such as salinity and temperature in the top 30–50 m of the Magdalen Shallows, for example.

El-Sabh (1976) used monthly averaged salinity and temperature data to generate a detailed picture of the horizontal currents in the Gulf. El-Sabh's mean surface currents computed for the month of August predicted several gyres of 20–100 km in diameter. Field observations have reported small but persistent gyres in some bays of the region:

- St. Georges Bay, Nova Scotia where the circulation is clockwise down to depths of 20 m (Petrie and Drinkwater 1978),
- St. George's Bay, Newfoundland where the circulation is also clockwise in the surface layer of water (Siebert 1972), and
- Chaleur Bay has a counterclockwise gyre that extends across its width in the region of Paspébiac (Legendre and Watt 1970)

These gyres can partially entrap water and anything that drifts passively with the water, such as fish larvae or chemical contaminants.

Winds and storms can cause localized and temporary changes in any of these horizontal circulation patterns.

Vertical Mixing

The Gulf is considered to be a moderately stratified system, but there are often local disruptions to stratification—bringing deeper, more saline waters to the surface—that are mainly caused by

- high fresh water flow increasing the occurrence of upwelling and entrainment,
- mixing of fresh water and salt water as occurs at the mouth of the Saguenay River in the Lower–Upper Estuary boundary and in the MTZ in the Upper Estuary,
- mixing of different layers of water due to intense tidal action (tidal mixing),
- heat exchanges with the atmosphere, and
- rapid changes in bathymetry as occur at the heads of the Laurentian, Esquiman and Anticosti channels (Bugden 1991).

There are five main areas in the Gulf where tidal mixing is predicted to reduce stratification (Koutitonsky and Bugden 1991): the head of the Laurentian Channel in the Lower Estuary, the eastern edge of Jacques Cartier Passage, the Northumberland Strait, the Strait of Belle Isle and around Îles-de-la-Madeleine.

Tidal Currents

Tidal currents in the Upper Estuary can be as high as 3 m/s and tidal ranges (from lowest to highest tide) can be up to 10 m (Mertz and Gratton 1990); these extreme values are due to the shallow mean depth. By contrast, tidal currents are about 0.2 m/s in most of the Gulf. In confined areas, such as in the northern Gulf, values greater than 1 m/s have been recorded (Farquharson 1970; Gratton et al. 1993).

In addition to the currents associated with the lunar and solar tides that cause the sea level to rise and fall, there are internal tides. These occur most frequently in the Gulf and Estuary when the boundaries that separate different layers of waters in a stratified system oscillate in the same way as ordinary surface tides. This is an important phenomenon at the head of the Laurentian Channel in the Lower Estuary where the vertical boundaries can fluctuate by 50–100 m over short horizontal distances. Internal tides bring cold, deep and highly saline waters to the surface and take warmer, low salinity water to deeper regions.

Ice Cover

There are three main sources of ice in the Gulf:

- locally formed ice fields,
- movement of ice from the Estuary, and
- movement of ice, including small icebergs, from the Labrador Shelf by passing through the Strait of Belle Isle.

Ice formation begins in December in shallower regions of the Estuary and Gulf and extends to the Cabot Strait by February (Koutitonsky and Bugden 1991). By the end of January, about half the surface of the Gulf is covered by close pack ice (Dickie and Trites 1983). The entire Gulf is covered by pack ice by the end of February. In spring, the ice breaks up and melts rapidly as prevailing winds and water currents transport it southeastward out of the Gulf and onto the Scotian Shelf. By early April, ice cover is reduced by half over all the deep-water channels except in the northeast. Figure 1.10 shows the variability of the median extent of pack ice over a 25-year period.

Box 1.2: Coastal Modifications, The Fixed Link

The Fixed Link, a bridge across the Northumberland Strait joining Prince Edward Island to New Brunswick, is scheduled to open in June, 1997. Concerns with this structure generally focus on the possibility of changes in the dynamics of currents and ice in the Northumberland Strait (Rice et al. 1989; Public Works Canada 1993). Changes in currents can affect shoreline erosion and sediment mobility and deposition. Changes to ice dynamics (Northumberland Strait Crossing Project 1994) could result in delaying ice-out during spring or premature ice-in during the fall, altering the ratio of open water to free-floating ice, modifying the extent of land-fast ice and increasing ice scouring of the sea bed. There will also be dredging and disposal of sediment throughout the operational life of the bridge.

Cumulatively, these effects may create conditions that could change phytoplankton species composition and productivity; the timing of fish spawning; fish egg and larval survival and development; timing of moult in lobster and crab; spawning habitat; and groundfish abundance.

Because these concerns are so wide-ranging, contingency plans are in place that will reduce any measured effects. In addition, there is an ongoing environmental monitoring program to monitor and document any changes from the pre-existing conditions in the Northumberland Strait (Northumberland Strait Crossing Project 1994).

Figure 1.10
Median historical ice cover in the Gulf (1962–1987) and 1993 extremes
Source: Gratton et al. 1994

Climate Trends

Trends in Air Temperatures

Most of Atlantic Canada has experienced a tendency toward lower temperatures since the 1980s (Findlay and Deptuch-Stapf 1991, in Colbourne and Narayanan 1994), which has also been true for the Gulf of St. Lawrence (Gratton et al. 1994). The winter of 1992–93 was one of near-record cold there. The summers of 1991–93 were colder than the long-term average. The summer of 1993 was also very wet, with 50% more precipitation than the average for the period 1951–1980 (Gratton et al. 1994).Winter air temperatures in 1994 were below the 1961–1990 normals, the sixth consecutive year this happened (Gilbert et al. 1995).

Trends in Ice Coverage

For the winter of 1991–92, the ice edge exceeded the median and, in April, approached the maximum. That winter's ice duration also exceeded the mean for most of the Gulf (Drinkwater et. al. 1992). The extremely cold winter of 1992–93 resulted in extensive ice formation in the area, close to the maximum extent recorded for sea ice (Figure 1.10). The ice also lasted longer than normal. Although above-normal air temperatures in the first half of January resulted in little ice forming then, a cold Arctic air mass resulted in a rapid spread of ice in the second half of the month. By February the Gulf was covered, and remained so for the month of March. New records were set for last ice on the Magdalen Shallows (Drinkwater 1993). The extent of ice cover in 1994 was also larger than the long term average (Gilbert et al. 1995).

Trends in Water Temperatures

1994 was the ninth consecutive year that the cold intermediate layer showed mid-summer temperatures nearly 1 °C below the 1948–1985 average

(Gilbert et al. 1995). Although the thickness of the cold intermediate layer steadily decreased between 1991 and 1993, the extent of this layer over the bottom of the Magdalen Shallows was greater than normal between 1989 and 1993. The temperature of the cold intermediate layer in the Laurentian Channel was 1 °C colder than average; in the Strait of Belle Isle, it was 2.2 °C colder than average. Deeper waters (100–200 m) were colder than average throughout the Gulf except in Cabot Strait. There has been a progressive warming of 200–300 m depth waters since 1991, except in the Esquiman Channel where temperatures were colder than normal (Gratton et al. 1994; DFO 1994). Bugden (1991) reported a 20-year warming trend in the deeper waters of Cabot Strait: in mid-1966, the temperature in the 250-m deep water averaged 4.5 °C and by 1985 had increased to 6.5 °C. The 1993 data point (B. Petrie, personal communication) in Figure 1.7 represents the warmest temperature measured in 39 years, after a sharp decline between 1986 and 1992. The 1994 temperature, however, was 0.5 °C colder than it was in 1993 (Gilbert et al. 1995).

Uncertainties

The physical oceanography of the Gulf is generally understood but there is a lack of data or understanding about some key processes:

- There are few data on water conditions under the ice cover. This prevents our understanding the dynamics of ice formation.
- The lack of oceanographic data in late winter and early spring also prevents our understanding the dynamics of ice breakup and the effects of the large seasonal source of fresh water that melting produces.
- There are few data on essential oceanographic parameters such as salinity and temperature for the Northumberland Strait and the relatively unexplored northeastern Gulf.
- There is little understanding of how the behaviour of waters in one part of the Gulf is related to other waters in the Gulf.

Chapter 2

Biological Status

Chapter 2 **Biological Status**

Tables

Figures

THE PREVIOUS CHAPTER EXAMINED the oceanographic processes in the Gulf and Estuary. It is often these processes that determine the availability of nutrients to marine life and, hence, where marine life is most numerous and diverse. In turn, understanding biological processes is essential to understanding how chemical contaminants move through the marine food web, thus potentially affecting the survival and reproductive success of marine animals.

In common with most estuaries, the temperature, salinity, nutrients and water movement in the St. Lawrence Estuary and the Gulf of St. Lawrence varies greatly over a short period of time within a small geographic area. The number of species that can survive such rigorous conditions tends to be relatively limited. Nevertheless, because there are high amounts of nutrients, marine life in the region is abundant and productive.

Overview

Classification of Marine Ecosystems and Organisms

Marine biological environments are generally divided into two broad categories: the pelagic environment, which contains organisms living in the water column; and the benthic environment, which contains organisms living in or on sediments and rocks on the sea bottom. In both the pelagic and benthic environments, changes in temperature, light and salinity throughout the water column (vertical gradients) and on the water's surface (horizontal gradients) are especially important in establishing different living regimes for different organisms.

The pelagic community is generally subdivided into plankton, which are passively floating or drifting organisms suspended in the water, and nekton, which are larger swimming organisms. Plankton consist of bacteria (bacterioplankton), algae (phytoplankton), animal species (zooplankton) and eggs and larvae of fish (ichthyoplankton). Nekton includes fish, seabirds, seals and whales. Plants and animals (e.g., seaweeds, crabs, lobster, worms, and seastars) living in the benthic environment are called benthos. Dunbar et al. (1980) and Steven (1974) provide surveys of species distribution in the Gulf. Most of the data was collected in summer surveys, thus there is only a limited understanding of the effects of winter conditions (e.g., ice cover and storms) on biological life. This is a major deficiency in our knowledge of the Gulf and Estuary system.

Food Web Composition

The basic components of a marine food web are shown in Figure 2.1. Phytoplankton are microscopic plants that form the base of the aquatic food web, occupying a position in the marine environment analogous to terrestrial plants on land. Zooplankton are animals that range in size from microscopic, single-celled organisms to jellyfish that are several metres in length. Zooplankton include both herbivores, which feed on phytoplankton, and carnivores, which consume other zooplankton. Most zooplankton though are omnivores, feeding on both plant and animal matter. Because zooplankton are the principal consumers of phytoplankton, they represent a critical link in the food web between phytoplankton and larger animals. Ichthyoplankton include several different stages of early fish life during which they consume phytoplankton, zooplankton or even other ichthyoplankton. Active-swimming nekton and many benthic animals can be consumers of phytoplankton, zooplankton, ichthyoplankton or other nekton.

Bacterioplankton play an important role in the breakdown and recycling of organic matter within the pelagic system. Many of the animals living in the benthic environment are also important in the breakdown and recycling of dead organic matter which "rains" down from above.

To understand an ecological system such as the Gulf and Estuary, biological organisms should be studied as components of a food web. These studies emphasize two important dynamics: how species interact with one another and their environment; and the flow of energy and nutrients among subregions and in the system as a whole. A food web approach does not consider benthic and pelagic environments separately, but rather it groups species by their function. For example, organisms that feed on and break down dead organic matter (detritivores) would be discussed as a group, whether they are bacteria, zooplankton or benthos.

Unfortunately, the present state of knowledge of the Gulf and Estuary, and for that matter, of most ecosystems in the world, does not support examining the region in this detail. However, de Lafontaine et al. (1991) made the first attempt at describing plankton and other organisms of the Gulf from a food web perspective.

Benthos are not included in this survey because they have only been described for the Lower Estuary, northwestern Gulf and a few

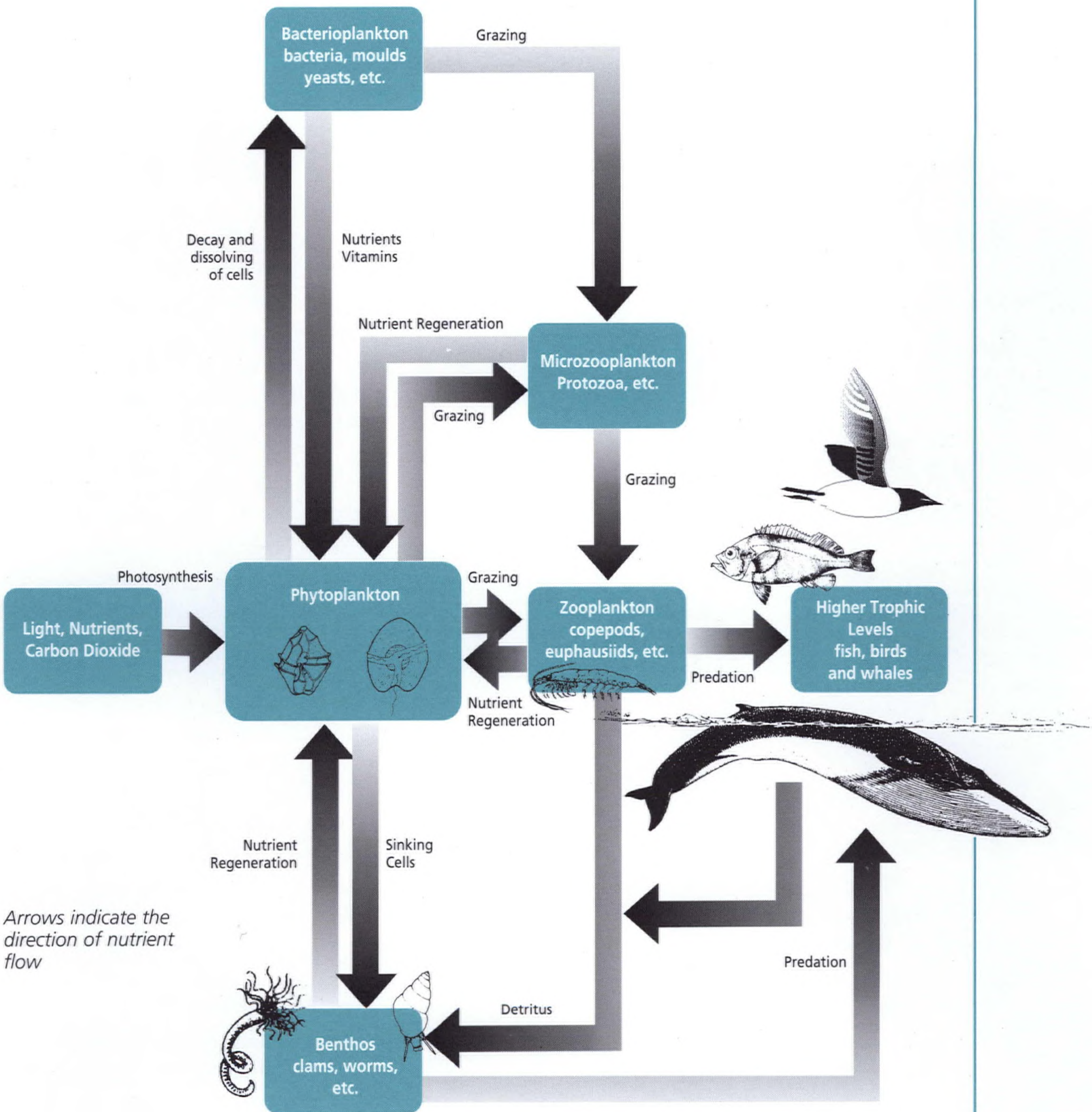

Figure 2.1
The role of plankton in nutrient cycling and the marine food web
Source: Adapted from Mobil Oil Canada, Ltd. 1983

isolated areas in the southern Gulf.

The following provides a brief summary of the various food webs in the Estuary and Gulf and relies heavily on the synthesis provided by de Lafontaine et al. (1991).

For the purposes of discussing food web composition, the St. Lawrence Estuary can be divided into two sub-regions, the Upper Estuary

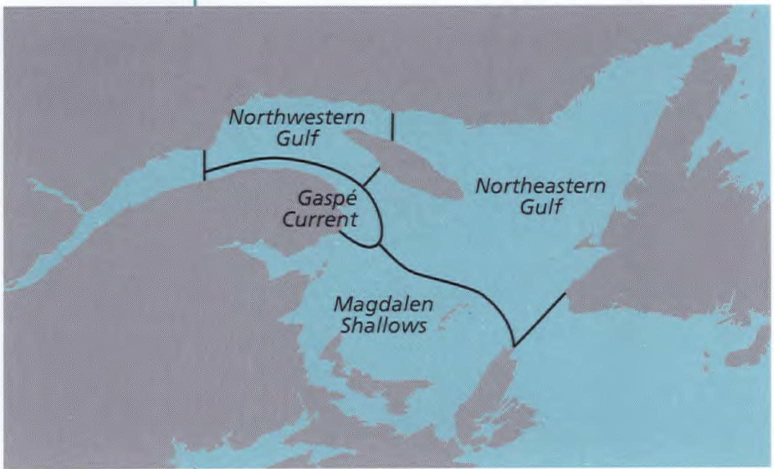

Figure 2.2
Biological-oceanographic divisions of the Gulf
Source: de Lafontaine et al. 1991

and the Lower Estuary (Figure 1.1 in Chapter 1). These boundaries are generally more useful in describing plankton than nekton because nekton distribution is less controlled by local physical oceanographic features than plankton. Extreme variability of the physical properties of the Upper Estuary waters causes it to be generally less productive and less biologically diverse than the downstream region. The Lower Estuary is a relatively productive area for all plankton, but much of this productivity is carried to the Gulf by the Gaspé Current. The diversity of nekton (e.g., fish, seabirds and marine mammals) in the Estuary tends to be lower than in adjacent, downstream areas of the Gulf.

Various subregions of the Gulf have been proposed based on biological, hydrological and topographical characteristics, but an acceptable rationale for a single, comprehensive system of subdivisions has yet to be made. The most recent division of the Gulf was proposed by de Lafontaine et al. (1991), who considered the Gulf as having four subregions: the northwestern Gulf, the Gaspé Current, the Magdalen Shallows (southern Gulf) and the northeastern Gulf (Figure 2.2).

Overall, the Gulf is very productive in lower trophic level organisms but the biomass of higher levels (e.g., birds, fish and crustaceans) is no higher than adjacent western Atlantic waters.

The northwestern Gulf supports a distinct community of phytoplankton consisting of predominantly large diatoms in spring and dinoflagellates in summer. It has high abundance of large zooplankton (large *Calanus* copepods, euphausiids, chaetognaths and shrimps), relatively low abundance of fish eggs and larvae (consisting almost exclusively of redfish), and high abundance of juvenile fish (primarily capelin). There are many breeding seabirds, and the region supports a high diversity of whales in the summer months.

The biological community of the Gaspé Current is strongly influenced by the downstream flow of plankton from the Lower Estuary. It is characterized by high concentrations of nutrients from tidal processes and from the Estuary, supporting large diatoms during most of the summer. The zooplankton community has not been studied in detail, but it probably consists of high numbers of a few large species (*Calanus* and euphausiids). Ichthyoplankton are more abundant than in the northwestern Gulf but comprise small individuals that are exported to the southern Gulf. The area supports high numbers of breeding seabirds.

The warm waters of the southern Gulf (Magdalen Shallows) has a higher diversity of zooplankton and ichthyoplankton than other regions of the Gulf. Phytoplankton species composition is poorly known but is probably highly diverse and dominated by smaller-sized species. Zooplankton also tend toward smaller species, and the highest concentrations are found in the western portion of the Magdalen Shallows. Larval fish are more abundant than anywhere else in the Gulf. The region, including its bays and inlets, is an important spawning, feeding and nursery area for numerous fish species. Seabird and whale populations in the southern Gulf are relatively low due to a lack of suitable breeding sites and shallow depths, respectively.

The northeastern Gulf supports very productive shrimp populations, other commercial fish populations and numerous seabirds and whales. Unfortunately, there is not enough information to attempt to describe the region's food web.

Phytoplankton, Primary Productivity And Nutrients

Primary Productivity

Phytoplankton use light to synthesize organic matter from inorganic carbon and nutrients (principally nitrogen compounds, phosphate and silicate) dissolved in fresh and marine waters. Thus, they are responsible for primary productivity. Animals that graze on phytoplankton are called secondary producers. The rate at which phytoplankton produce new organic matter in the marine environment is determined by nutrient availability (especially nitrogen compounds), light intensity and temperature. The maximum potential level of primary productivity in a system also depends on additional factors such as the stratification of the water column and the availability of micronutrients (e.g., trace metals and vitamins).

In most marine waters, phytoplankton undergo seasonal population explosions, called blooms, and species succession in which dominant species are replaced by others. These are generally associated with changes in the amount of light and the replenishment and depletion of nutrients, suggesting that most phytoplankton are "nutrient-limited," particularly by nitrogen compounds. After a period of intense vertical mixing in which nutrients are brought to surface waters from deeper layers, usually in winter, a spring phytoplankton bloom occurs when the water column becomes stratified and light is ample.

In general, the succession of species follows the progressive depletion of nutrients: fast-growing small diatoms that require high nutrient concentrations are replaced by larger diatoms and finally by large, slow-growing dinoflagellates that are better at surviving on low levels of nutrients. For estuaries, blooms and species succession are influenced by hydrodynamic forces—such as upwelling and fresh water flow—that determine the distribution and availability of nutrients, surface water temperature and the depth to which phytoplankton are found.

The following summary of nutrient sources and distribution in the Gulf and Estuary provides the background for understanding the productivity of the region and the important role of physical processes in nutrient dynamics.

Role of Nutrients

Nutrients enter the marine environment by terrestrial weathering and plant decomposition, regeneration from decomposing plant and animal matter in the water column and sediments, and air-sea exchange processes (e.g., rainfall). Human activities may influence all of these processes through sewage and industrial discharge, agricultural runoff (fertilizers, animal wastes, or soil) and atmospheric discharges from industries (GESAMP 1990).

In the Gulf, the lowest levels of nutrients occur in surface waters (top 30 m) during summer or fall after being depleted by a period of rapid phytoplankton growth. Dead biological material sinking in the water column dissolves or decays with the help of bacteria, benthic animals and others. This decay causes nutrients to be released back into the water column. This process is called regeneration (Figure 2.1). Nutrient concentrations, therefore, tend to build up in subsurface waters where there are few plants to consume them. A stratified marine system with limited vertical water exchange, such as large portions of the Gulf and Lower Estuary in the summer, causes nutrient depletion at the surface and higher concentrations of nutrients in deeper waters (Coote and Yeats 1979). The deeper waters are depleted of dissolved oxygen because, as dead organisms sink, the release of nutrients by the breakdown of tissue is an oxygen demanding process.

Generally, higher dissolved oxygen concentrations support a greater variety of marine life. Dissolved oxygen concentrations in the deep layer decrease from near saturation (about 10 mg/L) at Cabot Strait to less than 3 mg/L at the head of the Laurentian Channel (Dunbar et al. 1980;

Gearing and Pocklington 1990). Similar variations in concentrations occur in the Anticosti and Esquiman channels. Oxygen levels off the northern coast of the Gaspé Peninsula can be as low as 1.7 mg/L (D'Amours 1993). However, in the northeastern Gulf, high oxygen values in the deep layer are thought to derive from waters flowing in from the Strait of Belle Isle (Dunbar et al. 1980), which have oxygen levels as high as 10 mg/L (D'Amours 1993).

We have summarized the following from reviews on nutrients in the Gulf and Estuary by Yeats (1988 and 1990).

Nutrients in the Upper Estuary derive primarily from fresh water flow of the St. Lawrence River and are distributed relatively uniformly throughout the water column due to mixing processes.

In the Lower Estuary, nutrients are removed from surface waters by incorporation into biota, a portion of which sinks out of the surface layer into deeper waters. Upwelling and vertical mixing bring nutrient-enriched water from the intermediate and deeper layers to surface waters, particularly at the head of the Laurentian Channel. Nutrients from local rivers supply only a small fraction of the nutrients into the Lower Estuary. Nutrients not used in the Estuary itself are carried in surface waters by the Gaspé Current into the Gulf.

The concentrations of nutrients in the intermediate and deep layers of the Gulf are approximately three times higher than those at similar depths in North Atlantic waters outside the Gulf. Nutrient levels are highest at the head of the Laurentian, Anticosti and Esquiman channels and decrease toward Cabot Strait. Nutrients regenerated from decaying biota in the intermediate and deeper layers are returned to the upstream surface waters because the flow of these water layers is inward. This has the net effect of trapping nutrients within the Laurentian Channel.

Phytoplankton Dynamics

Recent reviews of phytoplankton dynamics in the Estuary (Therriault et al. 1990) and Gulf (de Lafontaine et al. 1991) are summarized below.

Little information is available on the species

Table 2.1 Productivity of phytoplankton in the Estuary

Region	*Species Type*	*Productivity*
Upper Estuary		
Fresh water region	fresh water	high productivity
Turbidity region	mixed fresh water and brackish water	negligible productivity
(Truly) Estuarine region	marine with some fresh water	highly variable productivity
Lower Estuary		
Outflow region	marine	low productivity
Upwelling region	marine	higher productivity than Outflow region
Plume region	marine	relatively high production
Near Gulf region	marine	massive phytoplankton production in spring and nutrient-limited production in summer similar to Gulf

Source: Therriault et al. 1990
Regions are keyed to Figure 2.3

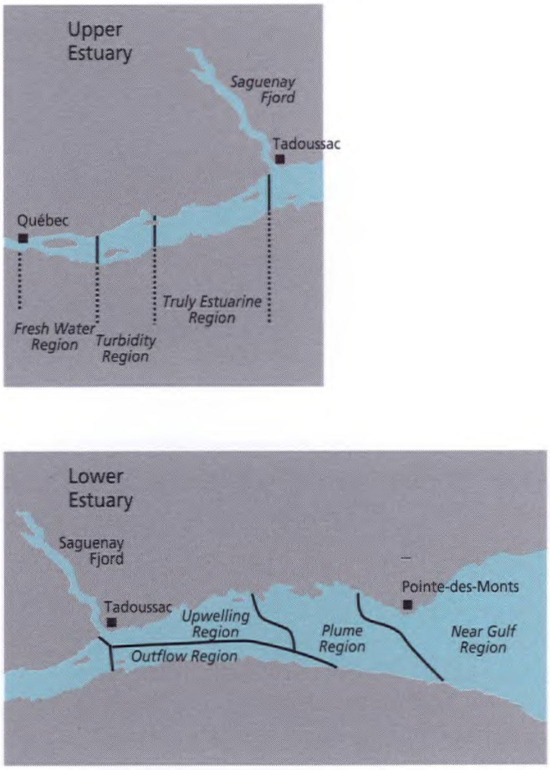

Figure 2.3
Biological subregions of the Estuary
Source: Therriault et al. 1990

composition or size structure of phytoplankton communities in the Gulf and Estuary though there is detailed information on the overall productivity (measurement of total cell numbers and chlorophyll levels). Taxonomy of phytoplankton is at a relatively preliminary stage, particularly for the Gulf. In recent years, research has focused primarily on identification of toxin-producing algal species that make shellfish poisonous to humans (see "Marine Phycotoxins", pages 85–87). Species lists are available for the Estuary (Sinclair 1978; Désilets et al. 1989), but no comparable species surveys have been produced for the Gulf.

Estuary

Phytoplankton in the Estuary include both marine and fresh water species (Table 2.1), with the proportion of marine species increasing toward the Gulf. Because there is a high downstream flow (seaward) of fresh water in spring, phytoplankton biomass accumulates downstream. High phytoplankton production occurs in the summer, in contrast to most estuaries which have early spring blooms. This high production in the Estuary coincides with the reduction of fresh water runoff and its associated high turbidity and stronger stratification of the water column. Sinclair et al. (1981) suggested that the large volume of spring runoff may be the major reason why the peak in primary production in the Estuary is delayed compared to the spring peak of productivity in the Gulf.

Table 2.1 illustrates the character of phytoplankton productivity in different regions of the Estuary (Figure 2.3).The area at the head of the Upper Estuary (Québec City) is almost entirely fresh water and, based on preliminary information, may have high productivity. Much of the remaining Upper Estuary has high turbidity, particularly in the MTZ. This turbidity tends to reduce the availability of light, and hence phytoplankton productivity, despite high nutrient influx in the spring. The turbidity region (the MTZ) is dominated by bacterial rather than phytoplankton production. The estuarine region has variable productivity because of the high turbidity, strong tidal mixing and fresh water runoff. The production in the Lower Estuary increases toward the near Gulf region where the waters are the least turbid and tidal mixing is lowest.

Because environmental factors in estuaries are so variable, it is generally difficult to demonstrate specific responses to single factors (e.g., salinity, temperature, turbidity, stratification, nutrients and fresh water runoff). However, the recent focus on a single species of toxin-producing phytoplankton associated with shellfish poisoning events (see "Marine Phycotoxins", pages 85–87) has shed light on some of the complex interactions between phytoplankton and their environment.

For example, in the Lower Estuary, blooms of the toxic dinoflagellate *Alexandrium excavatum* only occur in regions under the direct influence of the fresh water plumes of the Manicouagan and Aux-Outardes rivers and the Gaspé Current

(Therriault et al. 1985). Environmental conditions necessary for the occurrence of *Alexandrium* are low salinity, high temperature, high nutrients and stratification of the water column. Low wind velocities and reduced tidal mixing (neap tides) are additional conditions necessary to ensure stratification of the water column sufficient for the growth of this organism.

Gulf

Table 2.2 summarizes what is known about plankton in the Gulf, but the relationships between nutrient availability and productivity are not known. Detailed data on phytoplankton species only exist for coastal areas such as Chaleur Bay and St. Georges Bay, NS.

Most of the Gulf experiences high

Table 2.2 Description of plankton in the Gulf

Plankton Group	*Northwestern Gulf*	*Gaspé Current*	*Magdalen Shallows*	*Northeastern Gulf*
Phytoplankton				
Productivity	very high productivity in spring; nutrient-limited in summer	high, continuous productivity from April to October	lower productivity in spring; may be nutrient-limited	–
Species Composition	seasonal shift from large diatoms to small flagellates	large diatoms	large diatoms in spring and fall; dinoflagellates in summer	–
Zooplankton				
Productivity	high	high	lower	high
Number of Species	low	low	high	low
Dominant Species	large copepods, euphausiids, chaetognaths, shrimp	large copepods, euphausiids	small copepods, jellyfish, ctenophores immature stages of larger organisms	large copepods, shrimp
Ichthyoplankton				
Spawning	low	moderate	high	–
Number of Species	low	moderate	high	–
Dominant Commercial Species	redfish, capelin	redfish, capelin	mackerel, cod, herring, hake	cod, herring, redfish
Abundance	low	moderate	high	–

Source: Adapted from de Lafontaine et al. 1991; G. Harding, personal communication

Notes: Regions are keyed to Figure 2.2
"–" means there is little or no information

phytoplankton production in the spring in response to increased light intensity, stratification and high levels of nutrients in the upper water layer. After the nutrients become depleted in surface waters, phytoplankton production rapidly declines in the summer months. The Gaspé Current has high nutrient concentrations until mid-May, which may contribute to the higher productivity observed in this region through the summer and early autumn.

Autumn blooms of the toxic diatom *Pseudonitzschia pungens* along the eastern coast of Prince Edward Island appear to be connected to seasonal changes in nutrient availability. These changes are related to the amount of precipitation, which influences the timing and quantity of nutrients (especially nitrogen compounds) released from human activities: agricultural runoff, soil erosion, municipal sewage and aquaculture (Bates et al. 1991; Therriault and Levasseur 1992).

Zooplankton

A brief summary of zooplankton information in the Estuary (Runge and Simard 1990) and Gulf (de Lafontaine et al. 1991) follows.

Zooplankton in the Upper Estuary

In the Upper Estuary, zooplankton populations are dominated numerically by small copepod species (Table 2.3). The dominant zooplankton species in the Upper Estuary are similar to those found in other estuaries at similar latitudes. As salinity increases downstream, fresh water species are replaced by marine species. Fresh water species, particularly *Bosmina*, *Ectinosoma*, and *Neomysis*, are most abundant at the upstream portion of the Estuary near Île d'Orléans. *Eurytemora affinis* is most abundant in brackish water between Île d'Orléans and Île-aux-Coudres; *Acartia* and *Eurytemora herdmani* are most abundant in higher salinity waters downstream; and *Calanus finmarchicus* is most common in the cold saline water of the most downstream portion of the Upper Estuary.

Table 2.3 Zooplankton species composition in the Estuary

Species	*Percentage of Zooplankton Species*	*Total*
Upper Estuary		
calanoid copepods		**60**
Eurytemora affinis	43	
Acartia longiremis	35	
Eurytemora herdmani	17	
other species	5	
harpacticoid copepods		**20**
Ectinosoma curticorne		
cladoceran (*Bosmina longirostris*) and barnacle larvae (*Balanus crenatus*)		**15**
other zooplankton		**5**
opossum shrimp		
Neomysis americana		
Mysis stenolepis		
sand shrimp (*Crangon septemspinosus*)		
other species		
Lower Estuary		
copepods		**79–90**
large *Calanus* species	50	
C. finmarchicus		
C. hyperboreus		
smaller species	50	
Acartia longiremis		
Eurytemora herdmani		
Microcalanus pygmaeus		
Oithona similis		
Scolecithricella minor		
other zooplankton		**10–21**
ostracod *Conchoecia elegans*		
euphausiids		
Meganyctiphanes norvegica		
Thysanoessa raschii		
Thysanoessa inermis		

Source: Runge and Simard 1990

Table 2.4 Dominant Zooplankton Species in Selected Areas of the Gulf

Region	*Species*
Northern Gulf	
Laurentian Channel	*Calanus finmarchicus*
	Calanus glacialis
	Calanus hyperboreus
	Meganyctiphanes norvegica
	Thysanoessa raschii
	Thysanoessa inermis
	Pandalus borealis
Jacques Cartier Passage	*Meganyctiphanes norvegica*
	hysanoessa raschii
	Thysanoessa inermis
	Pandalus borealis
Strait of Belle Isle	*Calanus finmarchicus*
	Calanus glacialis
	Pseudocalanus sp.
	Oithona similis
	Temora longicornis
Southern Gulf	
Chaleur Bay	
fishing banks just outside	*Calanus* sp.
	Pseudocalanus sp.
	Oithona similis
central bay area	*Calanus* sp.
estuarine	*Acartia clausi*
	Temora longicornis
Miramichi Bay	*Temora longicornis*
	Tortanus discaudatus
St. Georges Bay, NS	
spring	*Temora longicornis*
summer	*Centropages hamatus*
	Tortanus discaudatus
	Acartia sp.

Source: de Lafontaine et al. 1991

Highest concentrations of zooplankton occur in the maximum turbidity zone (MTZ) and further downstream in the deep water. The MTZ is an important site for opossum shrimp species. Shrimp species dominate in total biomass—but not in numbers—because their size is large compared to other zooplankton.

Some species are unique to the Upper Estuary and are not carried into the Lower Estuary by the general surface water flow. Although various mechanisms for retention of zooplankton in estuaries are known, few studies have explicitly addressed such mechanisms in the Upper Estuary. Two properties of zooplankton result in their retention in the MTZ: 1) the vertical migration of some species to deeper waters in response to changes in light intensity and tidal rhythms and 2) a life stage in which eggs or larvae live in the benthic or near benthic environment. This retention is further enhanced by the same processes that maintain the MTZ: a repeating cycle of seaward flow of particles in the surface layer, settlement of particles to the upstream-moving deeper layer and rapid resuspension during flood tide at the head of the estuary.

Zooplankton in the Lower Estuary

Data for zooplankton in the Lower Estuary is somewhat limited, but there are indications that the species composition is unusual for the latitude, resembling communities found in the high Canadian Arctic and high latitude waters of western Norway. Copepods make up 79–90% of the zooplankton species and are dominated by large species in the genus *Calanus* (Table 2.3). Data indicate that abundance of small copepod species is unusually low. Little is known about the ostracod *Conchoecia elegans*, even though it ranks third behind the *Calanus* species in abundance. A distinguishing characteristic of the Lower Estuary—and the deep waters of the Gulf—is the relative abundance of euphausiids, commonly called krill. These animals tend to be patchily distributed, primarily accumulating in dense aggregations at the head of the Laurentian Channel in the Lower Estuary. Euphausiids make up more than 90% of the zooplankton biomass in areas where they are abundant. Zooplankton that are generally found in the surface waters of the Gulf (small copepods, gelatinous zooplankton such as jellyfish and arrow worms) are notably rare in the Lower Estuary.

Larval stage euphausiids and copepods produced in the Lower Estuary drift downstream to the Gulf, carried primarily by the Gaspé Current. Adult euphausiids, older stages of *Calanus* and possibly adult ostracods that live in the deep waters of the Laurentian Channel are brought into the Lower Estuary by the upstream movement of the deep saline water in the Channel. Surface-dwelling smaller copepod species are not brought into the Estuary by upwelling in the Laurentian Channel in the same relative proportion as *Calanus* species.

Plourde and Runge (1993) suggested that the Lower Estuary is a very important region for production of the dominant copepod species *Calanus finmarchicus* and that the region may act as a *Calanus* "pump" to the Gulf system. Because these populations drift with the Gaspé Current into the Gulf, the high production of *Calanus* in the Estuary is exported during the summer to the western Gulf.

Zooplankton in the Gulf

As in most northern temperate waters, copepods constitute more than 75% of zooplankton species in the Gulf. The zooplankton community in the deep and cold northern Gulf, where large species of *Calanus* dominate, is easily distinguished from the smaller species (*Temora*, *Centropages*, and *Tortanus*) that dominate the shallow and warm waters of the southern Gulf. (Table 2.2 and Table 2.4). Euphausiids (*Meganyctiphanes norvegica*, *Thysanoessa raschii*, and *T. inermis*) and shrimp (*Pandalus borealis*) are also common in the northern Gulf within the Laurentian Channel (Table 2.4).

The richest diversity and abundance of zooplankton in the Gulf are found in the Magdalen Shallows, where populations peak in August (Steven 1975). Although copepods are a major component of zooplankton in these waters, a great variety of larvae and immature stages of annelids, euphausiids, crustaceans, echinoderms, bivalves and gastropods are also present. *Cladocera*, *Podon* and *Evadne*—characteristic species of shallow coastal waters—are common as well. Jellyfish are probably an important component of the food web in the southern Gulf but little is known about their ecology.

Zooplankton biomass is highest in the western portion of the Magdalen Shallows, and the overall biomass in the Shallows is higher than in the adjacent Laurentian Channel (de Lafontaine 1994). Contrary to what one may expect, the pattern of plankton distribution is not related to horizontal gradients of salinity and temperature of surface waters (top 30 m). Rather, it was suggested by de Lafontaine (1994) that zooplankton distribution in the Magdalen Shallows may be primarily controlled by fish predation. The rich summer zooplankton in the Magdalen Shallows support the spawning and nursery areas for many commercially important fish and provide a seasonal feeding area for others. Ouellet et al. (1990) also found a lack of correspondence between horizontal gradients of temperature and salinity in the waters and the distribution of larval shrimp in the northern Gulf.

Detailed information on zooplankton in the Gaspé Current and northeastern Gulf is lacking.

Ichthyoplankton

Most fish produce eggs from which free-swimming larvae develop (Figure 2.4). The larval stage of most marine fish is generally planktonic and structurally quite different from the adults. Fish larvae do not have bones, fins or scales and range in length from 2–12 mm.

In temperate waters, fish are generally very fecund: a single female cod, for example, can produce millions of eggs. Fish may lay eggs that float in surface waters or in the water column (pelagic spawners); others deposit eggs on the bottom (benthic spawners). Spawning habitat is not related to the habitat preference of adults (e.g., pelagic herring spawn benthic eggs). Some eggs hatch within hours of being released, while others survive on their yolk sacs and hatch days, or even weeks, after spawning.

Biological information for the eggs and larvae of most fish, even for important commercial species, is scant. Although distribution patterns of ichthyoplankton are generally known, their diet, prey and predator-prey relationships are not; thus, the major factors affecting their growth and survival are poorly understood.

The ichthyoplankton communities in the Gulf and Estuary are dominated by larvae from benthic eggs, a characteristic of boreal-Arctic waters. It does not necessarily reflect adaptations to local hydrodynamic features or circulation patterns. Prevailing water currents determine the drift of larvae from spawning areas to nursery areas. Retention of post-larvae in these nursing areas is determined by other oceanographic processes such as gyres (see "Horizontal Circulation", pages 11–12).

The following is a brief synopsis of information on ichthyoplankton in the Estuary and Gulf, based on reviews by de Lafontaine (1990) and de Lafontaine et al. (1991).

Table 2.5 Common ichthyoplankton in the Gulf and Estuary

Pelagic Spawning Species	
Atlantic mackerel	*Scomber scombrus*
Atlantic cod	*Gadus morhua*
American plaice	*Hippoglossoides platessoides*
fourbeard rockling	*Enchelyopus cimbrius*
hake	*Urophycis* sp.
cunner	*Tautogolabrus adspersus*
yellowtail flounder	*Limanda ferruginea*
redfish (give birth to live young)	*Sebastes* sp.
Benthic Spawning Species	
Atlantic herring	*Clupea harengus*
rainbow smelt	*Osmerus mordax*
tomcod	*Microgadus tomcod*
winter flounder	*Pseudopleuronectes americanus*
capelin	*Mallotus villosus*
snailfish	*Liparis* sp.
shanny	*Lumpenus* sp. *Stichaeus* sp. *Ulvaria* sp.
sculpins	*Myoxocephalus* sp. *Icelus* sp. *Hemitripterus* sp. *Artediellus* sp.
sand lance	*Ammodytes* sp.
Crustaceans (Eggs attach to the underside of an adult female abdomen until the following year. Larvae drift in surface waters)	
lobster	*Homarus americanus*
boreal shrimp	*Pandalus borealis*

Sources: de Lafontaine 1990; de Lafontaine et al. 1991

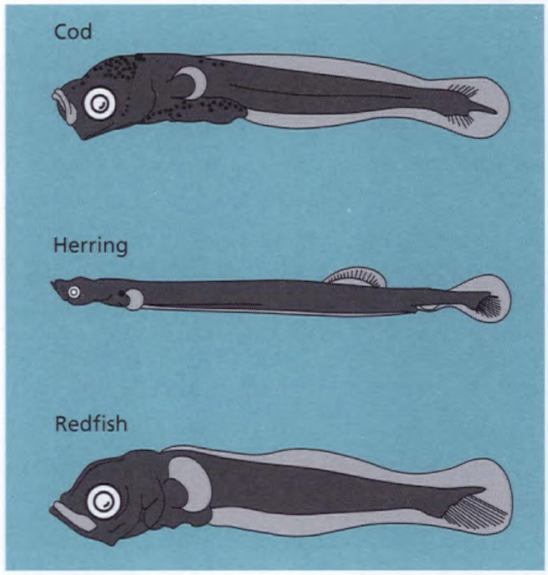

Figure 2.4
Representative fish larvae
Source: Kohler and Faber 1985

Ichthyoplankton in the Estuary

A total of 79 adult fish species have been documented in the Estuary but only 27 of them have been found in their larval form there. This may imply that many marine species either do not spawn in the Estuary or may spawn during the winter months when the Estuary is covered with ice, making observation difficult. Most larval and adult fish in the Estuary are typical inshore marine species (Table 2.5) of the northwest Atlantic and tend to be more abundant and widely distributed in the Gulf.

Three species (capelin, smelt and herring) contribute more than 95% of the total larval abundance. Table 2.6 lists the most prevalent

Table 2.6 Seasonal dominance of fish larvae in the Estuary and Gulf

Region		Early May	Late June	Late July
Estuary				
	Upper Estuary	rainbow smelt, tomcod, capelin, Atlantic herring	rainbow smelt, tomcod, capelin, Atlantic herring	rainbow smelt, tomcod, capelin, Atlantic herring
	Lower Estuary	sand lance	capelin, Atlantic herring, shanny, winter flounder, snailfish	capelin, Atlantic herring, snailfish
Gulf				
	Northwestern Gulf	sand lance	capelin, redfish	capelin
	Gaspé Current	sand lance, shanny	capelin	capelin
	Magdalen Shallows	shanny, sand lance	mackerel	mackerel, capelin, shanny
	Northeastern Gulf	sand lance	redfish, capelin	no information

Sources: de Lafontaine 1990; de Lafontaine et al. 1991

species of ichthyoplankton in the spring and summer months in the Estuary.

The head of the Upper Estuary is a nursery area for some species that spawn in fresh water such as smelt and tomcod. The presence of other species in this area is not well documented. Herring spawn in the lower portion of the Upper Estuary. Capelin larvae are distributed near the water's surface and drift into the Lower Estuary.

Although fish eggs and larvae are abundant in the Lower Estuary, the region is not a nursery area for larval fish species. Sand lance is the most prevalent species (more than 85%) during spring. The Gaspé Current is the main pathway for sand lance and capelin larvae drifting out of the Lower Estuary. Some capelin also drift to the northwestern Gulf where they spend their first year of life.

Ichthyoplankton in the Gulf

Fifty species of ichthyoplankton are found in the Gulf, representing almost two-thirds of the adult fish species found in the region. As in the Estuary, ichthyoplankton populations in the northern Gulf are dominated by benthic-spawning cold-water species (herring, capelin, snailfish, shanny and sculpin). Boreal shrimp larvae are concentrated in the deep waters. Most species that produce pelagic eggs (mackerel, cod, plaice, four-beard rockling, hake, cunner, yellowtail and flounder), of which many are warm water species, are primarily found in the Magdalen Shallows. At different times of the year, cunner, radiated shanny (*Ulvaria subbifurcata*) and winter flounder may comprise a significant portion of the ichthyoplankton in nearshore waters and shallow bays in the southern Gulf.

The dominant species of fish larvae in the Gulf in the spring and early summer months are listed in Table 2.6. The larvae of commercially important species such as cod, plaice and herring are less abundant than important forage fish (e.g., capelin and sand lance) on which other fish, seabirds and marine mammals feed.

Table 2.7 Dominant species of macrobenthos in the Lower Estuary

Benthic Zone	*Substrate*	*Dominant Species*
Intertidal	sand (north shore)	bivalves: *Mesodesma arctatum* marine snails (gastropods): *Littorina saxatilis, L. obtusata*
	mud/sand/gravel sediments (south shore)	bivalves: *Macoma balthica, Mya arenaria* marine snails: *Hydrobia totteni, Littorina saxatilis, L. obtusata* marine worms (polychaetes): *Nereis virens*
	rocky	barnacles: *Semibalanus balanoides* bivalves: *Mytilus edulis* marine snails: *Littorina saxatilis, L. obtusata*
Subtidal	rocky	green sea urchin: *Strongylocentrotus droebachiensis* seastar: *Leptasterias polaris*
	mud/sand	no information
Laurentian Channel	mud	marine worms: 65% bivalves: 16% water lice (amphipods): 8% peanut worms (sipunculids): 4% brittle stars (ophiurids): 4%

Source: Vincent 1990

Note: intertidal is the area of shore between the low tide and high tide marks and subtidal is the area of sea bottom that is always submerged

Benthic System

The sea floor has a great variety of physically diverse habitats, much more so than the pelagic environment. Benthic habitats differ in depth, temperature, light, type of substrate (e.g., rock, sediment and sediment grain size) and, along shorelines, the amount of time they are under water. These factors ultimately determine species distribution and associations. Describing assemblages of benthic marine organisms is difficult, particularly for large geographic regions. Small-scale variability in the distribution of bottom sediment types—a major determinant for the presence of specific benthic organisms—and the slowness and irregularity of benthic population dynamics require frequent sampling over a long time to adequately describe benthic communities. Because benthos are relatively sedentary, the distribution and number of benthic species are strongly influenced by the presence of mobile predators: sea urchins, whelks, seastars, lobster and fish.

Primary production also occurs in the benthic environment, and is largely restricted to near-shore regions where sufficient light is available for photosynthesis. Benthic aquatic plants include macroscopic (e.g., seaweeds) and microscopic algae. Benthic animals are divided into two categories. Infaunal species (e.g., clams, snails and worms) live wholly or partly within the sediments. Epifauna (e.g., mussels, seastars, barnacles and sponges) are large organisms that either lie on the sea floor or are attached to it. Benthos include herbivores, carnivores and detritivores. Detritivores play an important role in cycling carbon and nutrients in marine waters. The larvae of benthic animals spend some time in the water column; while there, some species do not feed but subsist on their yolk sacs while others feed on phytoplankton or bacteria. Benthos are essential to the diet of fish, birds and marine mammals.

Information on both benthic plants and animals is extremely limited or non-existent for much of the Gulf and Estuary, with the exception of the Lower Estuary and the Mingan Islands in the northern Gulf (Vincent 1990; Himmelman 1991). Most studies have concentrated on macroalgae and macrobenthos (greater than 1.0 mm in size); relatively little is known about the meiobenthos (0.1–1.0 mm) and microbenthos (smaller than 0.1 mm) of the region. More is known about commercially important benthic species in the Gulf, such as scallops, oyster, bay quahog, surf clam, blue mussel, lobster and snow crab.

Benthic Plants

Species lists of macroalgae (seaweeds) for the Gulf and Estuary are provided by Dunbar et al. (1980). Species and distribution of seaweeds in the subtidal regions of the Estuary and the Mingan Islands in the northern Gulf are similar, but they differ considerably from those found off western Newfoundland and Nova Scotia (Himmelman 1991). Rocky areas around the coasts of the Estuary and northern Gulf typically have two major zones: a shallow-water zone dominated by seaweeds and a deep-water zone dominated by microscopic algae that are resistant to grazing by sea urchins. Waves, low salinities and ice tend to limit numbers of, and grazing by, sea urchins in shallower regions.

Irish moss and kelp are generally absent from the Mingan Islands in the northern Gulf, but are common in the southern Gulf (Himmelman 1991). Irish moss is harvested commercially there, particularly around Prince Edward Island and St. Georges Bay, NS. It is generally found in shallow areas where ice abrasion of the bottom is minimal.

Benthic Animals

Almost all studies on macrobenthos in the Estuary have concentrated on the Lower Estuary (Vincent 1990). Studies in the Upper Estuary comprise little more than species lists. Since 1970, ecological studies in the Lower Estuary have focused on shallow water (inter- and subtidal) zones along the coast. Table 2.7 lists the dominant species in benthic zones of the Lower Estuary. They have slow annual growth, late reproduction and irregular recruitment of young into the adult population. Ice scouring can have a significant effect on benthos in the intertidal zone, but little is known about the effects that four to five months of ice cover have on benthos in other zones.

Benthic communities at the Mingan Islands are similar to those in the subtidal zone and the deeper regions of the Estuary (Vincent 1990; Himmelman 1991). The subtidal zone supports a benthic community of seastars, whelks, sea urchins, bivalves and sand dollars (Himmelman 1991). Species distribution changes with depth: mussels predominate in shallow areas, sea urchins in the rocky zone, and other bivalves and sand dollars at greater depths (Himmelman 1991).

At the Mingan Islands, the common predators are the northern whelk and the six-armed seastar. Himmelman (1991) suggested that these important predators in the region limit the distribution and numbers of bivalves such as mussels, barnacles, scallops and clams. Although common around the Mingan Islands, the six-armed seastar is rare in the southern Gulf. Along the southern Gulf coast, fish, lobster and crab are instrumental in determining the composition of the benthic community. Differences in key benthic predators imply that there may be substantial differences between the organization of benthic communities in the northern Gulf and southern Gulf (Himmelman 1991).

In the intertidal and subtidal zones near Îles-de-la-Madeleine, macrobenthic fauna consist mostly of bivalves, gastropods, polychaete worms, and crustacea (Bourget and Messier 1983). There are species lists for the Northumberland Strait (Caddy et al. 1977; Public Works Canada 1989) and the northern edge of the Magdalen Shallows along the Laurentian Channel (Peer 1963). Other studies in the southern Gulf region tend to be process oriented, focusing on the role of detritivore benthos in carbon and nitrogen cycling (e.g., Hargrave and Phillips 1986).

Seabirds

Cairns et al. (1991) reviewed the distribution, diet and abundance of seabird colonies in the Gulf and Lower Estuary. This comprehensive survey and other studies are summarized below.

Distribution and Diet of Seabirds

Breeding seabirds are concentrated most heavily in the north, central and western Gulf (Figure 2.5). One-quarter of Gulf seabirds breed off the eastern Gaspé Peninsula; large numbers are also found on the north shore of the Gulf and Îles-de-la-Madeleine. Seabird numbers are lowest in the southwestern Gulf and along the west coast of Newfoundland. Common breeding species of seabirds in the Gulf and Estuary are listed in Table 2.8.

Seabirds are classified as either inshore or offshore. Inshore species tend to be widely dispersed, breeding throughout the Gulf and Estuary in colonies scattered along the coastline. They usually feed within sight of land. Offshore species breed on a few islands in large colonies. They tend to forage in deep water, often out of sight of land. Seabirds, particularly offshore

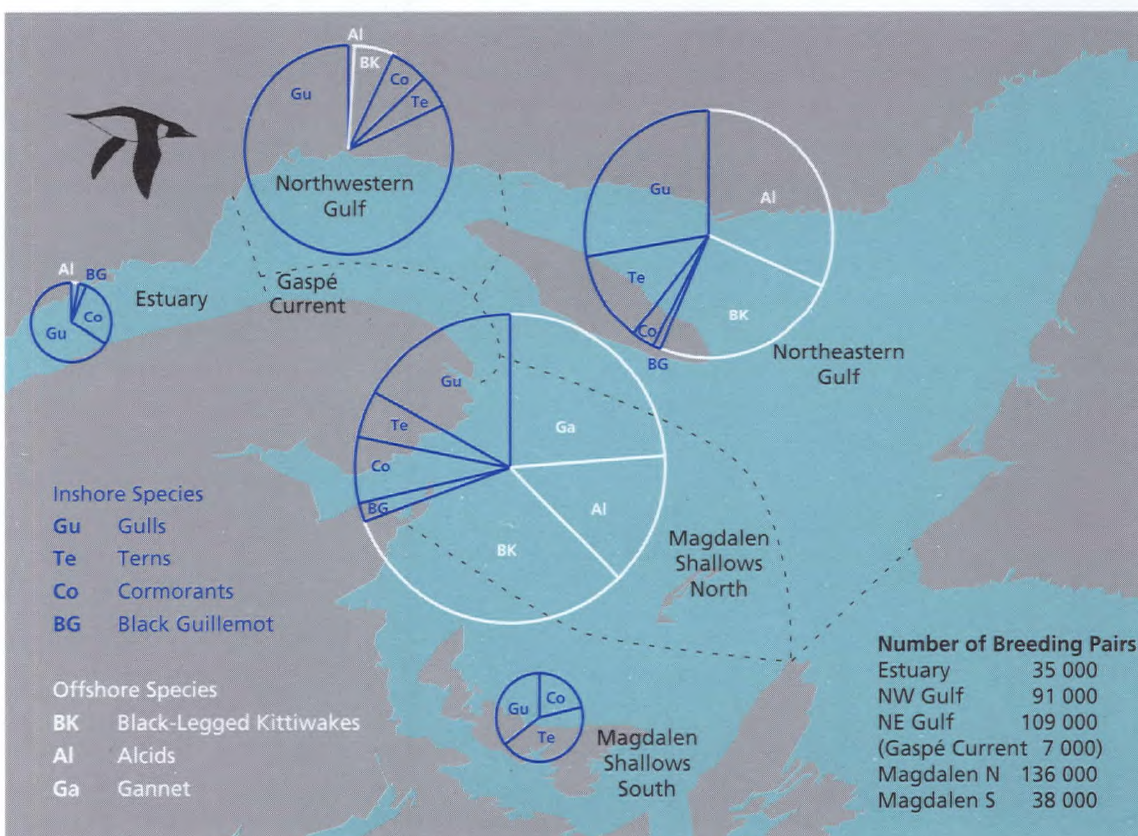

Figure 2.5
Distribution of breeding populations of seabirds in the Gulf and Lower Estuary
Sources: Adapted from Cairns et al. 1991; D. Cairns, personal communication

species, tend to concentrate their feeding efforts where tidal motion and water currents concentrate their prey or cause high biological productivity. There is a general absence of offshore species breeding in the southern Gulf and western Newfoundland, most likely because there is a shortage of high quality breeding sites in those areas.

Seabirds in the Gulf consume approximately 80 000 tonnes of marine prey annually. About 90% of this is estimated to be fish and squid, with capelin, sand lance and mackerel being the principal fish prey (Figure 2.6). The remaining 10% of the seabird diet mostly consists of benthic and pelagic crustaceans.

Table 2.8 Common breeding seabird species in the Gulf and Estuary

Gulls		
	Greater Black-Backed Gull	*Larus marinus*
	Herring Gull	*Larus argentatus*
	Ring-Billed Gull	*Larus delawarensis*
	Black-Legged Kittiwake	*Rissa tridactyla*
Terns		
	Arctic Tern	*Sterna paradisaea*
	Common Tern	*Sterna hirundo*
Cormorants		
	Great Cormorant	*Phalacrocorax carbo*
	Double-Crested Cormorant	*Phalacrocorax auritus*
Alcids		
	Atlantic Puffin	*Fratercula arctica*
	Razorbill	*Alca torda*
	Black Guillemot	*Cepphus grylle*
	Common Murre	*Uria aalge*
Gannets		
	Northern Gannet	*Morus bassanus*
Petrels		
	Leach's Storm-Petrel	*Oceanodroma leucorhoa*

Source: Cairns et al. 1991

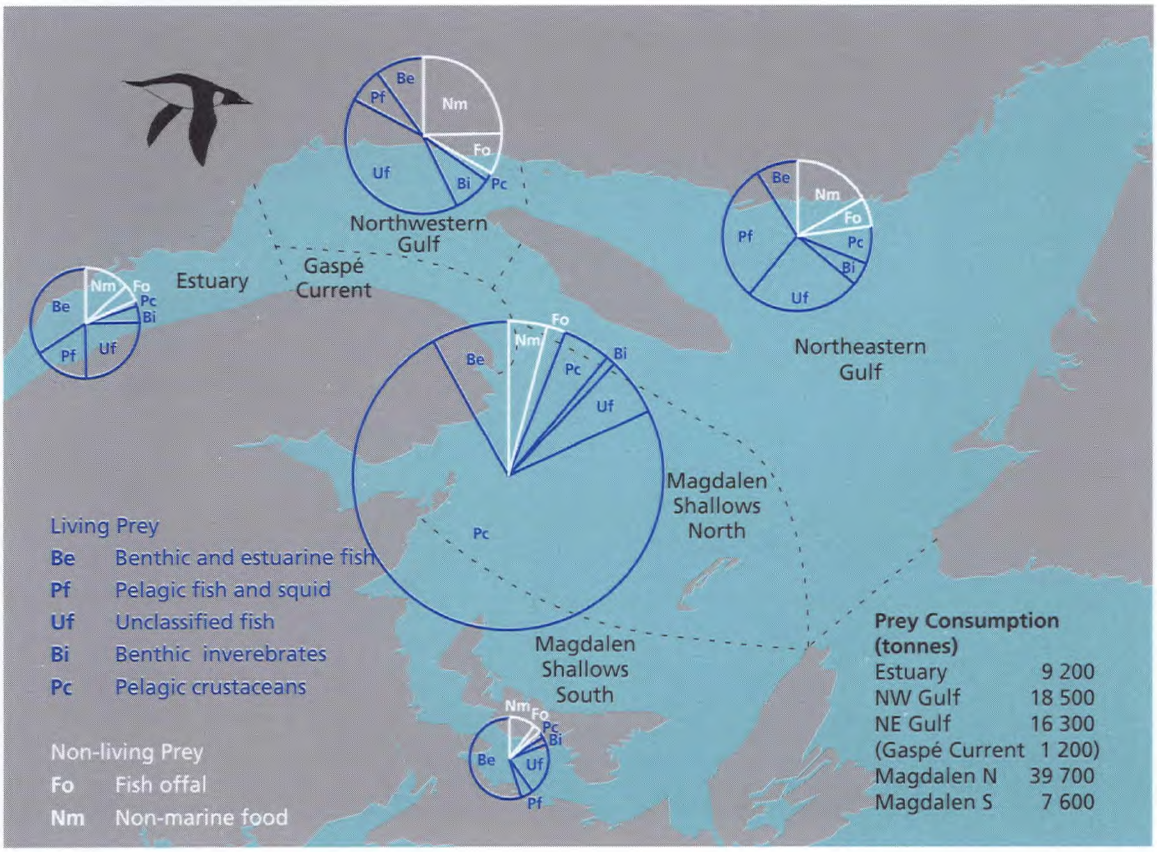

Figure 2.6
Estimated prey harvest of seabirds in the Gulf and Lower Estuary
Sources: Adapted from Cairns et al. 1991; D. Cairns, personal communication

Abundance and Population Trends of Seabirds

The seabird population of the Gulf and Estuary is about 400 000 breeding pairs. This is relatively low compared with the open Atlantic waters of eastern Canada, which support about 5.4 million breeding pairs. In the Gulf, the dominant group is gulls, while the most common offshore species is the kittiwake (Table 2.9).

At the time of European contact, the Gulf supported very large seabird populations. Since that time they have been greatly reduced by human exploitation. The north shore of the Gulf originally sheltered alcid (murres, puffins and razorbills) populations of 800 000 breeding pairs; the pre-disturbance gannet population on the Magdalen Bird Rocks (30 km northeast of Îles-de-la-Madeleine) was 125 000 pairs. The Great Auk, a flightless seabird that also may have nested in the Magdalen Bird Rocks, became extinct in the western North Atlantic through over-exploitation.

Throughout the 19th century, the large alcid colonies on the Gulf north shore were subject to

Table 2.9 Composition of seabird population in the Lower Estuary and Gulf

Species	*Breeding Areas*	*Percentage of Inshore/ Offshore*	*Percentage of all Species*
Inshore Species			
Gulls	all areas, but 50% in northwestern Gulf	68	40
Terns	eastern New Brunswick, north shore of Gulf	15	9
Cormorants	widespread, especially Estuary and southern Gulf, but not western Newfoundland	14	8
Guillemot	north shore of Gulf and Estuary	–	less than 1
All inshore species		100	58
Offshore species			
Black-Legged Kittiwake	Magdalen and Anticosti islands, and Gaspé but absent in southern Gulf	48	20
Alcids: Common Murre, Razorbill, Atlantic Puffin	Gaspé but absent in southern Gulf	33	14
Gannet	Gaspé and smaller numbers on Magdalen and Anticosti islands	19	8
Leach's Storm-Petrel	north shore of Estuary	–	less than 1
All offshore species		100	42
All species			100

Source: Adapted from Cairns et al. 1991

Notes: Total number of breeding pairs of seabirds is about 400 000, or 800 000 birds
"–" means there is little or no information

large-scale commercial collection of eggs and many colonies were eliminated or severely reduced. These colonies received legal protection following implementation of the Migratory Bird Treaty between Canada and the United States in 1917, but exploitation continued in remote areas. The general increase in seabird population is a result of vigorous conservation programs at bird sanctuaries, public education to deter illegal hunting and egg collecting on the Gulf north shore, and a possible increase in the prey species capelin and sand lance (Blanchard and Nettleship 1992; Chapdelaine and Brousseau 1989, 1991, 1992a, 1992b)

In the present century, there has been some recovery of seabird populations in the Gulf, and most colonies appear to be increasing (Chapdelaine 1993; Chapdelaine and Brousseau 1989, 1991, 1992a, 1992b; Chapdelaine and Bedard 1995). Despite these increases, numbers of many species are still far below pre-exploitation levels. For example, the 55 000 alcid pairs breeding on the Gulf north shore is less than 10% of the original population.

Herring Gull populations in the Estuary and the Gaspé and the Black Guillemot populations in the Estuary have been declining. Herring Gulls along the north shore of the Gulf are also declining (Chapdelaine 1993). This population decrease is associated with the decline and closure of the cod fishery in the northern Gulf. The loss of fish offal, generated by the commercial fishery, removed an important food source for the gulls.

The following are some of the indirect threats to seabird populations of the Gulf and Estuary that are causing increasing concern (Nettleship 1977):

- Oil contamination poses the single largest threat to seabird populations, particularly if a spill occurs near a breeding colony or during migration.

- Contamination of seabirds by chemicals has severely affected reproduction in the past and continues to be monitored (see "Seabirds", pages 78 and 81–83).

- The expansion of the commercial capelin fishery may threaten some species, particularly alcids, during the breeding season because capelin is an important food for young seabirds. Brown and Nettleship (1984) reported that when the Atlantic Puffin chick diet is reduced in capelin, the incidence of starvation and low fledgling weight increases, thereby reducing breeding success.

- The use of gill nets to capture groundfish, such as cod and redfish, is known to cause high mortality of diving seabirds in the north Atlantic and off western Greenland. There is not enough data to determine the mortality in eastern Canadian waters.

- In the past two decades, populations of Herring and Black-Backed Gulls have expanded dramatically in both their numbers and range because they feed on garbage, fish offal and sewage. Large populations of these gulls prey on puffins and terns by eating their eggs and chicks, robbing parents taking food to their young and displacing them from optimal nesting sites.

Marine Mammals

Unlike most other biological groups, reviews of marine mammal populations in the Gulf and Estuary are not available. Thus, the following discussion relies for the most part on individual scientific studies.

Distribution and Diet of Marine Mammals

Seals

Four species of seals are common in the Gulf: harp seals *(Phoca groenlandica)* and hooded seals (*Crystophora cristata*), which are migratory, and harbour seals (*Phoca vitulina*) and grey seals *(Halichoerus grypus)*, which are year-round residents. All four species belong to a group called

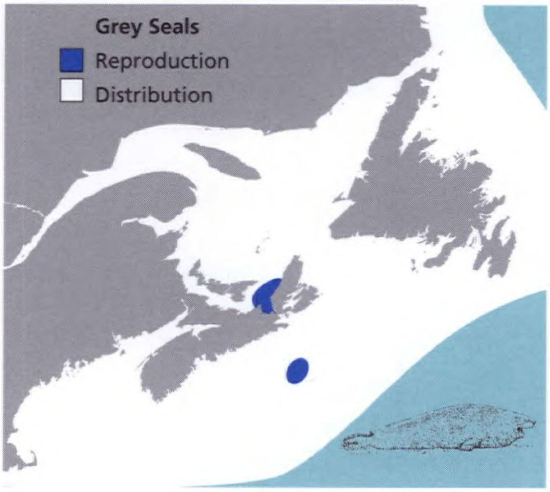

Figure 2.7
Seasonal distribution of grey seals
Source: G.B. Stenson, personal communication

Figure 2.8
Seasonal distribution of hooded seals
Source: G.B. Stenson, personal communication

phocid seals, also known as true or hair seals. Very small numbers of ringed seals *(P. hispida)* and bearded seals *(Erignathus barbatus)* also enter the Gulf and are hunted on the Gulf north shore (M. Hammill, personal communication). Walruses *(Odopbenus rosmarus)* are found infrequently in the Gulf.

All species except harbour seals breed on the pack ice in the Gulf during the winter months (grey seal, mid-December to late February; harp seals, late February to mid-March; hooded seals, March).

During the summer months, grey seals (Figure 2.7) disperse widely and feed offshore. The Gulf population of grey seals increases in the summer when seals that breed on Sable Island enter the Gulf (Stobo et al. 1990). Grey seals feed primarily on fish, including herring, flounder, cod and other commercial species (Benoît and Bowen 1990a, b; Mansfield and Beck 1977).

After a one-month breeding season, most hooded seals (Figure 2.8) migrate from the Gulf towards Greenland, where they moult in the summer. The autumn and winter distributions of hooded seals in Canadian waters are not well known (Stenson et al. 1991). The diet of hooded seals while in the Gulf also is not known, but the diet of hooded seals off the eastern coast of Newfoundland includes turbot, Arctic cod, capelin, squid, herring and redfish (Stenson et al. 1991). It is unclear whether hooded seals consume much fish while in the Gulf: they tend to spend most of their time on pack ice, remaining in the Gulf only until early May (M. Hammill, personal communication).

In late autumn, mature harp seals (Figure 2.9) migrate from the Arctic (Baffin Island and the west coast of Greenland) and feed heavily in the Gulf for two to three months before the breeding season (Sergeant 1991). Harp seals in the Gulf feed mostly on capelin from November–December to May–June (Sergeant 1991). In summer the Estuary is the prime feeding area in the Gulf for young-of-the-year harp seals. The only area where harp seals feed predominantly on herring is near Îles-de-la-Madeleine.

Harbour seals (Figure 2.10) live along inshore or shallow waters in open areas of the Gulf and Atlantic coasts, where they breed in small isolated groups from May to early June. In the past, harbour seals were also found in rivers and lakes far inland. The present distribution is thought to be the result of exploitation and displacement by humans (Boulva and McLaren 1979). The harbour seal diet includes inshore herring, flatfish and either gadoids, silver hake, alewife, smelt, mackerel and capelin or squid (Boulva and McLaren 1979).

Cetaceans (Baleen and Toothed Whales)

Baleen whales common to the region are finback, minke and blue whales, while the humpback is only rarely sighted. It has been many years since there has been a sighting of the endangered right whale in the Gulf; this species is generally found in the Bay of Fundy and Gulf of Maine. Baleen whales are generally much larger than the toothed whale species. For example, with an average length of 26 m, the blue whale is the largest mammal species in the world.

Toothed whales common in the Gulf and Estuary include beluga, pilot whale, white-sided and white-beaked dolphins and harbour porpoise. Killer and sperm whales are less common. The harbour porpoise is the smallest (at an average length of 1.5 m) cetacean species in the North Atlantic (Leatherwood et al. 1976).

The following information on the distribution and diet of whales was obtained from Katona et al. (1993), unless otherwise noted.

After ice break-up in March, baleen whales migrate into the Gulf and Estuary as far as the head of the Laurentian Channel near the mouth of the Saguenay Fjord. Blue and humpback whales leave the region by early autumn, while finbacks and minkes tend to remain in the region until November or December. Blue and humpback whales occur along the north shore of the Gulf near the Mingan Islands; finbacks and minkes are sighted throughout the region. All species breed in wintering areas outside the region.

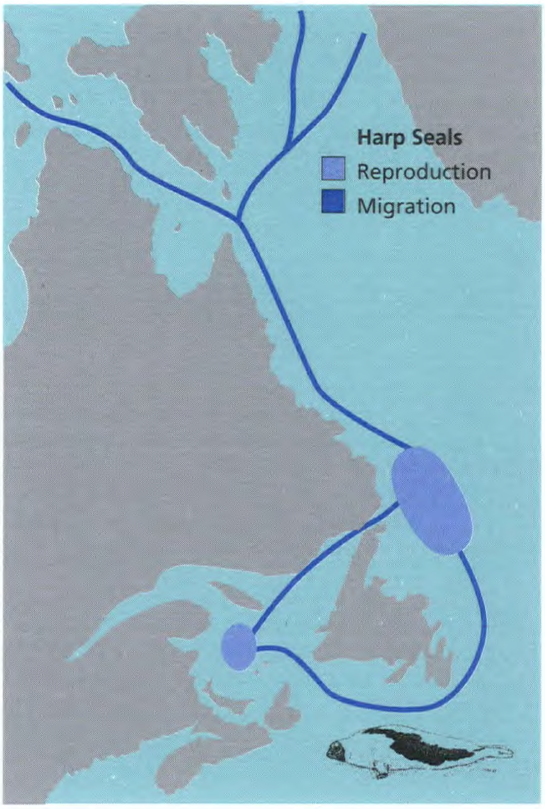

Figure 2.9
Seasonal distribution of harp seals
Source: G. B. Stenson, personal communication

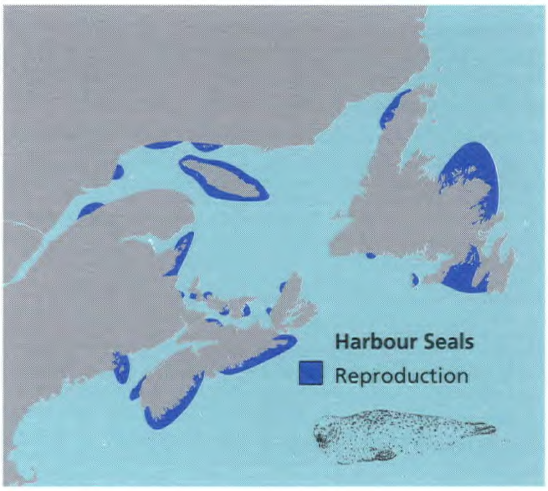

Figure 2.10
Seasonal distribution of harbour seals
Source: Boulva and McLaren 1979

Table 2.10 Diet of cetaceans in the Estuary and Gulf

Species		*Diet*
Baleen Whales		
blue whale	*Balaenoptera musculus*	krill (small shrimp-like crustaceans)
finback whale	*Balaenoptera physalus*	krill, capelin, squid, herring
minke whale	*Balaenoptera acutorostrata*	herring, cod, pollock, capelin, mackerel
humpback whale	*Megaptera novaeangliae*	krill, herring, capelin, sand lance
right whale	*Eubalaena glacialis*	copepods, zooplankton and probably krill
Toothed Whales		
sperm whale	*Physeter catodon*	squid, octopus
killer whale	*Orcinus orca*	squid, fish, sea turtles, seals, seabirds, baleen whales (minke, young finbacks and humpbacks) and, historically, belugas
pilot whale	*Globicephala melaena*	primarily squid, but also cod and other fish
beluga	*Delphinapterus leucas*	cod, capelin, eel, squid and benthic invertebrates (shrimp, crab, clams and worms)
white-sided dolphin	*Lagenorhynchus acutus*	herring, silver hake, smelt, squid
white-beaked dolphin	*Lagenorhynchus albirostris*	primarily squid, cod, herring, capelin
harbour porpoise	*Phocoena phocoena*	herring, mackerel, capelin, hake, pollock, squid, and inshore bottom-living fish and invertebrates

Sources: Leatherwood et al. 1976; Katona et al. 1993

Most toothed whale species migrate into the Gulf during the spring and remain until November. The range of white-beaked dolphins is generally more northern than that of white-sided dolphins, which are most common in the Gaspé region. Although the two species are sometimes observed together, their populations are generally separated spatially by water temperature and ecologically by diet. In the summer, pilot whales, white-sided dolphins and harbour porpoises give birth to young in the Gulf. Few data exist on the reproduction cycle of killer whales or white-beaked dolphins. Sperm whales breed in warm tropical waters or temperate waters outside the Gulf.

The beluga is a year-round resident of the Estuary and is the southernmost population of an essentially Arctic species (Reeves and Mitchell 1984). The beluga's current summer range in the Estuary is well documented (Michaud 1991). Comparisons of the beluga's present distribution with surveys in the 1940s and historic catch data indicate that their summer range has been substantially reduced (Michaud et al. 1990; Figure 2.11). In the winter, most of the population occurs in the northern Gulf in areas where ice coverage exceeds 70% (Michaud et al. 1990). Changes in the year-round distribution of belugas cannot be determined quantitatively because few surveys have been conducted outside the summer months.

Baleen whales generally consume small crustaceans and pelagic fish (Table 2.10), which they strain through their baleen plates. In the Gulf, small crustaceans such as euphausiids (krill) are an important part of the diet of most baleen whales. Only minke whales are almost exclusively fish eaters. Toothed whales generally pursue individual prey such as fish and squid (Table 2.10). Some toothed whales use echolocation to find food and it is suspected that many other whales also have that ability. Unlike other toothed whale species, killer whales eat other marine mammals; they have been observed attacking minke whales in the northern Gulf and, in the past, were known to prey on beluga in the Estuary.

Abundance and Population Trends of Marine Mammals

Seal or cetacean populations are usually estimated indirectly because it is difficult to count animals that spend much of their time underwater. For seals, annual pup production is usually estimated by aerial surveys during the winter whelping season on the pack ice. These surveys are used to derive total population size, based on the ratio of the number of pups to the number of juveniles and adults. This method can be applied to harp, hooded and grey seals, which breed in large concentrations, but not to species such as the harbour seal that are widely scattered during breeding.

Estimates for cetacean populations have used population modelling that is based on such data as catch statistics, reproductive variables and other information; but, these data generally are sparse and imprecise. Few surveys have been conducted for most whale species, and estimates of population size are generally limited to comparing the relative abundances in one region with those in adjacent ones. Estimates of the beluga population, though, are relatively good because that population is found in a confined area of the Estuary.

Seals

In Canada, humans have exploited the harp seal for more than a century. The population has steadily increased since restricted hunting quo-

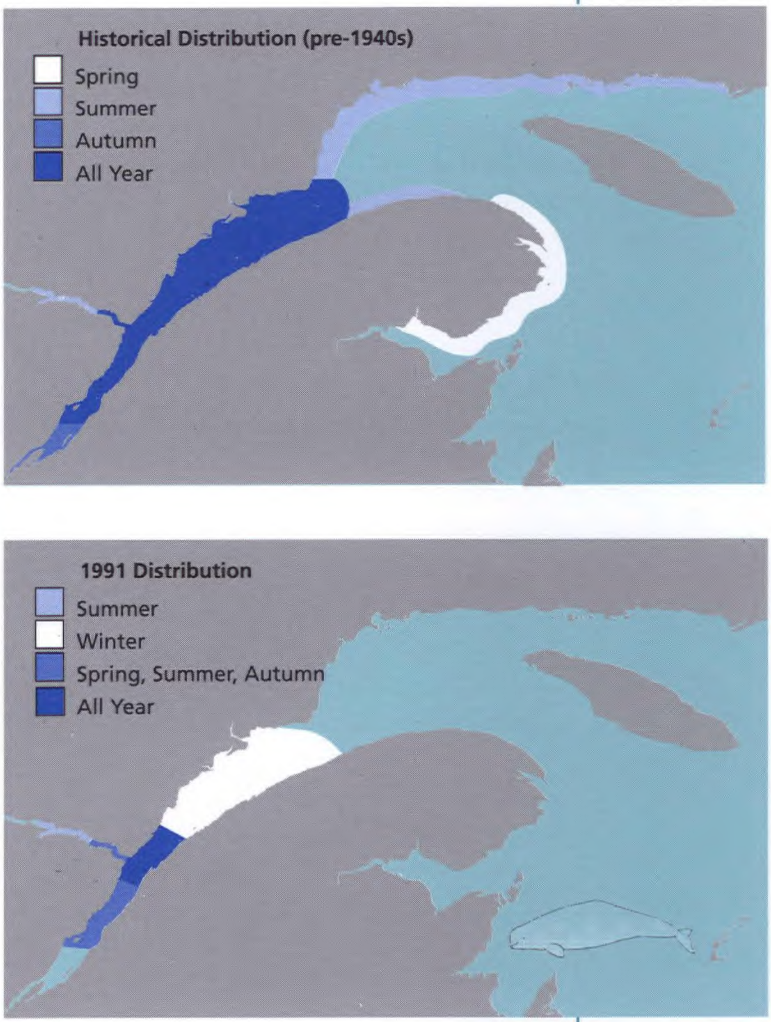

Figure 2.11
Historical and recent distribution of beluga in the Gulf and Estuary
Source: Lesage and Kingsley 1995; Michaud et al. 1990

tas were introduced in 1965 for the Gulf population and since the commercial hunt was closed in 1983. Stenson et al. (1995) estimated harp seal pup production in the Gulf at 256 200 for 1990. Data indicate that the total population is 5.4 times larger than the pup estimate (Shelton et al. 1992). Thus, the total population is estimated to be 1 383 480, including immature animals that may not migrate back to the Gulf until they reach breeding age.

Although not hunted commercially, grey and harbour seals were hunted as part of a bounty program on the east coast. Additionally, grey seals were subject to a government cull program during their breeding season in the Gulf. The bounty and cull were considered necessary to control population levels of all eastern Canadian seal species because there were concerns regarding damage done by seals to fishing gear, their consumption of commercial fish, and the transmission of parasites between seals and commercial fish species (Malouf 1988).

In 1973, the eastern Canadian harbour seal population was estimated at 12 700 (Boulva and McLaren 1979). The population in 1950 was estimated at 28 000. The decline was attributed primarily to bounty hunting, which ceased in 1976. In the mid-1980s, it was estimated that the population was increasing by about 2% per year (Malouf 1988).

Since the cancellation of the annual government cull program in 1983, grey seal pup production is thought to have increased exponentially, but the overall rate of increase is unknown. It is believed to be less than the rate of production of Sable Island seals, which is 12%. The cull may have restrained the rate of increase of grey seals, but the cessation of the bounty in 1992 appears to have had no effect (W. Stobo, personal communication). In 1987, the estimated population in the Gulf was between 30 000 and 60 000 (Zwanenburg and Bowen 1990).

The hooded seal population in the Gulf has declined throughout this century (Reeves and Ling 1981). The commercial hunt for this species ended in 1972. The only estimate of pup production in the Gulf since the cessation of the hunt was 2 006 for 1991–1992 (Hammill et al. 1992). No total population estimate was calculated because a population model for hooded seals has not been developed.

Cetaceans (Baleen and Toothed Whales)

In 1974, the finback population in the Gulf was estimated to be 340 (Katona et al. 1993). Finbacks feeding in the Gulf are thought to be separate from other finback populations in the north Atlantic.

Fifty blue whales were sighted during a 1981 census flight over the northern Gulf. Between 1979 and 1988, the number of individual blue whales identified from the Saguenay River to the Strait of Belle Isle was 203 (Sears et al. 1990). Humpbacks are relatively rare in the Gulf (155 ± 61; Katona and Beard 1990) compared with surrounding areas: several hundred animals both in the Gulf of Maine and western Greenland coast and several thousand in the Newfoundland-Labrador region. There are no estimates of the minke population in the Gulf.

With the exception of the beluga, estimates have not been made for any of the toothed whales in the Gulf and Estuary. There are large numbers of dolphins, moderate numbers of porpoises and smaller numbers of pilot and killer whales. Sperm whales are known to occur in the Gulf; there have been sightings of single animals and strandings of small groups.

Beluga were hunted commercially from the beginning of the early eighteenth century. Reeves and Mitchell (1984) estimated that the 1885 population was at least 5 000. Anecdotal observations indicate that belugas were locally abundant throughout the 1920s, 1930s and early 1940s (Reeves and Mitchell 1984). Intensive hunting of the beluga was banned in the 1950s. In 1979, the Canadian government passed a resolution that protected the Gulf beluga population and banned all forms of hunting. In 1983, the beluga was assigned endangered status. Population estimates since 1973 show that the population has remained at about 500. Various causes have been suggested to explain the lack of recovery in the beluga population: illegal hunting, habitat alteration, harassment and chemical pollution ("Marine Mammals", pages 78 and 83–85) (Reeves and Mitchell 1984).

Most threats to seal and cetacean populations other than hunting are relatively undocumented (Kellert 1991):

- incidental by-catch in fishing operations,
- entanglement in lost or discarded fishing gear,

- expansion of the capelin fishery, which threatens those populations that depend on capelin as a major food source,
- destruction and degradation of habitat,
- dredging and dumping, and
- contamination by chemicals.

Uncertainties

Clearly, much basic ecological information on the biological groups discussed in this chapter is lacking. Some of these gaps in our knowledge are discussed in more detail by de Lafontaine et al. (1991):

- The ecology and dynamics are virtually unknown for bacteria and microzooplankton, which are responsible for much of the breakdown and recycling of organic matter within the water column.
- Most meiobenthic and microbenthic species are unknown and this precludes a clear understanding of the importance they have in the cycling of nutrients and organic matter.
- Descriptions of benthos distribution, particularly relative to sediment type, in the Gulf are needed.
- Basic descriptions of individual phytoplankton species, their life history and the factors that control their abundance, distribution, and productivity have not been compiled or are only at a preliminary stage.
- Little is known of the species that are present and their interactions during the four to five months when ice covers the Estuary and Gulf.
- For many species or populations, basic life history information such as growth, reproduction, and age-specific mortality, as well as species interactions (e.g., prey availability) are not well understood.
- The biology of some areas of the Gulf has received little attention; particularly neglected is the northeastern Gulf, an area of intense feeding by seabirds and whales, which generally indicates high productivity. Previous data indicating that the northeastern Gulf was relatively unproductive may be erroneous (Cairns et al. 1991).

These information gaps reveal an inadequate knowledge of existing conditions (baseline data). This lack of knowledge restricts our ability to predict, detect or estimate changes at an individual, population or community level as a result of either natural fluctuations or human activities.

Chapter 3

Commercial Fisheries

Chapter 3 **Commercial Fisheries**

Tables

Figures

HUMANS GENERALLY ARE AWARE of their biological environment only at larger scales and see it usually as little more than a resource to be exploited. This narrow focus defines the marine ecosystem as merely a source of fish for consumption and undervalues the complexities of managing fish resources. In the 1990s, many Gulf fisheries experienced changes in the availability or viability of fish, partly as a result of that narrow focus. The main commercial species (groundfish) began a rapid decline and collapsed. Invertebrate fish populations, such as lobster, snow crab and shrimp, fluctuate in size but are healthy.

Overview

Most research on fish in the Gulf and Estuary has been carried out in association with commercial fisheries. Consequently, although there is a considerable body of knowledge about commercially important species in the region, few studies have examined the fish community as a whole. Over 145 different species of marine fish and shellfish live in the Gulf and Estuary (Srivastava 1971), but only about 28 of these are commercially fished (Messieh and El-Sabh 1988 and Table 3.1).

Table 3.1 Major commercial fish species of the Estuary and Gulf

Groundfish	
Atlantic cod	*Gadus morhua*
redfish	*Sebastes mentella*
	Sebastes fasciatus
flounders	
American plaice	*Hippoglossoides platessoides*
winter flounder	*Pseudopleuronectes americanus*
witch flounder	*Glyptocephalus cynoglossus*
Greenland halibut	*Reinhardtius hippoglossoides*
white hake	*Urophycis tenuis*
Atlantic halibut	*Hippoglossus hippoglossus*
Pelagic	
Atlantic herring	*Clupea harengus*
capelin	*Mallotus villosus*
Atlantic tomcod	*Microgadus tomcod*
Atlantic mackerel	*Scomber scombrus*
tuna	*Thunnus thynnus*
Diadromous	
American salmon	*Salmo salar*
gaspereau	*Alosa pseudoharengus*
American shad	*Alosa sapidissima*
rainbow smelt	*Osmerus mordax*
American eel	*Anguilla rostrata*
Invertebrate	
American lobster	*Homarus americanus*
snow crab	*Chionoecetes opilio*
shrimp	*Pandalus borealis*
blue mussel	*Mytilus edulis*
American oyster	*Crassostrea virginica*
clams	
soft-shelled	*Mya arenaria*
surf	*Spisula solidissima*
scallops	
Atlantic deep sea scallop	*Placopecten magellanicus*
Iceland scallop	*Chlamys islandicus*

Sources: Chadwick and Sinclair 1991; Gagné and Sinclair 1990; Dickie and Trites 1983

Groundfish populations in the Gulf are close to or below record lows. Portions of the cod, redfish and white hake fisheries, since 1995, have been closed to commercial fishing. In general, pelagic fish and invertebrate populations are near or above the long term averages.

This chapter focuses on commercial fish and commercially important crustacean species. We have not attempted, except in a general way, to summarize the voluminous literature on how commercial fishing activities and fishery management practices and policies may have affected fish populations.

Classification of Fish

Fish that spend most of their time at or near the bottom of the water column are called groundfish; those found in the middle of the water column and surface waters are called pelagic fish; and those that spend part of their lives in both fresh water and salt water are called diadromous. This chapter discusses the most important commercial fish species: groundfish species such as cod and redfish; pelagic species such as herring, mackerel and capelin; and crustaceans such as lobster, crab and shrimp. However, the distinction between pelagic and groundfish species sometimes is more a reflection of fishing practices rather than habitat preferences by fish. For example, redfish feed in mid-water (habitat for pelagic fish), where they are mostly caught. On the other hand, herring are often caught on the bottom (the habitat for groundfish).

Aquaculture in the Gulf is thriving and expanding, particularly the oyster and mussel operations of Prince Edward Island. The aquaculture of Atlantic salmon in the Gulf lags behind other Atlantic coastal regions because of extensive local ice coverage and cold surface temperatures in the Gulf. These species are not discussed further in this survey. There is little information on most non-cultured molluscs (clams, scallops, mussels, bay quahog) because they tend to be fished in small quantities by traditional fisheries.

Fisheries Management

Information on commercial fisheries is organized by stocks of a particular species. A stock is a management unit defined by geographical boundaries within which a particular species of fish is caught (Figure 3.1). Ideally a stock is a distinct population but, in practice, it may be a single population, part of a population, or more than one population or species (e.g., redfish). Although cod, herring and mackerel stocks

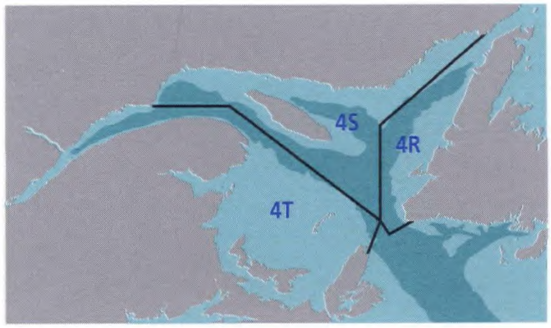

Figure 3.1
Fisheries management divisions of the Gulf of St. Lawrence

Table 3.2 Distribution of commercial fish stocks in the Gulf and Estuary

Species	*Stocks*	*Distribution*
Groundfish		
Atlantic cod	2	northern Gulf southern Gulf
redfish	1	Laurentian Channel
American plaice	1	throughout the Gulf
Greenland halibut (turbot)	1	Estuary and western Gulf
witch flounder	2	southwest coast of Newfoundland, Magdalen Shallows
white hake	1	throughout the Gulf
winter flounder	?	inshore areas
Pelagic Fish		
herring (spring and fall spawning)	6	southern Gulf, western Newfoundland, northeastern Gulf, northwestern Gulf and Estuary
capelin	1	throughout the Gulf but more abundant in western Newfoundland and northeastern Gulf, northwestern Gulf and Estuary
mackerel	1	spawning in Magdalen Shallows and feeding throughout Gulf in summer; part of western Atlantic population
Crustaceans		
lobster	1?	throughout coastal areas of Gulf
snow crab	1?	western and northern Gulf and Estuary
shrimp	1?	northern Gulf

Sources: I. McQuinn, personal communication; DFO 1995, 1994a, 1994b; Savard and Simard 1994; CAFSAC 1993; FRCC 1993; Hare and Dunn 1993; Pezzack 1992; Iles and Sinclair 1982; Carscadden 1981

Notes: For capelin and crustaceans, the stock is composed of many populations probably represent distinct populations, the number of distinct populations for redfish, winter flounder and most crustaceans is unclear (Table 3.2). For example, although three principal aggregations of shrimp are managed in the northern Gulf, they may not represent three distinct populations (Ouellet et al. 1990). Even well defined stocks are sometimes redefined (e.g., southern Gulf cod, redfish) to account for changes in seasonal distribution. For species such as white hake that are continuously distributed, existing management units may not account for all catches (Marine and Anadromous Fish Division 1994).

Since the establishment of the 200-mile fishing zone in 1976, landings (total catch) of commercial fish from the Gulf have represented about 20% of the Atlantic Canadian fishery (Chadwick and Sinclair 1991). Most catches of herring, mackerel, crab and lobster occur in the Magdalen Shallows. Most groundfish, capelin and shrimp landings occur in the Laurentian Channel and the northern Gulf. Until 1993, Atlantic cod dominated the fishery landings in the Gulf. In 1993, redfish catches dominated landings (60%) of groundfish in the Gulf (Marine and Anadromous Fish Division 1994).

In 1995, both the cod and redfish fishery were closed for the entire Gulf (J. Hansen, personal communications). Lobster, shrimp and snow crab fisheries have expanded steadily through the 1980s and provide the greatest economic return and employment in the Gulf (Chouinard and Fréchet 1994).

The Estuary fishery is much smaller and has been studied less. In 1986, the Estuary represented only 0.3% of Atlantic Canada's fishery (Gagné and Sinclair 1990). High value species such as snow crab, shrimp and halibut have contributed a large percentage to the total value of the catch since the mid-1980s (Gagné and Sinclair 1990).

Most research on commercial fish has focused on distributions, migratory patterns and trends in population size. These data are used by fisheries management to develop exploitation policies and strategies. Less attention has been paid to other important aspects of fish biology such as the factors affecting the successful development of larvae into juveniles, survival of juveniles into mature fish (recruitment), species interactions and prey availability.

Distribution And Migration Patterns

The distribution of many fish species is not confined to the stock boundaries but varies seasonally in response to changes in physical and chemical conditions (such as temperature and salinity) and as a result of seasonal habitat requirements such as spawning (the deposit and fertilization of eggs) and feeding. Migratory species make annual movements between spawning grounds and feeding and wintering areas. Fishing for finfish can occur where and when fish congregate for spawning and migration.

Fish Habitat

Spawners of benthic eggs are found where oceanographic factors (such as water currents) and bottom substrates are suitable. Local oceanographic conditions determine whether pelagic eggs and larvae are either retained within an area (e.g., Upper Estuary and Chaleur Bay) or transported towards areas with adequate food for larvae survival (e.g., the Gaspé Current carries larvae to the Magdalen Shallows).

Juvenile habitats are known for only a few species or populations. Inshore areas tend to be important for invertebrate juveniles and some fish species such as herring and capelin. Oceanographic features help retain larvae and juvenile fish and also play an important role in defining juvenile nursery areas in the Gulf. Such features include gyres found in the northwestern Gulf, Chaleur Bay and St. Georges Bay, Nova Scotia (see "Horizontal Circulation", pages 11–12). The northwestern Gulf is a nursery for post-larval and juvenile capelin because larvae drift there from the Estuary and the Gulf north shore. Post-larval and juvenile capelin are also concentrated around the Gaspé Peninsula and near Chaleur Bay in the southern Gulf. Little information is available for the northeastern Gulf.

Fish Migration

Most pelagic species such as herring (Figure 3.2) and mackerel and groundfish species such as cod (Figure 3.3) undertake long annual migrations. These species use the Gulf primarily for feeding and spawning during the warm summer months and migrate out of the region during the winter period of ice cover (Dickie and Trites 1983). Gulf redfish consists of two species that inhabit the Laurentian Channel during warmer months and overwinter either in the Cabot Strait area or in the deeper waters of the Laurentian Channel (Figure 3.4).

Shrimp (Figure 3.5), American plaice, white hake, winter flounder and lobster live in the Gulf year-round (Dickie and Trites 1983). In response to changes in temperature and food supply, these species undertake seasonal migrations within the Gulf, generally to deeper waters (Dickie and Trites 1983; Clay 1991). Adult snow crabs are relatively sedentary, moving no more than 25 km (Figure 3.6).

Among anadromous species, gaspereau migrate into rivers bordering the Gulf in May and June, salmon migrate upriver to spawn in October and November, and smelt migrate into estuaries and bays in late fall and remain until late March.

American eels (*Anguilla rostrata*) are the only catadromous fish in the Gulf; this species lives its adult life in fresh water and spawns in the Sargasso Sea in the mid-Atlantic Ocean—the migratory home for all Northern Hemisphere eels (Jessop 1984). After spawning, they migrate first as larvae and then as juveniles to the coastal rivers of North America. Most juvenile eels entering the St. Lawrence River spend four years migrating to Lake Ontario. Smaller numbers are found in tributary rivers of the St. Lawrence River and coastal rivers of the Gulf. There they spend most of their lives (12–16 years) growing to adulthood before migrating back through the St. Lawrence River, Estuary and Gulf to the Sargasso Sea to spawn. Studies have indicated that the American eel is a single population that interbreeds with individuals along the North American coastal system.

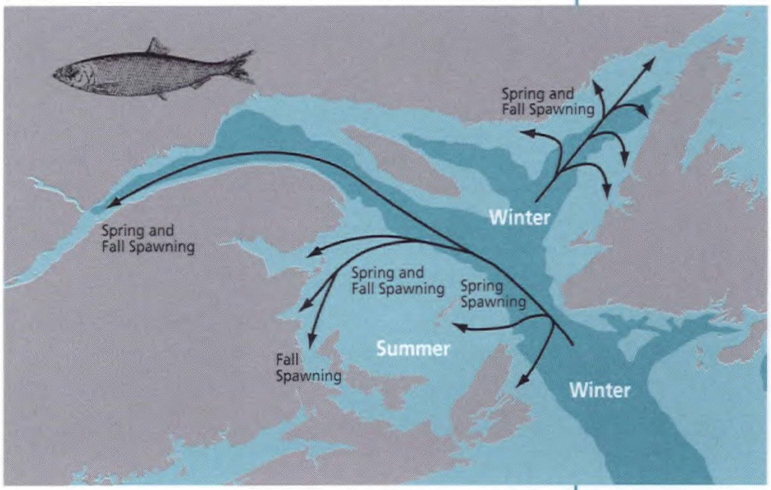

Figure 3.2
Migration routes and spawning areas of Atlantic herring in the Gulf and Estuary
Source: Adapted from Iles and Sinclair 1982; I. McQuinn, personal communication

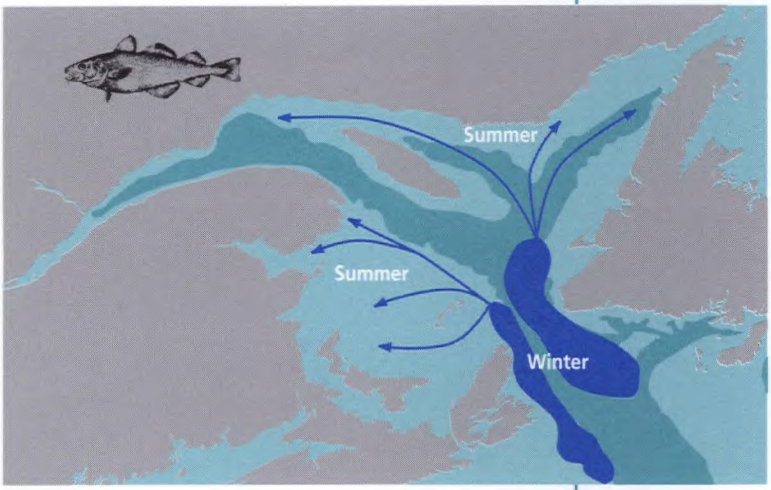

Figure 3.3
Major spring migration routes and winter distribution of Atlantic cod in the Gulf
Source: Lear 1993

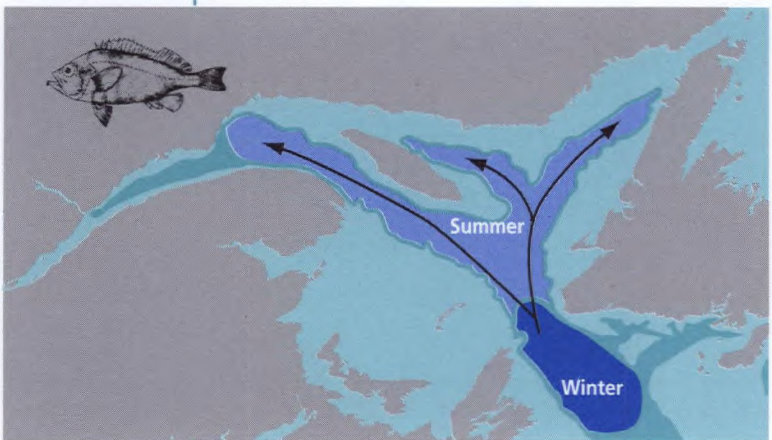

Figure 3.4
Migration and distribution of redfish in the Gulf
Source: Adapted from McKone and LeGrow 1984

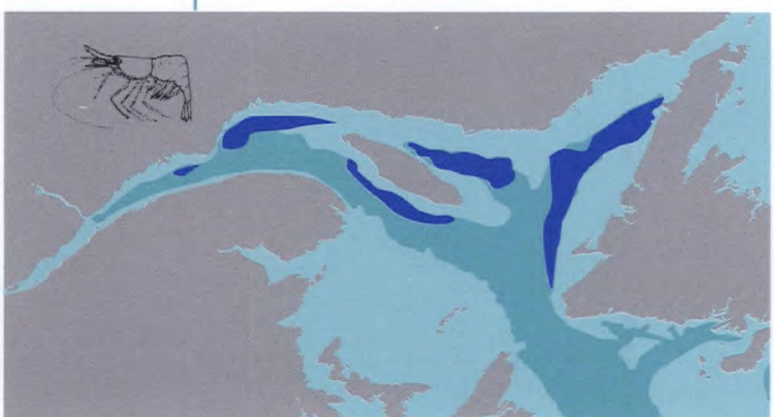

Figure 3.5
Principal areas of northern pink shrimp concentrations in the Gulf and Estuary
Source: CAFSAC 1993

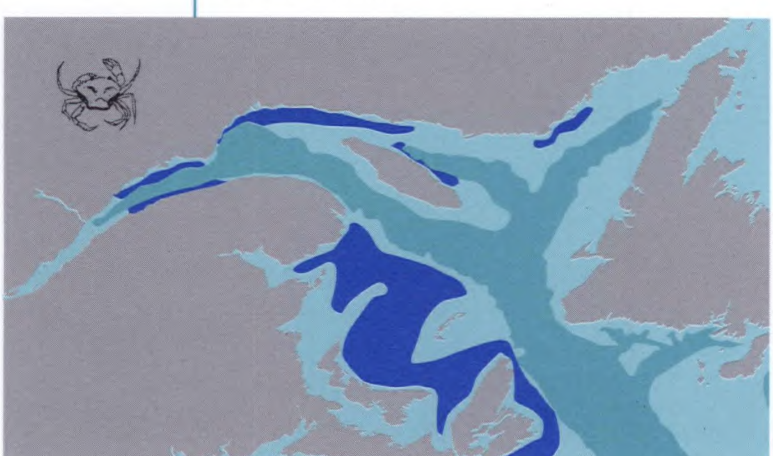

Figure 3.6
Distribution of exploited crab stocks in the Gulf and Estuary
Source: Adapted from Hare and Dunn 1993

Diet

With few exceptions, fish are simultaneously predator and prey (Table 3.3). The few fish that, as adults, are strict herbivores (eating algae) or detritivores (eating dead plant or animal material) tend, as young fish, to prey on invertebrates. Most fish tend to be opportunistic, taking a wide selection of organisms that are usually of a similar size and occupy a similar habitat. It is not uncommon for adults to feed on smaller, early-life stages of their own species (cannibalism). The diet of fish tends to be highly variable and may differ with developmental stage (larva, juvenile, adult), size (Table 3.4) and availability of prey.

Population Trends In Major Commercial Fisheries

Scientists estimate the abundance and productivity of commercial species from statistics gathered from the commercial fisheries, such as landing tonnage, the number of hours or days fished and abundance surveys carried out by government vessels. The catch per unit effort is usually assumed to be proportional to the actual stock size. However, these measures of fish abundance can be biased. For example, "sampling" by fishermen is restricted by season and fishing grounds, and the increasing efficiency of fishing vessels is not considered. Stock assessments are critically dependent upon accurate catch and effort data but since 1985, misreporting, dumping and discarding in groundfish fisheries have often occurred.

Catch rate data do not give a reliable estimate of fish production (Chadwick and Sinclair 1991). Most stock assessment models assume that catchability, the proportion of the population captured per unit effort, remains constant. This assumption frequently does not hold for pelagic fish. Pelagic species typically do not show declining catch rates because their schooling behaviour results in their being found in high densities even when their total abundance is low (Hilborn and

Table 3.3 Predator-prey relationships for adult commercial fish

Commercial Species	*Predator*	*Prey*
Atlantic cod	juvenile: seals young: squid, pollock, cod	capelin, herring, sand lance, flounders, turbot, crabs, shrimp, other invertebrates and shellfish
redfish	cod, turbot, swordfish, seals	capelin, small fish and invertebrates
American plaice	cod, halibut and other large fish	sand dollars, brittle stars, euphausiids, marine worms, capelin, sand lance
herring	cod, tuna, dogfish, sharks, seabirds, seals, whales	euphausiids, copepods, ichthyoplankton
capelin	cod, redfish, plaice, winter flounder, halibut, haddock, herring, salmon, dogfish shark, seals, whales, seabirds	zooplankton
sand lance	cod, salmon, other commercial fish	large copepods, other zooplankton, marine worms, ichthyoplankton
Atlantic salmon	tuna, sharks, swordfish, cod, pollock	herring, capelin, sand lance, mackerel, smelt, shrimp, squid, euphausiids
American eel	migrating adults: beluga, large fish larvae and young: seabirds, haddock	bottom invertebrates, small fishes
lobster	flounder and halibut	shellfish and crustaceans
snow crab	cod, flounder, turbot, dogfish shark	shellfish, worms, invertebrates
shrimp	cod, turbot, dogfish shark, seals	benthic worms and small crustaceans, marine plants, copepods and euphausiids

Sources: Scott and Scott 1988; DFO 1988; Jamieson 1990; Parsons 1984

Walters 1992). Even for groundfish species such as cod, low stock abundance may result in fish concentrating in fewer areas, making them easier to catch (Swain and Wade 1993; Swain et al. 1994). In addition, commercial catches are influenced by the availability of markets for specific fish products and thus landings may be a poor indicator of the abundance of a particular fish species (e.g., capelin, mackerel) when the market demand is low.

Since the early 1970s, catch rate statistics have been supplemented by research programs that independently measure fish abundance. Although these surveys may be limited in space and time compared to sampling by the commercial fleet, research programs produce data without many of the biases inherent in data from the commercial fishery. They also provide data that are otherwise unavailable, such as estimates on the abundance of young fish. These data are used to obtain estimates of the health of the exploited stock: stock abundance, biomass (weight of stock), weight or length at particular ages and recruitment (entrance of young into the fishable population).

Table 3.4 Change in important prey items of southern Gulf cod with age, 1992–1993

Cod Length Classes (cm)	*Prey*
20 to 29	Shrimp
30 to 39	Shrimp, Capelin, Clams, Smelt
40 to 59	Herring, Capelin, Shrimp, Clams
60 to 69	Herring, Capelin
>70	Herring, Cod

Source: Adapted from data in Hansen 1994

Population Trends in Groundfish

Cod

Cod fluctuations in the Gulf stocks have followed those of other northern cod stocks in Atlantic Canadian waters. Gulf cod, particularly the southern stock, showed a period of high abundance in the 1950s and 1960s, a decline to low levels in the mid-1970s, an increase to high levels in the mid-1980s, and then a sharp decline to the lowest levels on record (Figure 3.7). This decline has been attributed to intense fishing pressure and changes in environmental conditions. In the past nine years, the cold intermediate layer where cod are generally found has cooled considerably (see "Stratification", pages 9–10 and "Trends in Water Temperatures", pages 14–15). Although no direct evidence is available, it is assumed that such cooling conditions have created unfavorable environmental conditions for growth and recruitment of young cod.

In recent years, less than 50% of adult cod present at the beginning of the year was alive at the end of the year (FRCC 1993). Thus, commercial catches depend on two or three young age-groups. In a healthy fishery, in which fish may live for up to 20 years, many more age groups contribute to the catch. Under those circumstances, a few years of poor recruitment have much less effect on population size.

The following assessment of Gulf cod stocks has been summarized from Chouinard and Fréchet (1994).

Estimates of the northern cod stock indicate that its population abundance in 1993 was 45% of what it was at the beginning of the 1980s (Figure 3.7) and population biomass was less than 50% of levels in the early 1980s. Of all the Canadian cod stocks, growth decline has been most pronounced in the northern Gulf: the average weight in 1993 of northern Gulf cod at age seven was 60% of that observed in the mid-1970s (Figure 3.8). Overall, the abundance of young fish has been declining since the early 1980s.

Population abundance and biomass of the southern Gulf cod stock in 1993 were at their lowest levels since the early 1980s: at 22% (Figure 3.7) and 29%, respectively. The average weight in 1993 of cod at age seven was 46% of what it was in the mid-1970s (Figure 3.8). In addition, the abundance of young fish has declined continuously since 1980.

Significant changes in the winter distribution of cod stocks in the Gulf have been observed by groundfish surveys and the commercial fishery (D'Amours et al. 1994). Since 1986, northern Gulf cod have been found at deeper depths and mixed with southern Newfoundland cod. They also have extended their migration southward of traditional stock boundaries.

Southern Gulf cod also have extended their migration southward to such an extent that they mix with Scotian Shelf cod on the eastern Scotian Shelf in winter. In addition, spring migration of the southern cod stock into the Gulf was delayed by the late ice melt during the period 1986–90 (Sinclair and Currie 1994). These changes in distribution have resulted in catches or surveys of Gulf cod being erroneously attributed to other stocks. The management units of these stocks may require redefinition (D'Amours et al. 1994; Sinclair and Currie 1994). In 1995, the cod fishery in the Gulf and other Atlantic Canadian marine waters was closed.

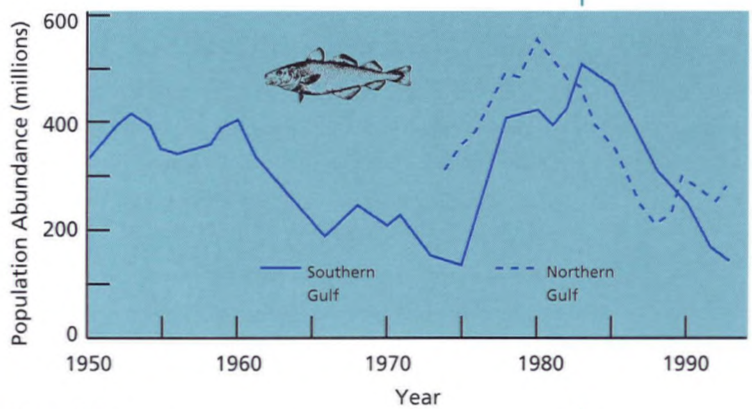

Figure 3.7
Trends in population abundance of northern and southern Gulf cod
Source: Chouinard and Fréchet 1994

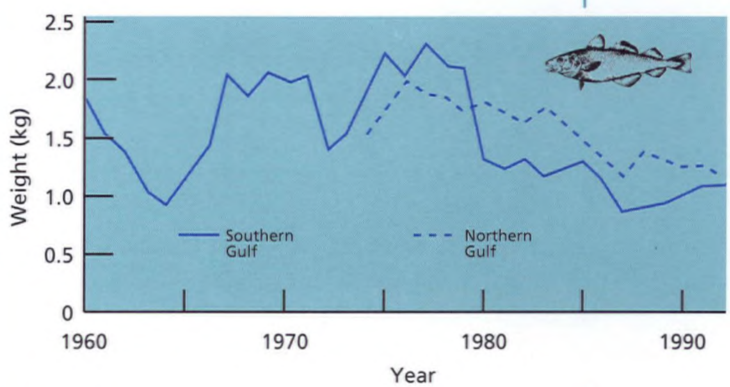

Figure 3.8
Trends in average weight of seven-year-old northern and southern Gulf cod
Source: Chouinard and Fréchet 1994

Redfish

The redfish stock consists of the two species *Sebastes faciatus* and *Sebastes mentella.* Because effective methods of distinguishing between them have only been recently developed, biological differences in distribution and reproduction are beginning to be discovered (Gascon 1994).

The redfish stock appears sporadically in very large year-classes: the late 1950s, early 1970s, 1982 and 1988 (Sinclair 1993). Catches of redfish tend to fluctuate as strong year classes move through the population. Commercial catches in 1993 were dominated by fish born around 1970 and 1980, mainly of the species *Sebastes mentella* (Morin and Bernier 1994).The exploitation rate (28%), an estimate of available animals being harvested, was high for slow growth species such as redfish. Research surveys indicate that biomass declined by 73% overall between 1990 and 1993. The decline was particularly strong in 1993 (FRCC 1993).

Although the growth and condition of redfish have not changed, there has been no significant recruitment to the Gulf redfish population since 1980 (DFO 1995). *Sebastes fasciatus* born in 1985 and 1988 were expected to contribute significantly to the fishery in 1997. For unknown reasons, they appear to have almost completely disappeared (Gascon 1994).

Since 1990, the fall migration out of the Gulf appears to have occurred earlier than usual and redfish seem to be travelling farther. This has lead to difficulties in defining and managing the stock (D'Amours et al. 1994; FRCC 1993). The redfish fishery in the Gulf was closed in 1995.

Population Trends in Pelagic Fish

Herring

In the 1970s, herring stocks in the Gulf underwent a severe decline due to lack of significant recruitment and heavy year-round fishing pressure (Messieh 1991). Spring-spawning herring in the northern Gulf declined further in the 1990s. Reduced stock size has affected the spawning activity, and special measures have been taken to protect the local spawning aggregations in St. George's Bay (Newfoundland) and Port-au-Port areas (DFO 1996a). Fishing mortality is very low for fall-spawning herring, and this stock appears to be in relative good condition.

In the southern Gulf, all indicators show that herring population abundance remained high between 1988 and 1995 and increased sharply from the low biomass levels of the late 1970s and early 1980s. Exploitation levels have generally been below target levels since the mid-1980s (DFO 1996b).

Mackerel

In winter, mackerel congregate on the continental shelf off New England and Nova Scotia. In summer, a major portion of this population moves into the Gulf to spawn, after which they disperse. By the end of their first summer, young mackerel migrate with adults out of the Gulf to overwinter. Over the past 30 years, two year-classes were particularly abundant (1967 and 1982) and resulted in a considerable increase of mackerel biomass (Gregoire and Levesque 1994). After mature fish from the 1982 year-class entered the adult population in 1985, biomass remained high until 1991. The decrease of this particular year-class has resulted in a significantly lower biomass. Since fishing pressure on mackerel is very low, this decline is primarily due to natural variations in recruitment (Gregoire et al. 1994).

Capelin

Capelin in the Gulf have been studied less than those off Newfoundland, where landings are higher and the fishery has a much longer history of exploitation and management. Gulf capelin are not fully exploited, principally because market demand has been poor (DFO 1994b). Fishing effort on capelin has been increasing steadily since 1987, and scientific and management monitoring of the Gulf capelin fishery is increasing in response to this expanding activity. Abundance of capelin tends to vary a great deal because the species' life cycle is short: three to five year-old fish spawn, and most of them die after spawning. Abundance therefore depends on recruitment from one or two year-classes (Carscadden 1981). (See the bullet lists on pages 37, 43 and 59 for concerns about the expanding capelin fishery.)

Population Trends in Crustaceans

Traditionally, abundance of lobster and snow crab populations have been based on commercial landing data but biological factors are coming into use to predict future recruitment. For example, different classes of moult are used to predict the number of catchable snow crab in a similar way as different year classes of fish allow prediction of finfish recruitment. Current population models assume that prerecruits will moult to commercial size in a given year. However, in both snow crab and lobster, moult may sometimes take place over a two-year period. Between 30 and 40% of adult male snow crab never reach commercial size (Gendron 1994).

Lobster

Directly estimating lobster populations is difficult because they have a complex life cycle and they spend much of their lives in burrows in the sea bottom (Pezzack 1992). Lobster populations are estimated by landings, but there are few quantitative data on lobster fishery effort. Fishing effort has increased significantly due to sophisticated navigational equipment, bigger boats and traps, and more trips to sea. Various management methods are used to minimize capture of immature lobster, reduce "ghost fishing" of lost traps, and protect females carrying eggs (M. Mallett, personal communications).

The lobster fishery had above average landings in the 1950s, near-record lows in the 1960s and 1970s and this century's highest landings in the 1980s, peaking in 1990. Landings in the 1990s have declined slightly, about 4–10%, but still remain high in most areas of the Gulf (Gendron et al. 1994; Lanteigne et al. 1994; G. Ennis, personal communication).

Sutcliffe (1973) noted a relationship between periods of high nutrient-rich fresh water runoff from the St. Lawrence River and lobster landings, which he assumed resulted from increased survival of larval lobsters. A subsequent study has shown that storm surges in the Gulf may also affect the distribution and age of recruitment (Drinkwater et al. 1990). Because neither runoff nor storm surges can fully explain the increase in lobster biomass in the 1980s, Drinkwater et al. (1990) suggested that the increase in lobster populations in eastern North America may be due to larger-scale environmental or ecosystem change.

Snow Crab

The Gulf snow crab fishery began in the 1960s, and by 1988 it appeared to be on the threshold of total collapse (Hare and Dunn 1993). This lucrative fishery developed, expanded and declined without effective monitoring or control over the fishing fleet. There is insufficient knowledge of snow crab biology and the effect of fishing pressures. The scientific consensus in 1994 was that the fishery depends on annual recruitment. Intense fishing pressure results in the disappearance of larger and older males that have reached their terminal moult; as a result, fishing pressure increases on smaller and younger moulting crabs. The snow crab population is experiencing some fertility problems among large adult females, apparently because fishing pressure has resulted in fewer large males being available for mating (Saint-Marie and Dufour 1994).

The stock is beginning to recover, possibly because actions are being implemented that lower crab catches and close subareas when more than 20% of catch is soft-shelled crabs. Although the life cycle of the snow crab is complex, scientific knowledge of its life history is beginning to be used to predict abundance. Landings in 1993–1994 were high but they are expected to decline until the 1998–99 recruits enter the fishery (M. Mallett, personal communication).

Shrimp

Commercial harvesting of northern shrimp began in 1965 near Sept-Îles in the northern Gulf. Landings steadily increased, peaking in the early 1990s (Chiasson et al. 1992). Recent data indicate a reduction in landings over the entire Gulf; catches in 1992 declined 9–34% from 1991 levels. Shrimp biomass will remain stable or possibly increase in the short term (DFO, 1995). Management of the shrimp fishery is more difficult than for crab and lobster because shrimp change sex from male to female as they get older; males are thus smaller and younger whereas females are larger and older. Females (usually with eggs) are the fishery's principal target (Savard and Simard 1994), comprising more than 90% of the catch in April and 55% for the rest of the season. Most fishing occurs in spring when females gather in areas to release their larvae. A correlation between the quantity of reproducing females and the number of recruits has not been established (Savard and Simard 1994). However, as a precaution, fishermen have suggested changing the spring date of the fishery opening to reduce exploitation of egg-bearing females.

Influences On Population Trends In Major Commercial Fisheries

The debate over whether environmental factors or fishing pressure are responsible for the collapse of fisheries started in the 1940s. Exploited fish populations generally have collapsed when both high fishing effort and changes in the marine environment were occurring simultaneously, effectively preventing the identification of either factor as being the principal cause of the collapse. The debate cannot be resolved without an understanding of the factors that influence recruitment (the age or size at which a fish enters the adult fishable population). Prediction of changes in recruitment is probably one of the most long-standing problems in fisheries research (Sinclair 1988). Early life stages of fish determine recruitment. Thus, a better understanding of the ecology and dynamics of early—especially juvenile—stages is necessary for assessing, managing and protecting fish resources (de Lafontaine 1992).

Scientists have different views on the relationship between the abundance of adult spawning fish (biomass) and recruitment. The absence of any apparent correlation between these two variables complicates resolving the issue. Frequently, high recruitment occurs from a relatively small spawning biomass and *vice versa*. The search has been unsuccessful in finding a way to use abundance of fish eggs or larvae to estimate recruits into the fishery. Current research focuses on predicting adult stocks by studying the abundance, distribution and mortality of juvenile fish populations.

Fecundity—the total number of eggs laid—depends on the age, size, energy stores, spawn timing and habitat of adult fish, which are often interrelated and can all be affected by heavy fishing pressure. Changes in salinity, temperature and oxygen can also affect the growth, condition and distribution of adult fish and, thereby, fecundity.

Egg, larval and juvenile survival tend to be affected primarily by environmental (e.g., temperature and salinity) and biological factors such as nutrition, growth, and predation. Qualitative evidence of fish predation on juveniles exists but its impact on recruitment variability is not known (de Lafontaine 1992). Cannibalism is potentially the most powerful mechanism for regulating recruitment but it rarely has been quantified. Information regarding other factors—increased predation, competition among fish species and disease—is limited (FRCC 1993).

An additional complication is the observation that many fish populations show compensatory changes in production such as increased fecundity, maturation, individual growth and survival rates when the density of fish populations is reduced (Rosenburg et al. 1993). Fishing not only reduces the abundance of fish but also removes the large older fish. To compensate, younger fish may grow to sexual maturity faster. Overfishing reduces the size of the sexually mature population to the point where it may be too small to replace numerical losses. Stocks of relatively small, young fish—which are less fecund—may be more vulnerable to the negative effects of climatic changes on recruitment and hence, they may be more susceptible to collapse.

Influence of Environmental Factors on Population Trends

Relationships between environmental factors and long-term trends in fish stocks are not well understood. Despite compelling indications that some environmental conditions have a detrimental impact on fish stocks, these effects are unclear and have not been quantified. Recent short-term trends in environmental conditions (see "Climate Trends", pages 14–15) may have affected Gulf fish populations in the following ways:

- Altered distribution and migration patterns—increase in winter ice coverage, colder bottom temperatures and low salinity may have caused adult cod and redfish to move into deeper, warmer and more saline waters during winter (D'Amours 1993; Chouinard and Swain 1994).

- Reduced growth and food availability—colder temperatures can affect fish physiology, resulting in changes in food availability and slower growth rates (Lambert et al. 1994); the latter may explain the lower mean weight-at-age observed in cod stocks in the Gulf and other areas in Atlantic Canada (FRCC 1993).

- Decreased survival of young fish—lower water temperatures and greater ice extent in surface waters can decrease survival of cod eggs and larvae (Chouinard and Fréchet 1994); higher than average water temperatures are associated with decreased survival of mackerel larvae in the southern Gulf (Ware and Lambert 1985).

Influence of Commercial Fishing on Population Trends

Fisheries management tends to focus its efforts on fish abundance, but fishing may also have other profound effects on fished populations:

- Habitat destruction by certain fishing technology such as bottom trawls or draggers (Messieh and El-Sabh 1988)—trawling can stir bottom sediments, killing benthic species that are the food sources for bottom feeders. High amounts of suspended sediment can affect benthic egg and larval survival (Appleby and Scarratt 1989). Trawling can also alter the substrate sufficiently to make it unsuitable for certain benthic organisms (e.g., Caddy 1973) or cause changes in benthic species dominance and reduce their economic importance (e.g., worms may take over from bivalves) (Messieh et al. 1991). The effect of such influences on exploited fish populations has yet to be determined. Disruption of bottom sediments may increase predation by exposing benthic organisms. For example, predatory fish and crabs in the Northumberland Strait were attracted to scallop dredge tracks—within one hour—in densities 3 to 30 times greater than that observed outside the tracks (Caddy 1968).

- Disruption of the food web or species interactions—harvesting or over-exploitation of species that are important food sources for other commercial stocks may affect recruitment. Both fishermen and scientists have expressed concern that expansion of the capelin fishery in the Gulf may detrimentally affect cod recovery by removing an important food source for cod. Abundance of some species appears to be inversely related: when one species is abundant, the other species is scarce, as has been observed for herring and mackerel (Skud 1982) and cod and flatfish (Sinclair 1993). Although these relationships may follow natural cycles, overfishing of one species may affect its abundance and, hence, dominance over other species. The overfished species may not be able to recover.

- Mortality of non-target and target species—Caddy (1973) observed that scallop dredging in Chaleur Bay caused mortality of about the same amount of scallops as were caught, particularly on rough bottoms. In the Northumberland Strait, Caddy (1968) found that approximately 30% of scallops in the drag track were partially buried, and both shell damage and tissue damage occurred in scallops not retrieved by the dredge. Overfishing and discarding of undersized cod in the late 1980s and early 1990s could have depleted above-average year-classes that might otherwise had been able to support a commercial fishery in 1993-94 (Sinclair et al. 1995). When fish of a species other than that which is the target species is caught, these non-target fish are referred to as by-catch. Until recently, there was no monitoring of by-catch unless it was of commercial value.

- Changes in growth rate of exploited fish—there is evidence that selective fishing mortality of fast-growing cod in the southern Gulf has resulted in the population being dominated by slow-growing fish in recent years (Hansen and Chouinard 1992).

- Changes in the genetic composition of fished populations—there is a possibility that the fishery may be altering the genetic composition of lobsters in the southern Gulf by selectively removing larger lobsters (Harding et al. 1993).

More efficient fishing gear has made it possible to catch a significant portion of fish populations, which has heightened the debate about the influence of fishing on fish abundance (Sinclair 1993; FRCC 1993). Fishing mortality has exceeded target quotas since 1987 in the Gulf. Although management strategies to control catches were introduced to decrease fishing mortality as stocks were declining, they were not successful.

Reduced fishing effort is needed, particularly in fisheries with severe overcapacity problems such as those of Atlantic Canada (Sinclair 1993; FRCC 1993). Most participants in the Atlantic Canadian fishery agree that overcapacity in the harvesting (number of boats, number of fishermen and technological developments) and fish processing sectors has overwhelmed efforts to manage stocks at sustainable levels. Technological developments alone have resulted in dramatic increases in catching capacity: increased number of gill nets, use of acoustical detection devices, enhanced ability to detect sea bottom habitats, mid-water trawls (in the redfish fishery), and new high-powered vessels in the inshore otter trawl fleet.

Most fishery collapses have been associated with an inability to reduce fishing pressure, even when the biological need was obvious (Hilborn and Walters 1992). This failure to reduce fishing pressure most often resulted from the fishing industry fearing that there would be a short-term loss of income. Fluctuations in fish abundance and, therefore, in catches are natural phenomena that cannot be eliminated (Rivard and McGuire 1993). If groundfish stocks are to recover, a dramatic reduction in fishing capacity must occur, and any changes in the biological indicators of fish population health ideally should be responded to by rapid changes in policies by fisheries managers and fishing practices by the commercial fishery (FRCC 1993; Hilborn and Walters 1992).

Overfishing and unfavourable environmental conditions for growth and recruitment may be significant factors causing the decline in many Gulf stocks. The result of this decline has been the closure of many commercial fisheries and a reduction in quotas for other fish stocks within the region (DFO 1995).

Uncertainties

In the past, fisheries management often neglected issues related to fish biology. The establishment of a sustainable fishery in the future will depend on resolving certain important biological issues related to recruitment:

- identifying the crucial stages in the development of young fish, particularly the role of environmental factors and those factors that affect the fecundity of adult fish;

- determining the dominant predators of juvenile fish; and

- identifying the seasonal habitat preferences of juvenile fish.

Another important issue is more far reaching: understanding the inherent, cyclic variability of fish populations so that such knowledge can be incorporated into fisheries management.

Chapter 4

Occurrence of Chemicals

Chapter 4 **Occurrence of Chemicals**

Discussion Boxes

Tables

Figures

BOTH NATURAL AND INDUSTRIAL sources contribute to the presence of chemicals in the waters, sediments and biota of the St. Lawrence Estuary and Gulf. Generally, chemicals tend to accumulate in coastal areas close to their point of discharge but long range transport by winds and ocean currents results in the widespread, sometimes global, distribution of organochlorines and toxic metals. Over the past two decades many chemicals (e.g., mercury, PCBs and DDT) have been decreasing in the environment and biota as a result of regulatory controls on local sources. Atmospheric transport is becoming the dominant mechanism by which some chemicals are entering the Gulf and Estuary.

Overview

Chemicals are categorized as either inorganic or organic. The presence of inorganic chemicals, such as metals, generally has a natural origin but industrial activities may locally increase their concentrations to high levels. Organic chemicals come from the decay of organic matter or may be wholly man-made such as polychlorinated biphenyls (PCBs). Other organic chemicals, such as oil and polycyclic aromatic hydrocarbons (PAHs), are present naturally in the environment but their distribution has been altered by human activities.

Before discussing the presence of chemicals in the marine environment of the Gulf and Estuary, it is necessary to have some understanding of the main sources and processes that govern chemical behaviour in the marine environment. Figure 4.1 and Box 4.1 briefly describe the processes discussed in the next two subsections.

Natural Sources of Chemicals

Irrespective of whether the source of chemicals is natural or man-made, they are either in dissolved form or they adhere to solid particles, such as dust, rock fragments, plant or animal material. Sources of particulate matter in water include biological processes (e.g., decay of dead organisms and waste products from organisms), erosion of land surfaces (weathering) and deposition from the atmosphere.

In most locations on Earth, weathering of rocks is the main process that yields inorganic particulate material, which is carried into the marine environment by rivers and winds. Many of the features of marine waters and sediments derive from natural weathering processes. For example, sediment near the southwestern part of Newfoundland contains high concentrations of nickel, chromium and vanadium, related to weathering of ultra-basic rock in that area

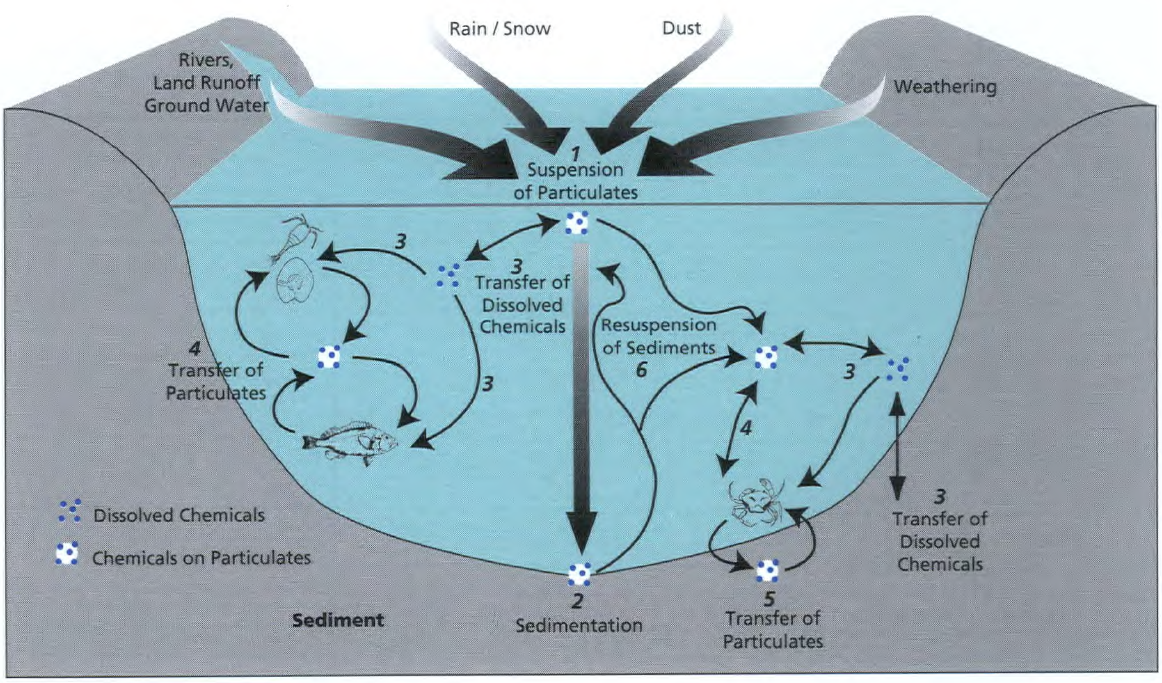

Figure 4.1
Particulate and chemical processes in the marine environment
See Box 4.1 for a detailed explanation

Box 4.1: Particulate and Chemical Processes in the Marine Environment

Figure 4.1 shows particulate matter entering the marine environment by land runoff, groundwater flow, inputs from rivers, weathering of rocks and atmospheric deposition of dust and precipitation (1). The surface of particulate matter can bind both organic and inorganic chemicals, and the particles can immediately settle to the bottom (2). But chemical processes can dissolve inorganic chemicals into the waters (3) before the particles settle to the bottom. (Organic chemicals generally do not readily dissolve but remain on the particles.) Biota in the water column can take in both dissolved chemicals and particles and release them by decay or excretion (4). Benthic animals will also take up particulate matter directly from sediment (5). Sediment is often resuspended (6) by biota or, in shallow waters, by propeller wash from passing ships and by tides and storms. Once resuspended, the cycle of settling and uptake recommences.

(Loring 1988). For inorganic chemicals in the environment, it is often difficult to clearly distinguish the proportions due to human activity and those due to natural weathering.

Natural Processes Influencing the Distribution, Transport and Fate of Chemicals

Distribution

The large drainage basin of the Estuary and Gulf (Figure 1.1 in Chapter 1) provides an enormous volume of particulate material. However, the supply of this material is substantially reduced by processes occurring in the Great Lakes, which trap particles and their adsorbed chemicals. This results in a relatively low ratio of suspended particulate matter (or SPM, the term used by chemists to refer to particulate matter in water) to the volume flow for the St. Lawrence, compared to other major rivers in the world (Figure 4.2).

Modern (post-glacial) sediments are primarily formed by the deposition of suspended particulate matter from the overlying water. Biota can incorporate chemicals directly from solution, contaminated particulate matter, the surface layer of sediments, and contaminated tissue of other organisms.

Transfer of chemicals among the four environmental compartments—water, suspended particulate matter, sediments and biota—depends on many different chemical and biological processes. These processes are a very active area of research. Usually, inorganic chemicals are found both on particles and dissolved in water. Organic chemicals are primarily found adsorbed onto particulate matter. The distribution of a particular chemical among these compartments depends on the following general properties:

- the specific chemical properties determine in which part of the environment it accumulates (e.g., the chemical's relative solubility in water);
- pH of water, size of the particulate matter and habitat of an organism; and
- the specific physiological processes of particular living organisms, which determine the ease of uptake of a chemical and how rapidly it is excreted or metabolized.

The mixing of saline and fresh water in an estuarine environment adds another level of complexity to the chemical transformations that substances undergo. Whether a chemical is predominately dissolved in water or bound to particulate matter can be influenced by the salinity of the water, which can vary by location and season.

Transport

Particulate matter is carried both vertically and horizontally in waters by prevailing currents, gyres and tidal action. In the Gulf and Estuary, dominant water circulation patterns determine whether chemicals are transported out to other areas or are retained. Gyres (e.g., northwestern Gulf) and estuarine flow (e.g., the full length of the Laurentian Channel) tend to retain water and cause eventual settling of particulate matter into the sediments. Extreme tidal forces (e.g., Upper Estuary) and upwelling due to topography (e.g., heads of the Laurentian, Anticosti and Esquiman channels) tend to move particles vertically within the water. Persistent water currents (Gaspé Current), general circulation patterns in the Gulf, strong bottom currents (Upper Estuary) and water exchange (through the Cabot Strait) move particles over large distances.

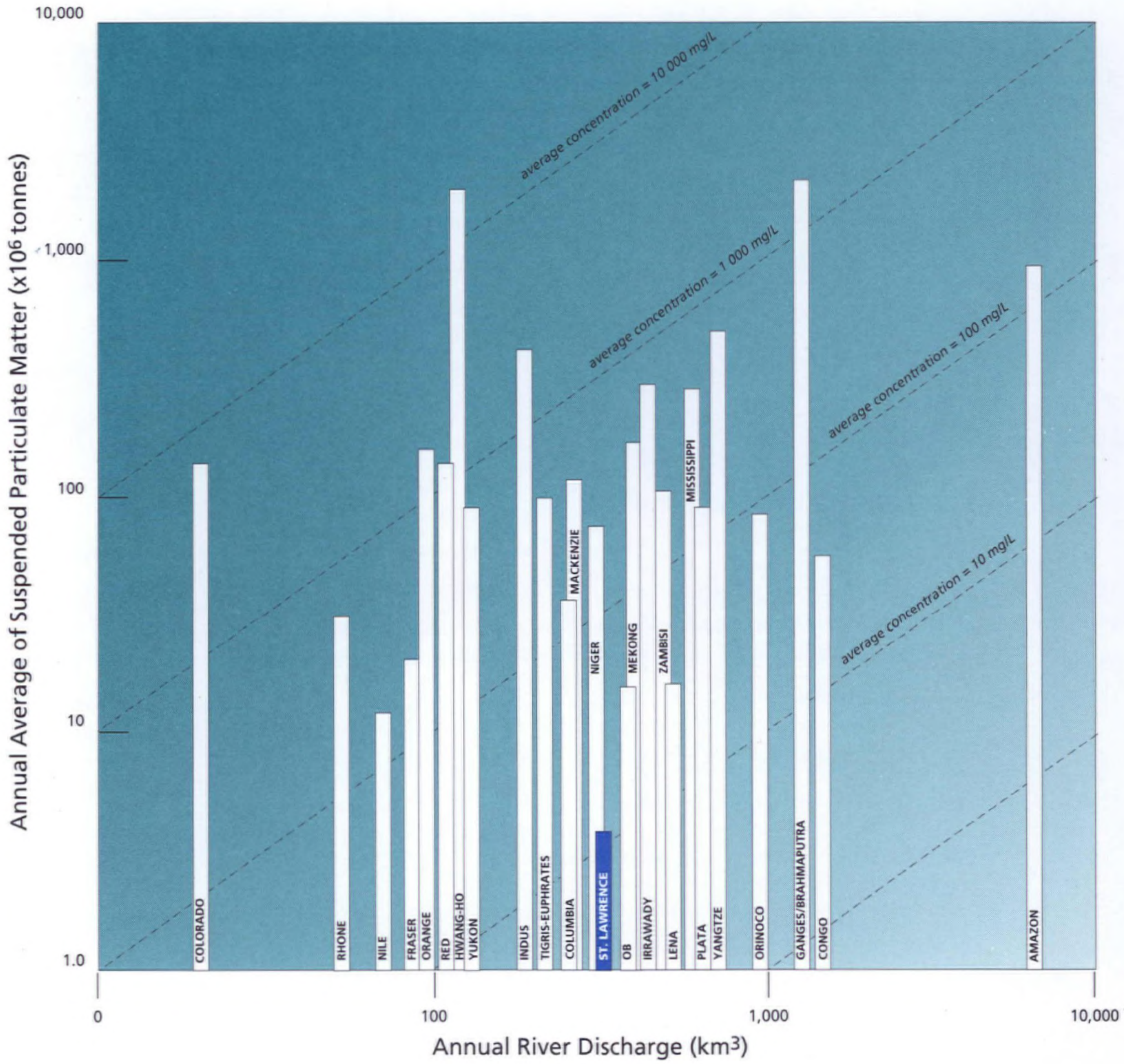

Figure 4.2
Particulate matter concentrations in selected rivers
Source: Milliman and Meade 1983

Note: The St. Lawrence River has one of the lowest concentrations of particulate matter in the world, for a river with a large discharge volume. One would expect the St. Lawrence to have about ten times the suspended matter that it does.

Fate

Regardless of whether chemicals enter the marine environment in dissolved or particulate form, they eventually become part of the bottom sediments or are incorporated into biological organisms (Figure 4.1). Most chemical contaminants of biological concern, such as metals and organic compounds, are associated primarily with particulate matter. Thus, transfer of contaminants to marine biota and humans and the disturbance of ecological systems also depends on the availability and persistence of contaminants within sediments and transport by benthic organisms and oceanographic processes.

The distribution of naturally occurring chemicals is related to the grain size of the sediments, with the highest concentrations found in muds, silts and clays (Loring 1988), whether their origin is from weathering or human activities. Generally, coarse sediments (gravel and sand) occur where there are strong bottom currents and turbulence that carry away smaller particles. Muds originate from the settling of fine particulate matter (the size of silt and clay) in areas where the bottom currents are weak.

Natural Regime Of Suspended Particulate Matter And Sediments

Estuary

Up to 60% of the organic particulate matter in the Estuary comes from land runoff into rivers, streams and groundwater. The remaining 40% comes from within the marine environment (Gearing and Pocklington 1990).

Upper Estuary

The most dominant feature of the Upper Estuary, as in most estuaries, is the presence of the maximum turbidity zone (MTZ). The surface flow tends to carry particles downstream, but if a particle is large enough, it will descend to the bottom layer of water where the flow is upstream. Thus, the particle returns upstream and, if it is small enough, is upwelled by tidal action back to the surface. The MTZ is that region where SPM

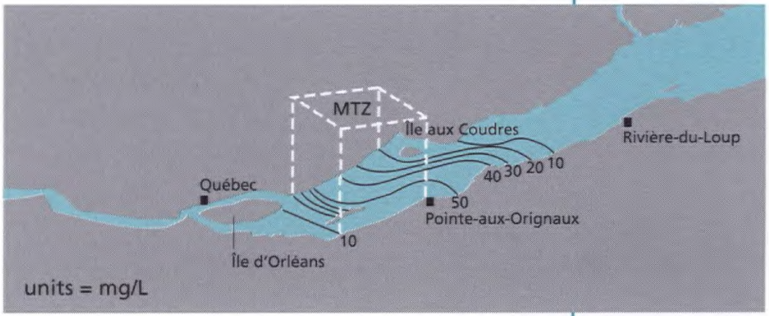

Figure 4.3
Particulate matter concentrations in the MTZ, 1975
Source: Adapted from Kranck 1978

concentrations exceed 20 mg/L (d'Anglejan 1990). Concentrations generally range from 20–200 mg/L but peak values can exceed 400 mg/L (d'Anglejan 1990).

Figure 4.3 depicts the distribution of SPM in the MTZ immediately after the spring runoff in June 1975 when the SPM concentrations exceeded 20 mg/L well beyond the geographic borders of the MTZ, thus indicating the large variability in the system. The high SPM values are due to three causes: 1) the strong turbulence keeps smaller particles in suspension, 2) the strong turbulence acts to resuspend silts and clays back into the water column, and 3) the strong flood tide brings more particles from downstream than the weak ebb tide can carry particles away (d'Anglejan 1990).

Lower Estuary

Particle distribution and transport in the Lower Estuary are controlled by fresh water flow, biological production and, in the summer, the three-layer vertical structure of the water column (see "Stratification", pages 9–10). Concentrations of particulate matter generally tend to decrease as depth increases. Higher concentrations near the bottom are due to the resuspension of bottom sedimentary material. High surface concentrations occur with the low salinity water that flows seaward (Yeats 1988a).

The Lower Estuary is a region of net sedimentation; annual deposition rates are between 1.5 mm/y near the Gulf and 4 mm/y at the west end of the Laurentian Channel. Of the estimated 3.6 million t/y of particulate matter that enters the Estuary, a significant fraction accumulates in the sediments of the Lower Estuary. The accumulation of sediment in the Lower Estuary is high because there is a net landward water flow along the bottom (d'Anglejan 1990). Much of the organic material derived from the St. Lawrence River is adsorbed onto SPM that settles out within the Estuary.

The sediments of the Laurentian Channel in the Lower Estuary contain primarily minerals from the Canadian Shield. The sediments can be up to 60 m deep in the southern section of the channel (d'Anglejan 1990).

Gulf

High values of SPM at the surface are related to the net flow of low salinity waters from the Estuary. The high values at the bottom come from the erosion of adjacent shelves and coastlines. SPM entering the Gulf from the Estuary is predominantly inorganic; over 90% settles onto the sediments, providing 6.2 million tonnes of new sedimentary material annually (Yeats 1988a).

A budget calculation for SPM in the Gulf (Yeats 1988a) shows that the SPM from the Estuary is more than 90% inorganic but the SPM that exits through the Cabot Strait is two-thirds organic. Thus the organic SPM in the Gulf originates there, and internal resuspension and redeposition of particulate matter account for about 40% of the total Gulf sedimentation (Strain 1988).

Anthropogenic Sources of Chemicals

Atmosphere

The atmosphere is a principal pathway for the transport of various relatively volatile anthropogenic chemicals. This is particularly important for Atlantic Canada, which is in the downwind path of most weather patterns that first pass through industrialized regions of North America. There, they pick up chemicals, some of which fall out in eastern Canada (Eaton et al. 1994).

There is ample evidence that, for a number of chemicals, atmospheric transport into the oceans from distant sources is a major contributor: lead may enter the ocean from the atmosphere at about forty times the rate from natural sources. Atmospheric deposition of mercury and cadmium is probably equal to inputs of their dissolved forms from rivers (Brandon and Yeats 1984). Preston (1992) estimated that atmospheric deposition contributed 80% of the total PCBs into the world oceans. He also concluded that, even in nearshore regions, regional and local atmospheric transport of contaminated particles is of considerable importance. For regional seas, riverine input can approach atmospheric input for PCBs and exceed atmospheric input for many metals (GESAMP 1989a).

Use of DDT has been banned in North America since the early 1980s, however, current inputs of DDT by long range transport are believed to result from its continued use in Central America and Mexico (Rapaport et al. 1985). The transport is facilitated by anticyclonic airflow that sweeps the eastern seaboard of North America. Current inputs of new DDT are 0.2 to 1.1 $\mu g/m^2$ per year. Preston (1992) cited several reasons for the scarcity of data for atmospheric input:

- difficulty in carrying out ship-based measurements,
- difficulty in interpreting sporadic sampling, and
- little understanding of the dynamics of air-sea exchange.

Land Runoff

The drainage basin of the St. Lawrence River and Estuary contains a large amount of agricultural land. Land runoff from these areas contributes additional nutrients, mainly phosphate and nitrate, as well as pesticides and herbicides (Wells and Rolston 1991). However, it is difficult to identify and quantify accurately releases of a particular pesticide or herbicide into the environment: these substances may react as they enter waters in association with other agricultural wastes (organic and inorganic nutrients, animal waste, fertilizer and wastewater). Their chemical form may therefore change, making them harder to trace to a specific source.

Industry

Industry produces a large number of marketable chemicals and, inevitably, a large quantity of by-products enter the environment as solid, gaseous or liquid effluents. These include metals (such as lead and cadmium) and organic chemicals (e.g., PCBs and PAHs).

The Gulf's drainage basin contains 50–100 pulp and paper mills (Pocklington 1988). Organic matter from the discharge or dumping of mill wastes has a significant impact on the water and sediment quality of the receiving environment, primarily by oxygen depletion (Eastern Designers Ltd. 1986). Also, the substantial quantities of particulate material discharged can blanket sediments locally. Such effects are largely confined to the immediate vicinity of the discharge and do not cause large-scale effects in other areas of the Gulf.

Figure 4.4 depicts 17 priority industrial sites near the Estuary (Bouchard and Gingras 1992). Figure 4.5 shows industrial contaminant sources that surround the Gulf (Eaton et al. 1994).

The St. Lawrence-Great Lakes system is an international shipping route that averages 1 000 vessel movements per year. Hazardous materials and petroleum products constitute almost 20% of the total volume of merchandise handled in the ports of the St. Lawrence (Environment Canada 1991). The potential for accidental release and operational discharge associated with emptying of ballast and vessel maintenance from such traffic is an ongoing concern. Fortunately only one significant spill has occurred since 1978 in the Estuary or Gulf, when 200 tonnes of bunker "C" oil spilled near Matane (in the Lower Estuary) in 1980. However, see Box 4.2 for the *Irving Whale* situation.

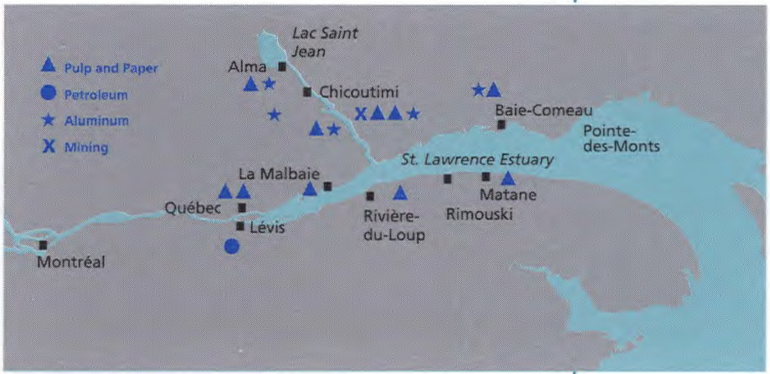

Figure 4.4
Major industrial sites in the Estuary
Source: Modified from Bouchard and Gingras 1992

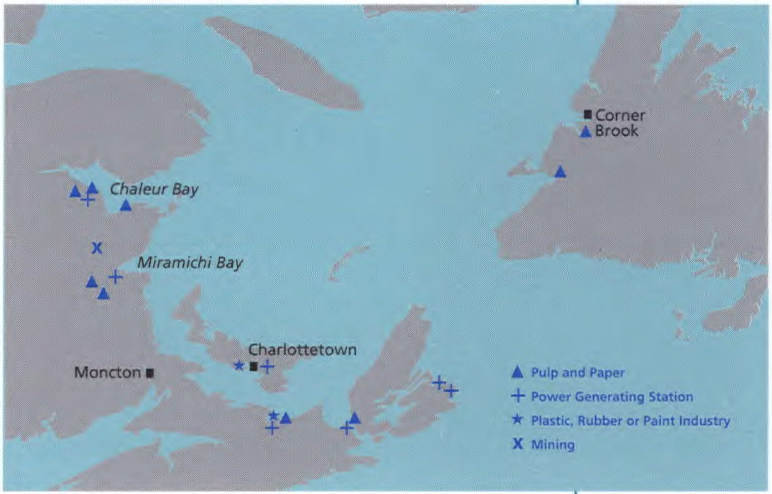

Figure 4.5
Industrial sites surrounding the Gulf
Source: Adapted from Eaton et al. 1994

Dredging and Ocean Dumping

Harbours and shipping lanes are dredged to increase the depth and width of navigation channels. Dredging sometimes remobilizes chemicals trapped in the sediments. Dredging can affect the stability of the seabed and cause siltation problems, particularly in shallow areas.

For example, in 1983 when a navigational channel was dredged in the Miramichi Bay in the Gulf, millions of tonnes of dredge spoil became concentrated in one area of the Bay (Kranck and Milligan 1989; Messieh and El-Sabh 1981, 1988). Subsequent study found the area had unstable bottom sediments that became resuspended by waves and currents and

Box 4.2: The Sinking of the *Irving Whale*

In 1970, the oil barge *Irving Whale* sank in 67-m deep water 60 km northeast of the northern tip of Prince Edward Island in the Gulf of St. Lawrence. It contained 4200 tonnes of Bunker "C" oil in its storage tanks and 6800 litres of PCBs (Aroclor 1242) in its closed-loop heating system. The heating system also contained about 1360 litres of chlorobenzene.

Since the time of its sinking, it has leaked about 1100 tonnes of Bunker "C" oil—some of it during the first two days when nearby coastlines and birds were soiled and some of it sporadically over the following 26 years. PCBs were also released from the barge with the initial oil spill that followed sinking in 1970. Recent anaylses of archived oil samples and sand-oil samples collected from burial sites on beaches of the Magdalene Islands revealed concentrations of PCBs of 127.2 and 32.3 µg/g in oil and sand-oil, respectively (Gilbert and Walsh 1996). Site samples before the barge was lifted indicate that bottom sediments contained Aroclor 1242 at concentrations greater than background up to a distance of 5 km from the barge. Contamination of snow crabs, shrimp and sculpins appears to have been limited to the area within 2 km of the barge (Gilbert and Walsh 1996).

The Irving Whale barge was brought to surface and recovered on July 30, 1996. However, only 1600 kg (21%) of the initial amount of PCBs contained in the barge were recovered and destroyed during the salvaging operation (M. Gilbert and G. Walsh, personal communication). Intensive investigations are underway to determine the location of the PCBs in the marine environment and determine what threat, if any, they pose to the food web of the southern Gulf.

Source: Department of Fisheries and Oceans and Environment Canada 1996

showed a complete absence of benthic organisms (Kranck and Milligan 1989).

Studies in other Canadian waters clearly demonstrate that dredging has numerous short-term effects on both the seabed and benthic organisms (Messieh et al. 1991). Study of long-term negative impacts has been hampered by the lack of historical data on benthic communities. The most important effect of dredging is the resuspension of sediments into the water column. This decreases phytoplankton production, affects the survival of egg and larval stages of fish species, impairs feeding and respiration of adult fish and smothers benthic organisms (Messieh et al. 1991).

Channel dredging and ocean dumping can also produce long-term negative effects through increased coastal wave action, erosion and permanent alterations to seabed topography. These activities may result in the loss of spawning areas, making them uninhabitable for benthic organisms (including commercially important groundfish and crustaceans).

Cities and Towns

The Québec portion of the St. Lawrence River's discharge basin is inhabited by 6 million people, but only 8% of their municipal waste discharge undergoes any kind of treatment (Harding 1992). The detrimental effects of such discharge are usually restricted to nearshore areas. There are three concerns associated with the discharge of untreated sewage into coastal regions (Harding 1992):

- Oxygen is removed from the waters and, in extreme cases, can render the waters unsuitable for marine life.
- Often industries co-discharge waste with municipal waste, creating complex compounds that further stress the ecosystem.
- Human pathogens (bacteria, viruses, fungi and parasites) enter marine waters. Their presence is a common cause for closing shellfish beds to harvesting.

Urban areas also have major concentrations of vehicular exhausts. Globally, exhaust is one of the most important contributors to PAHs and metals entering the atmosphere. For example, as a global average, 75% of all lead originates from automotive sources (GESAMP 1989a).

Chemicals In The Environment

Field investigations of contaminant levels in the marine environment of the Estuary and Gulf began in the early 1970s. Because measurement techniques have improved so markedly since then, apparent trends over time in chemical levels in the environment sometimes are the result of changing analytical techniques more than changing environmental conditions. In fact, GESAMP (1989b) recommends improving and calibrating the methods of detecting chemicals. They note the internationally recognized need for standardization of methods, coordination and intercomparison of data interpretation, improved sampling techniques and better data analysis.

Also, estimating temporal trends of contamination through examining sediments is difficult in areas of low sedimentation or where bottom dwelling organisms mix surface sediment layers (bioturbation). Areas for which long term temporal trends exist are the Saguenay Fjord and regions of the Laurentian Channel.

Throughout the remainder of this section, wherever possible, we have relied upon reviews and their interpretation of existing data rather than on primary literature. We have made extensive use of collections of reviews in El-Sabh and Silverberg (1990) and Strain (1988). We review here a selection of potential contaminants for which information is available and concern exists.

Table 4.1 describes the measurement units that are used throughout the following sections.

Metals in the Environment

Concentrations of most metals (both dissolved and particulate) in the water column of the St. Lawrence River decline seaward due to dilution, sedimentation and incorporation into biota. Overall, studies of metals in the waters of the Gulf and Estuary reveal little that is abnormal about either their concentrations or distributions except in areas close to major sources, as in the case of mercury in the Saguenay Fjord and cadmium in Belledune Harbour near Bathurst, New Brunswick. Lead contamination decreased between 1970 and 1990, primarily because use of leaded gasoline has decreased. Zinc levels are much less significant, while distributions and concentrations of copper are not influenced by human activities (Cossa 1990). The levels and seasonal variability of metals in the St. Lawrence River are relatively low compared to other rivers of similar size and industrialization (Yeats 1990). The main reason for this is the low particulate matter concentrations in the St. Lawrence (Figure 4.2).

Coakley and Poulton (1993) concluded from statistical analyses of sediment concentration data (gathered in 1989–1990) in the Upper Estuary that zinc and chromium show a steady decrease with distance downstream from Île d'Orléans. This decrease is consistent with sources of these metals being located upstream in the St. Lawrence River. Lead and mercury, on the other hand, show rather different distribution

Table 4.1 Measurement units

Mass	
pg = picogram = one-trillionth of a gram = 10^{-12} g	
ng = nanogram = one-billionth of a gram 10^{-9} g	
μg = microgram = one-millionth of a gram 10^{-6} g	
mg = milligram = one-thousandth of a gram 10^{-3} g	
kg = kilogram = one thousand grams = 10^{3} g	
Volume	
m^3 = cubic metre	
L = litre	
Concentration (combined units)	
mg/kg =	milligrams of a chemical per kilogram of a sample of sediment or biological tissue
μg/L =	micrograms of a chemical per litre of a sample of water
ng/g =	billionths of a gram of a chemical per gram of a sample of sediment or biological tissue
pg/kg =	trillionths of a gram of chemical per kilogram of a sample of sediment or biological tissue
Conversion	
mg/kg = μg/g	ppm = μg/g ppb = ng/g

trends. Lead shows a peak in the middle of the Upper Estuary, suggesting a source in that region. Mercury showed relatively high values in the sediments of the MTZ, followed by a rapid decrease downstream, then a sharp increase at the mouth of the Saguenay.

Shipping and fishing harbours in the Gulf and Lower Estuary are likely to show evidence of local inputs because industry and shipping releases of chemicals preferentially accumulate in fine-grained sediments.

Estuary

Mercury

The predominant anthropogenic sources of mercury have been mining, fossil fuel combustion and the chloralkali industry, which supplies chemicals to the pulp and paper industry (e.g., in the Saguenay Fjord). Although chloralkali factories have ceased production or greatly reduced their mercury output, some areas of the fjord still show high concentrations of mercury.

Generally accepted background values for mercury are 0.3–1.4 ng/L for open ocean total (dissolved and particulate) concentrations in water (Ray and Bewers 1984; Bruland 1983; GESAMP 1986) and 20 ng/L (GESAMP 1986) in "clean" coastal areas.

Adsorption onto SPM, which subsequently settles to the bottom, results in rapid removal of mercury from the water column and a net reduction of mercury potentially reaching the Gulf. Figure 4.6 shows the vertical and horizontal distribution of total mercury (dissolved plus adsorbed on suspended particulate matter) in the waters of the Estuary from data gathered between 1980 and 1984. Total mercury concentrations peak at 75 ng/L (Yeats 1988b) and correspond to peak values of SPM concentrations in the MTZ. About 80% of the mercury is transported in particulate form; most of this is removed in the MTZ. Downstream from the MTZ, concentrations decrease to 0.3 ng/L (the limit of detection) in the cold intermediate waters of the Laurentian Channel (Cossa 1990).

Between 1975 and 1987, mercury concentrations in surface sediments decreased from levels greater than 500 ng/g to 170 ng/g in the Lower Estuary (Cossa 1990). Mercury concentrations at depths greater than 25 cm are about 30 ng/g (Gobeil and Cossa 1993) and represent pre-industrial levels in the sediments. Analyzing sediment data from 1985–1988, Gobeil and Cossa (1993) found mercury concentrations of 520 ng/g at the head of the Laurentian Channel.

Sediments in the Saguenay Fjord and in the adjacent portions of the Laurentian Channel contain comparatively high levels of mercury. Sediment layers with the highest concentrations are 4 to 17 times higher than pre-industrial levels (Cossa 1990). Recent anthropogenic mercury flows into the Estuary are 1/500th of their levels in the 1970s (Cossa 1990). This reduction is likely a consequence of the closure of a chloralkali plant on the Saguenay River. The one major uncertainty is the relative importance of bioturbation in remobilizing mercury from the sediments of the Saguenay Fjord (Cossa 1990). Any disturbance of the sediments, whether natural or human-caused, has the potential to make mercury re-available for uptake by marine life.

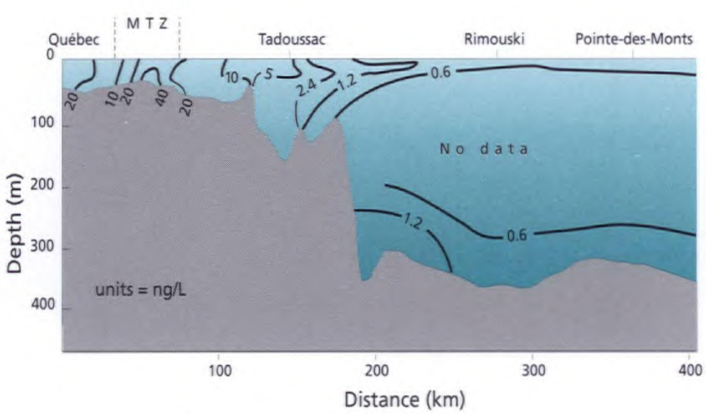

Figure 4.6
Mercury concentrations in the Laurentian Channel, 1980–1984
Source: Cossa 1990

Zinc

Total zinc concentrations in the waters of the deep ocean average 350 ng/L (Ray and Bewers 1984); by contrast, zinc concentrations are 486 ng/L (dissolved) in the Upper Estuary, 1 300–2 300 ng/L (total) in the Lower Estuary, and 810–1 900 ng/L in the Saguenay Fjord (Cossa 1990). The high values in the Lower Estuary and Fjord are unexplained.

Zinc in surface sediments varies from 185 µg/g in the Upper Estuary to 115 µg/g in the Lower Estuary and an intermediate value in the Saguenay Fjord of 131 µg/g (Cossa 1990). Wells and Rolston (1991) reported values of 179 µg/g near Île d' Orléans and 112 µg/g near Rimouski in the Lower Estuary. There does exist a definite time trend for zinc: in pre-1940 sediments, zinc concentrations are 24–116 µg/g and in post-1940 sediments, concentrations are 45–201 µg/g (Cossa 1990).

Lead

Total lead concentrations in deep ocean waters average 3 ng/L (Ray and Bewers 1984); dissolved levels of lead concentration in the Upper Estuary are 146 ng/L. These levels are higher than those considered representative of pristine regions (Cossa 1990).

Gobeil and Silverberg (1989) estimated that about two-thirds of the lead in the surface sediments (top 8–10 cm) is anthropogenic in origin, primarily from leaded gasoline combustion and mining and smelting industries. This result assumes that the 15 µg/g lead concentration at a 35-cm sediment depth represents the natural, pre-industrial concentration. The concentration of lead begins to decrease in sediment layers corresponding to the period when leaded gasoline began to be phased out in North America.

It appears that about 17–20% of the lead deposited in sediments is recycled back into the overlying water (Gobeil and Silverberg 1989) as a result of oxidation of organic matter in surficial sediments.

Chromium

Total concentration of chromium averages 0.23 µg/L in the waters of the deep ocean (Ray and Bewers 1984). Dissolved chromium exhibits a rapid decrease in concentration from 0.7 µg/L in the St. Lawrence River to 0.4 µg/L in the Estuary, with most of the metal being lost in the MTZ (Yeats 1988b). The rapid decrease coincides with high SPM concentrations in the MTZ and may be due to the formation of organic-chromium particulate in the MTZ (Yeats 1990).

Few measurements exist for chromium in the sediments of the Estuary.

Cadmium

Deep ocean concentrations of cadmium are about 0.08–90 ng/L (Ray and Bewers 1984; Bruland 1983; Cossa 1990). Cossa (1990) notes the following facts about the occurrence of cadmium in the Upper Estuary:

- Dissolved concentrations vary from 11 ng/L to 25 ng/L.
- Concentrations on suspended particulate matter in the MTZ are 200–500 ng/g.
- Concentrations on suspended particulate matter leaving the Upper Estuary are much smaller than those that enter the Upper Estuary.

The concentration range for cadmium (20–28 ng/L) in the Lower Estuary is similar to Atlantic ocean waters. The distribution exhibits a general trend of concentrations increasing with depth, which is consistent with the removal of cadmium by primary production and its release during nutrient regeneration in deeper waters (see "Role of Nutrients", pages 23–24). There does not appear to be any significant cadmium contamination in the Estuary, where levels in water and sediment are close to the levels of generally uncontaminated coastal areas. The Saguenay Fjord does not appear to be a source of cadmium (Cossa 1990).

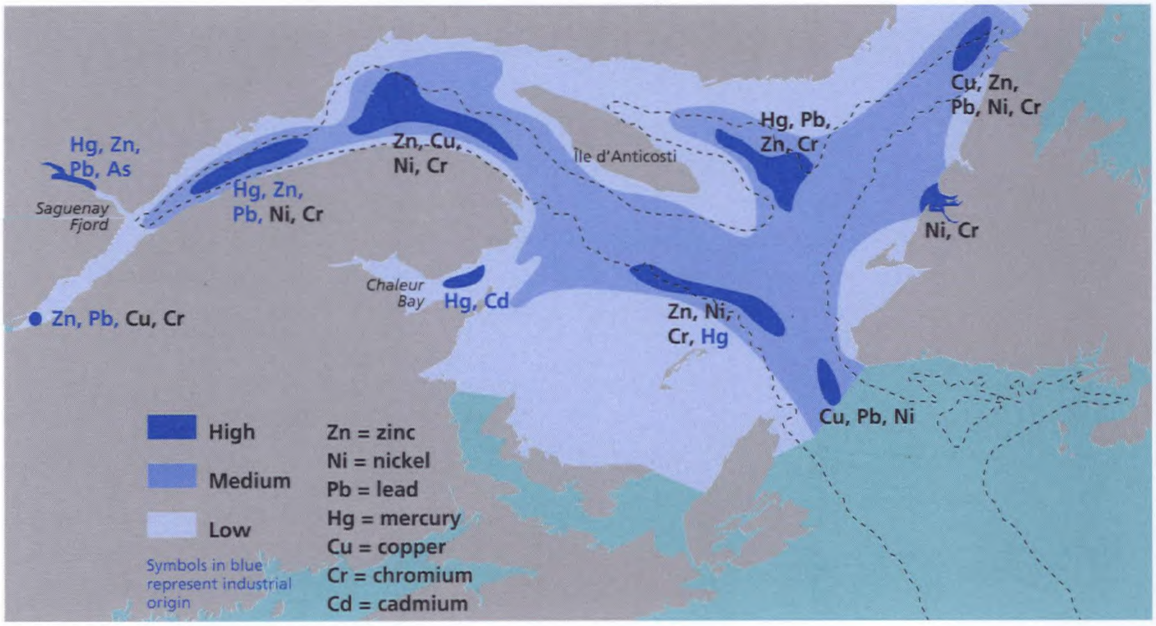

Figure 4.7
Metal distribution in surface sediments of the Gulf and Estuary
Source: Loring 1988

Note: High concentrations are defined for specific metals as follows: greater than 100 mg/kg for zinc, 30 mg/kg for copper, 20 mg/kg for lead, 0.3 mg/kg for mercury, 30 mg/kg for nickel, 70 mg/kg for chromium and 0.5 mg/kg for cadmium

Only about 25% of total cadmium in the Estuary may be of anthropogenic origin. About 80% of the total cadmium flow to the sediment returns to the water column (Gobeil and Silverberg 1989). The mechanism for this is the release of cadmium from the decay of organic matter, which occurs in the oxygen-rich surface sediments.

Gulf

Data on dissolved and particulate matter concentrations of metals in the Gulf are so sparse as to preclude any meaningful assessment of conditions.

Figure 4.7 shows the distribution of various metals in the sediments of the open Gulf and part of the Estuary. Concentrations of most metals in the Gulf sediments are typical of sedimentary material that originates from the glacial erosion of the crystalline rocks of the Canadian Shield. Also typical is the occurrence of higher concentrations in the clay-like sediments found at the bottom of the deep channels. Mercury shows a contamination pattern that suggests a strong anthropogenic origin in the Lower Estuary (Loring 1988).

Total metal concentrations are higher in sediments with smaller grain sizes, such as clay, silt and mud. Thus, for example, zinc concentrations in the muds of the Estuary can be directly compared only to zinc concentrations in the muds of the Gulf.

High concentrations of zinc, lead and chromium occur in fine-grained sediments at the mouth of the Estuary and on the floor of the deep channels. Locally high values of nickel and chromium occur on the west coast of Newfoundland as a result of weathering of nearby rocks. Zinc, lead and mercury show a decreasing trend from the Upper Estuary seaward to the Gulf except for higher concentrations near the mouth of the Saguenay Fjord (Loring 1988).

Gobeil and Cossa (1993) estimated that up to 50% of the mercury in Gulf sediments (near the branching of the Laurentian Channel into the Esquiman Channel) comes from anthropogenic sources, and that a significant fraction of this percentage results from atmospheric transport and deposition.

The only area in the Gulf that seems to have high metal contamination of cadmium due to human activities is Belledune Harbour in Chaleur Bay (Cossa 1990) where there are pulp and paper, mining and smelting, and power generating facilities.

Organic Contaminants in the Environment

The details of the distribution, fate (chemical transformations and ultimate disposition) and effects of organic contaminants in the smaller estuaries and coastal areas have been poorly studied. The limited information available suggests that trace organic chemicals are contaminating localized areas (Cossa 1990). Substantial improvements made since the 1970s in the analy-tical techniques used for measuring industrial organics, particularly PCBs, can complicate efforts to establish time trends even when calculation procedures are used to compensate for changes in measurement technology.

The chemicals that have been most studied are polychlorinated biphenyls (PCBs), chlorinated pesticides, and other chlorinated hydrocarbons and compounds found in fossil fuels and their combustion products. Many classes of contaminants include a large number of individual compounds. For example, there are 209 PCB compounds and several hundred polycyclic aromatic hydrocarbon (PAH) compounds and 207 types of dioxins and furans. PAH and many pesticides continue to enter the environment. Although restrictions on PCBs began in 1980 (Government of Canada 1991), they still enter the environment from landfill leachate, spills and atmospheric transport from countries that still use PCBs. Only a small number of the more toxic compounds of each group have been investigated in detail. The partitioning of these compounds depends on their specific chemistry, water properties (salinity, temperature and pH) and the relative abundance of organic materials in sediments and SPM. Compounds with medium to high molecular weight are not soluble and, thus, tend to bind onto SPM (Farrington 1991).

PCBs

PCB concentrations in the sediments of the Laurentian Channel near Rimouski are similar to those of coastal sediments in other industrialized areas. The highest concentrations are found in sediments in the 7–9 cm layer, which (discounting the tendency of bioturbation to confuse the chronological record) would correspond roughly to deposition in the 1950s (Cossa 1990).

Concentration levels in the Estuary are much lower than in the St. Lawrence River except for Baie des Anglais (maximum value of 27 µg/g). In sediment samples near Rimouski in the Lower Estuary, PCB concentrations increase from levels near the detection limit of 0.01 µg/g (at the surface) to 0.33 µg/g (at a depth of 8 cm). The concentrations continue their decrease in the deeper layers (Cossa 1990).

In the Gulf, PCB concentrations of up to 12 ng/g have been measured in the Miramichi Estuary and Northumberland Strait (Pocklington 1988). The generally accepted value for background levels in the Gulf is 0.1 ng/g (Gilbert and Walsh 1996).

PAHs

PAHs primarily occur throughout the environment bound to particles. Dissolved organic matter also can adsorb PAH and contribute to their settling and burial in marine sediments. Since microbial degradation of PAH in cold sediments is slow, these compounds are persistent. PAH levels are excessive when they are greater than 2 µg/g (Gearing et al. 1994).

PAH levels in sediments of the Saguenay Fjord are 9–80 times higher than background levels in uncontaminated sediments (Cossa 1990). These high levels are attributed to three aluminum refineries and several pulp and paper mills that operate in the area (Gearing et al. 1994). PAH concentrations on particulate matter in the Saguenay Fjord are 3.4 µg/g and decrease seaward to 0.6 µg/g. The latter value is typical for the Estuary and corresponds to levels in other nearshore waters close to industrialized areas (Cossa 1990).

A review of PAH in sediments of the Saguenay Fjord and Lower Estuary (Gearing et al. 1994) reported that values of PAH in the Saguenay Fjord steadily decrease from 20 µg/g to 1 µg/g closer to the Estuary. They also noted a small but consistent decline in PAH values over time. In the Laurentian Channel, concentrations are low, 0.7–1.6 µg/g, and show no apparent geographical or temporal trends. The only area of the Lower Estuary that shows elevated levels of PAH is in Baie des Anglais (up to 9 µg/g).

Petroleum Hydrocarbons

Levels of dissolved/dispersed petroleum hydrocarbons in the Estuary in 1976–1979 were generally 25–30% lower than those in 1971–1973 (Gearing and Pocklington 1990; Levy 1985). There was a general trend towards lower levels closer to the open Gulf and away from major cities and rivers. There is some evidence that hydrocarbons move from the open Gulf to the Lower Estuary (Gearing and Pocklington 1990). Background concentrations of petroleum hydrocarbons are low in the Gulf (0.35–2.9 µg/L) and Estuary (0.35–1.9 µg/L); slightly higher levels in the Cabot Strait (0.4–6.0 µg/L) are due to the influence of the Atlantic Ocean (2.3–6.0 µg/L) (Levy 1988).

The major source of dissolved and dispersed petroleum residues entering the Gulf appears to be the inflow through the Cabot Strait from the Atlantic Ocean (Figure 4.8). The data suggest that by 1975 the Gulf was able to assimilate dissolved and dispersed petroleum residues at a rate greater than the input (Levy 1988). Levy (1985) proposed that since 1975, petroleum hydrocarbon inputs into the Gulf have been predominantly from the atmosphere (Levy 1985).

Figure 4.8
Petroleum concentrations in the surface waters of the Gulf and Estuary
Source: Levy 1988

Chemicals in Biota

The effect of chemicals on biota depends principally on three processes:

- The ease by which chemicals enter an organism;
- The residence time of a chemical in an organism, which depends on the balance between uptake, metabolism and elimination; and
- The sensitivity of a particular tissue in an organism to a particular chemical—the presence of a contaminant in an organism does not by itself imply adverse effects.

The following summary of physiological processes governing contaminant levels is primarily from Rainbow (1993) and Walker and Livingston (1992).

The tendency of biota to take up a specific chemical depends upon the properties of the chemical (e.g., molecular structure), the physiology of the organism, (e.g., age and breeding status), the nature of the habitat (e.g., dissolved organic content of water) and which other chemicals are present. Details of all factors that can influence uptake are often not known for a particular species in a particular area.

Metabolism of a chemical may reduce the body burden of that chemical, but sometimes the metabolites (breakdown products of metabolism) are more toxic than the parent compound.

Elimination of the metabolites from the animal completes the process. Metabolic capabilities and elimination rates differ between species, populations and individuals. They are also dependent on physiological (e.g., reproductive and nutritional) and environmental (e.g., temperature and salinity) factors.

Persistence of a chemical refers to the continuing presence of the unchanged parent compound and its metabolites. It occurs when uptake exceeds an animal's metabolic capabilities to break down and eliminate the compound. The storage of a chemical in an animal is called bioaccumulation. Persistent chemicals build up within an ecosystem because they are transferred through trophic levels (e.g., plankton to fish to birds or mammals) and frequently to the next generation.

In the following discussion of chemicals in biota, some care should be used in directly comparing levels in biota from different regions and between species because little is known about the biological significance of differences in chemical concentrations in even closely related species.

Metals in Biota

Cadmium, lead and mercury are naturally present in the environment but appear to be biologically non-essential. These metals are toxic even at relatively low concentrations. Metals such as chromium, copper, iron and zinc are biologically essential to the health of organisms but may be toxic when present in excess amounts. When concentrations of these metals become excessive, most organisms have mechanisms to convert more toxic forms into less toxic forms that are readily excreted (i.e., water soluble forms). Detoxifying mechanisms include the binding of some metals (e.g., zinc, copper, iron and manganese) to certain proteins or the binding of metals to metabolically inert granules. Organs such as the liver and the kidney tend to have the highest metal concentrations because they act as temporary or permanent repositories for detoxified metals.

Commercial Fish

Most information on contaminant levels in fish is from studies of shellfish and lobsters in the Estuary and industrialized harbours in the Gulf. In the 1970s, cadmium, lead and mercury concentrations in blue mussels were usually lower in the Gulf than in the Estuary. This trend reflects dilution of metal-rich waters originating from the Upper Estuary and Saguenay Fjord (Bourget and Cossa 1976). The highest levels of mercury in blue mussels sampled in 1977 and 1979 were found in areas of fresh water input such as the Upper Estuary, the head of the Lower Estuary and brackish regions of Chaleur Bay. Lowest levels were found near Cabot Strait (Cossa and Rondeau 1985). Comparison of results with a previous survey (Bourget and Cossa 1976) indicated that the high mercury levels found at the mouth of the Saguenay Fjord had declined (Cossa and Rondeau 1985). It is not clear whether the decline of mercury levels in mussels along the south shore of the Estuary and Gaspé Peninsula was merely attributable to seasonal differences in sampling. A 1977 survey demonstrated that cadmium and lead concentrations in blue mussels from the Estuary and northwestern Gulf were relatively low compared to values in other parts of the world. The data did not indicate any local point source of contamination (Cossa and Bourget 1980).

At Belledune Harbour in Chaleur Bay, cadmium in lobster muscle peaked in 1979 at 2.7 µg/g. These levels were high enough to close the fishery in that harbour in 1980. By 1981, cadmium levels had decreased to approximately the same level (0.40 µg/g) as in 1975 (Uthe et al. 1982). Between 1981 and 1985, cadmium concentrations in muscle decreased 63–69% and those in hepatopancreas (digestive gland) decreased 56–64% (Uthe et al. 1986). Improved effluent treatment by the lead smelter industry in Belledune Harbour may have been the main factor leading to these decreases. However, high levels of cadmium in harbour sediments threaten recontamination of lobster if sediments within the harbour become disturbed by dredging

(Uthe et al. 1986). The lobster fishery in Belledune Harbour reopened in 1985 under marketing restrictions.

High tissue concentrations of cadmium were not observed in scallops from Belledune Harbour or other areas in Chaleur Bay (Uthe and Chou 1987). Levels of cadmium from this area, which has known anthropogenic inputs, were lower than those from Browns Bank, a relatively remote and pristine area on the Scotian Shelf. They suggested that factors such as starvation may affect tissue concentrations or body burdens of chemicals in scallops.

Mercury levels in the whole bodies of migratory eels in the Estuary and sedentary eels from surrounding rivers are similar, which suggests that the mercury originates from natural sources or atmospheric deposition (Hodson et al. 1994).

Levels of mercury, copper and cadmium in liver and zinc in muscle of Atlantic cod from the southern Gulf of St. Lawrence increased significantly over the eight-year period 1977–1985 (Misra and Nicholson 1994). Sources of metals in these fish have not been identified.

Seabirds

Organic mercury (as methylmercury) is lipid soluble. Therefore, it is one of the few metals transferred from female birds to eggs. Mercury levels in seabird eggs were stable between 1972 and 1980 (Noble and Elliot 1986). Metal concentrations (cadmium, mercury, lead and 18 other trace elements) in seabird tissues collected during the 1988 breeding season in Atlantic Canada (Elliot et al. 1992), including four locations in the Gulf and Estuary, were similar to those in other seabird species from around the world. Examination of liver and kidney tissues did not reveal any evidence of tissue damage associated with elevated levels of heavy metals. Marine birds appear to tolerate appreciable body burdens of cadmium and mercury without any apparent health effects.

Marine Mammals

Ronald et al. (1984a) detected cadmium, mercury, selenium and copper in tissue of newborn harp seals, indicating some transplacental and transmammary transfer of these elements between mother and pup. Despite such transfer, which should lower contaminant levels, adult females had significantly higher levels of mercury and cadmium than adult males. Mercury levels in the liver of harp seals from the Estuary did not change between 1971 and 1979 (Sergeant 1980).

Stranded St. Lawrence belugas have significantly higher levels of lead, mercury and selenium but significantly less cadmium in liver, kidney and muscle tissue than Arctic beluga (Wagemann et al. 1990). The authors suggested that the low cadmium levels in the St. Lawrence beluga may be due to the high mercury levels displacing cadmium in the kidneys.

Organic Contaminants in Biota

Many organic contaminants—particularly the synthetic ones—persist in living tissue because they are metabolized slowly, if at all. Organic contaminants generally do not dissolve easily in water but are highly soluble in lipids (fats) and thus their tissue distribution depends on the lipid content in tissue. Since organisms often store lipids as energy reserves, their contaminant levels can vary in response to seasonal energy demands such as reproduction, migration and winter stress.

Females of both invertebrate and vertebrate organisms tend to have lower levels of organic contaminants when they are laying eggs, gestating or nursing because lipids are transferred from their bodies to their young. In seals and other marine mammals, females transfer some of their organochlorine burden to pups through transplacental transfer (relatively minor in seals) and lactation of fat-rich maternal milk (Addison and Brodie 1977; Ronald et at. 1984b; Beck et al. 1994). For example, 98% of organochlorine burden in grey seal pups comes from ingestion of maternal milk (Addison and Stobo 1993); adult

Box 4.3: PCB Contamination in the Food Web of St. Georges Bay, NS

Because it is relatively remote from local sources of PCBs, St. Georges Bay, Nova Scotia (front map) is the site of studies of PCB levels in the marine pelagic food web. The Bay receives most of its input of PCBs from long range atmospheric transport and a small amount via river flow from upstream dump leachate and spills. Most (98%) of the PCBs in the environment is in seawater, most likely associated with suspended particulate matter. Only 2% of the PCB is in plankton, fish and marine mammals (G. Harding, personal communication).

Studies over the last two decades indicated that PCB (as Aroclor 1254 equivalent) levels in plankton were related to the amount of deposition from the atmosphere (Ware and Addison 1973; Harding et al., in press). Recent work, which compares PCB levels in similar-sized plankton from the Bay, shows that average concentrations dropped exponentially—by a factor of 6 000—from the early to late 1970s but have remained relatively constant at low levels since 1977 (Figure 4.9). Similarly, pelagic fish such as herring also show a consistent decline in PCB levels from the 1970s to the 1990s (Figure 4.10). PCB concentrations (per gram lipid) were 38 times higher in fish than plankton and were 2 times higher in marine mammals than fish, which provides evidence of bioconcentration of PCBs in the food web (Harding et al., in press).

females transfer 30% and 15% of their body burden of total DDT and PCBs, respectively, to their pups (Addison and Brodie 1977).

Since the toxicity of individual compounds within classes (e.g., PCBs and PAHs) also differs, the properties of specific compounds ideally

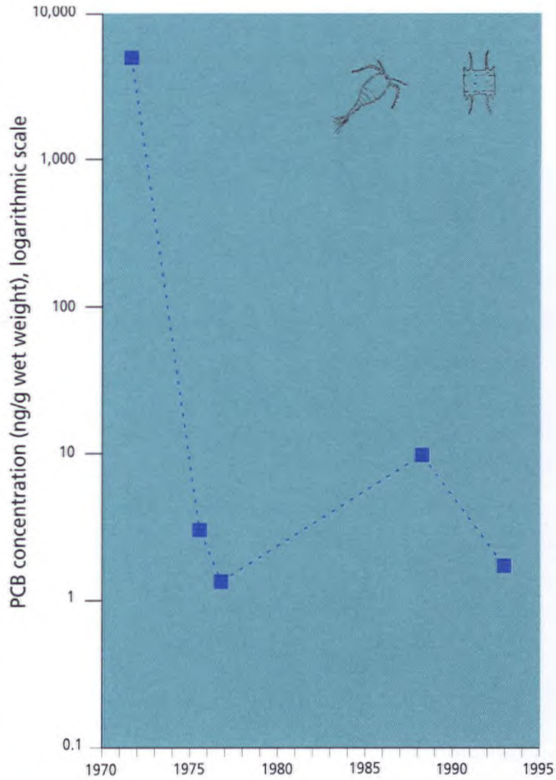

Figure 4.9
Average PCB concentrations (as Aroclor 1254 equivalent) in plankton collected in St. Georges Bay, NS
Source: adapted from Harding et al., in press
Notes: The plankton sizes ranged from 125 µm to less than 509 µm. This size range includes both phytoplankton and zooplankton.

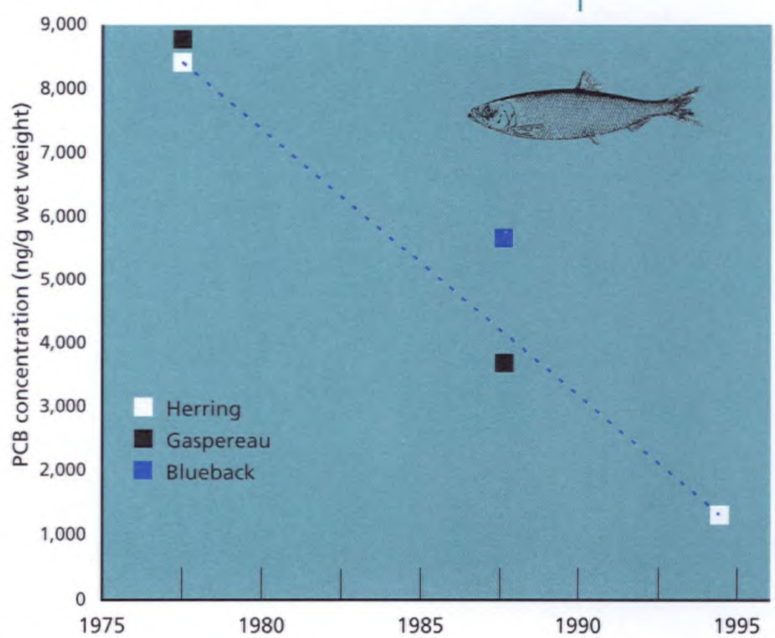

Figure 4.10
Average PCB concentrations (as Aroclor 1254 equivalent) in fish collected in St. Georges Bay, NS
Source: G. Harding, personal communication

should be used to assess their effect on biota. However, time trend data use the total amount of a class of organochlorines because earlier measurement techniques were not able to distinguish between different individual compounds (congeners). For example, the two most critical chemical properties that distinguish one individual organochlorine compound from another are the number of chlorine atoms and their location in the molecular structure.

Commercial Fish

Levels of PCB and HCB in the livers of cod from the southern Gulf significantly decreased over the eight-year period 1977–1985 (Misra and Nicholson 1994).

Blue mussels taken from the Saguenay Fjord and its mouth in the late 1970s showed elevated concentrations of 3,4-benzopyrene, a carcinogenic PAH, compared to concentrations detected in mussels sampled in other regions of the Gulf and Estuary (Picard-Bérubé et al. 1983). This contamination was due to discharges from an aluminum smelter in the Fjord. Subsequent changes to plant operations resulted in substantial reduction of PAH emissions from the smelter; consequently, it was expected that the PAH input into the Fjord has decreased (Cossa 1990).

Recent analysis of chemical contamination of migrating American eels has shown a decrease in organic contaminant levels, including mirex (Castonguay et al. 1989; Hodson et al. 1992; Dutil et al. 1985). Between 1982 and 1990, levels of PCB, DDT and mirex in migrating eels in the Estuary had declined by 69%, 77% and 56%, respectively (Figure 4.11). Levels of the pesticide dieldrin in eels had remained unchanged since 1982, while levels of other pesticides had declined. Dioxins, furans and PAHs were virtually absent from eels collected in the Estuary and north shore rivers.

Nevertheless, levels of PCBs, mirex and pesticides in 1990 were 10–100 times higher in migrating eels throughout the Estuary than those resident in a relatively uncontaminated river along the north shore of the Estuary (Hodson et al. 1994). They also noted that eels from the St. Lawrence River had more deformities and lesions than those from a nearby uncontaminated river. Eels in Lake Ontario have similar levels of mirex and PCBs as Estuary eels; thus, suggesting that Lake Ontario is the likely source of contamination of Estuary eels (Desjardins et al. 1983). Use of mirex is restricted to Lake Ontario and two of its tributaries.

Historically, the adult eel population in the Estuary has been subject to mass mortalities, peaking in the early 1970s in fresh water portions of the St. Lawrence River (Dutil et al. 1987). Mortalities were attributed to damaged gills resulting from migration through highly contaminated waters of the St. Lawrence River (Castonguay et al. 1989). Deformities in Estuary eels have been observed by fishermen, and the number of juvenile eels migrating towards Lake Ontario has declined by more than 98% since 1985 (Castonguay et al. 1994). This decline is particularly significant since eels in the St. Lawrence River basin tend to be predominantly female (the males are found mainly in the coastal rivers of the United States). Because toxicity data are lacking it is not known whether levels of contaminants affect the eels, though the highest concentrations are in the reproductive organs (Hodson et al. 1994). Castonguay et al. (1994) concluded that it is not clear to what

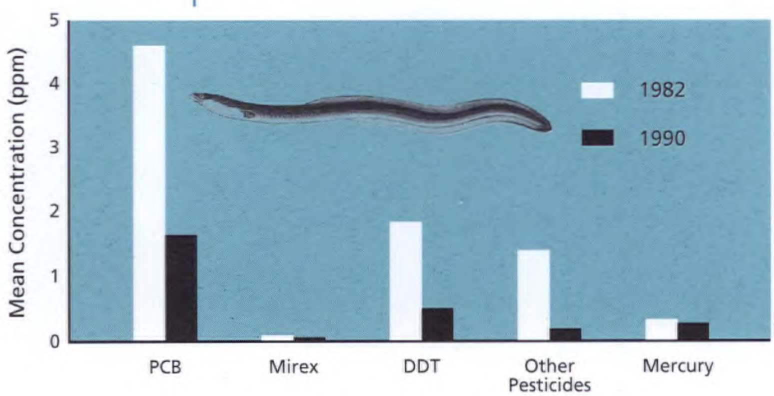

Figure 4.11
Geometric mean levels of PCBs, mirex, DDT, mercury and other pesticides in adult migrating American eels in the Lower Estuary
Source: Castonguay et al. 1989; Hodson et al. 1994; C. Desjardins, unpublished data

extent chemical contamination has contributed to the decline in eel populations. They suggested that the decline may be species-wide. Aside from chemical contamination, other contributing causes for the decline in American eel populations include habitat modifications, changes in the ocean environment where they spawn and commercial fishing.

Seabirds

Since 1972, the Canadian Wildlife Service has had a monitoring program on the east coast of Canada to measure organochlorine contaminants in seabird eggs. Monitored species include Northern Gannet, Double-Crested Cormorant, Leach's Storm-Petrel, Common Tern, Atlantic Puffin and Razorbill. Contamination in these species is representative of contamination in different types of marine waters:

- storm-petrels—the pelagic food chain in offshore surface waters;
- puffins and other alcid species—deep-water fish along the continental shelf; and
- cormorants, terns and gannets—inshore fish.

The findings of this program have been summarized by Noble and Elliott (1986), Pearce et al. (1989), Elliott et al. (1992), and N. Burgess (personal communication). In general, PCBs are the dominant organochlorine found in seabird eggs; it contributes more than two-thirds of the total organochlorine concentration. DDT-group chemicals account for approximately 20% and the other pesticides make up the remaining 10–15%.

Between 1972 and 1992, levels of PCB, DDE, dieldrin and HCH in Double-Crested Cormorant eggs from the Estuary showed the most significant declines (Figure 4.12). These declines are similar to the temporal trend reported in gannets (see Box 4.4) from the Gulf of St. Lawrence (Elliott et al. 1988) and have been attributed to cessation of PCB use in 1977, severe restrictions

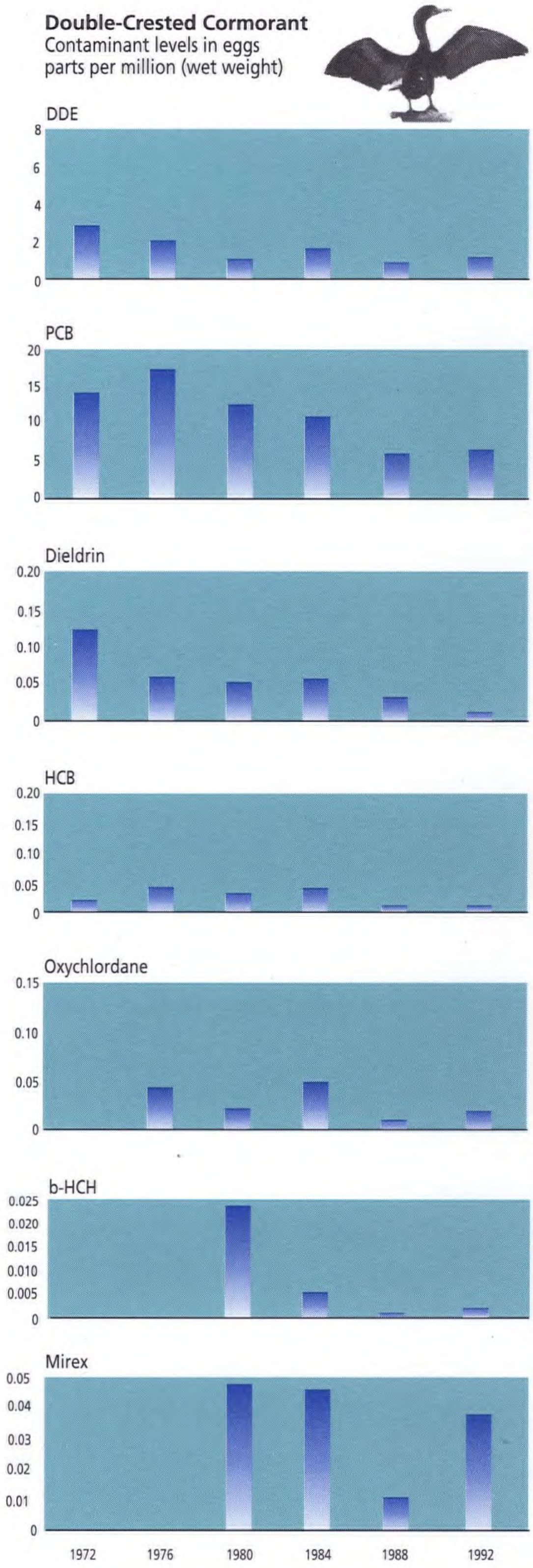

Figure 4.12
Time trends for organochlorine concentrations in Double-Crested Cormorant eggs in the Estuary
Source: N. Burgess, personal communication

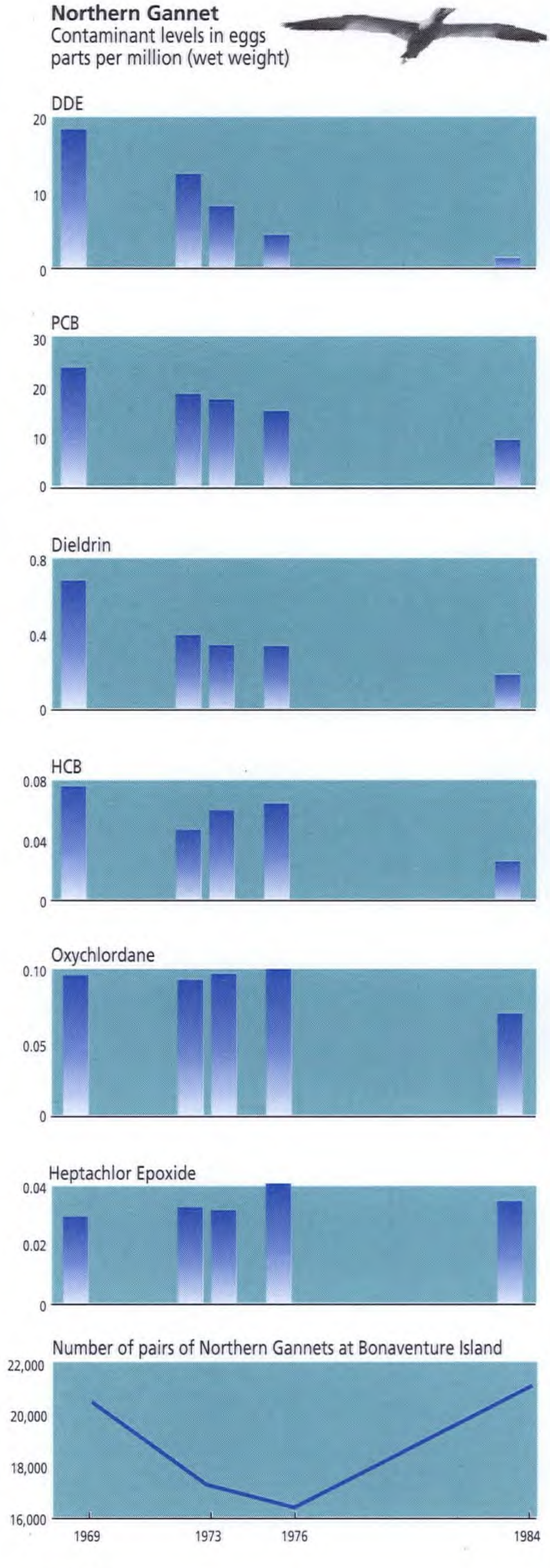

Figure 4.13
Time trends for Northern Gannet population and selected organochlorine concentrations in eggs.
Source: Noble and Burns 1990

Box 4.4: Effect of Organochlorines on Reproduction of the Northern Gannet

The Northern Gannet is the best documented case of contaminants implicated in the population decline of a Gulf seabird species. Approximately 70% of the North American population of northern gannets breed at three colonies in the Gulf (Nettleship and Chapdelaine 1988). Nesting gannets increased substantially over the last century, reaching a peak in 1966 (Nettleship 1975). The population underwent a subsequent decline of 23% between 1966 and 1972–73 because there was a very low hatching success between 1966 and 1970. The data strongly implicated DDE-induced shell thinning and embryonic mortality as the main factor in reduced productivity (30% net productivity in 1966–1967 compared with 77% in 1979) (Chapdelaine et al. 1987). Improved breeding success, increased eggshell thickness and increased population have coincided with a significant drop in DDE and dieldrin levels in eggs (Elliot et al. 1988; and Figure 4.13). On Bonaventure Island, where 75% of gannets in the Gulf breed (Nettleship and Chapdelaine 1988), a 1984 survey indicated that the population had recovered to pre-1966 levels.

on use of dieldrin and b-HCH in the early 1970s, and the ending of extensive use of DDT in New Brunswick forests to control spruce budworm (Pearce et al. 1989). Levels of HCB, oxychlordane and mirex have been fluctuating and appear to be as prevalent today as in the mid-1970s (Figure 4.12).

Geographic differences in contaminant concentrations on the east coast have generally decreased since the mid-1980s. In the early 1980s, seabird eggs from the Gulf and, in particular, the Estuary had the highest contaminant levels in birds for any Canadian coastal site. But in the early 1990s, levels of organochlorines were similar to those in the Bay of Fundy.

Seabirds in the Great Lakes have organochlorine levels two to four times higher than in the Gulf and Estuary. However, levels in seabirds from Newfoundland, the west coast, and Arctic regions of Canada are lower than Estuary seabirds.

At the present time, organochlorine levels apparently pose no threat to seabird populations. Based on time trends in marine birds, DDE, PCB and dieldrin residue levels in the ecosystem of the North American continental shelf—originating from land runoff and riverine inputs to the marine ecosystem—have generally declined, in response to regulatory actions. Contaminant levels in storm-petrels breeding in Newfoundland and the Bay of Fundy have the highest concentrations of organochlorines (except for PCBs). Because these seabirds feed on surface organisms far offshore, the data suggest that atmospheric inputs of organochlorines to the open ocean may be more important than inputs from rivers to the marine environment (N. Burgess, personal communication).

Marine Mammals

Seals

Concentrations of DDT and its metabolites in the blubber of male harp seals caught within the St. Lawrence Estuary in 1982 were one-fourth the levels in 1971 (7.7 µg/g lipid mass; Addison et al. 1973, 1984). Concentrations of DDT-group chemicals may have further declined by 1988/89 but changing analytical methods and biological variables (age and blubber mass) prevent an unequivocal answer (Beck et al. 1984). The fraction of DDE as a proportion of total DDT declined between 1982 and 1988/89, indicating that metabolism of DDT may be occurring. Between 1971 and 1982, PCBs declined only slightly in male harp seal blubber but a substantial decline was observed between 1982 and 1988/89 (4.2 and 2.5 µg/g lipid mass, respectively; Beck et al. 1994). Very low concentrations of PAHs were detected in the fatty tissue of harp seals in the Gulf; there was insufficient data to allow an analysis of time trends (Hellou et al. 1990).

Whales

Levels of PCBs in the blubber of a dead, stranded minke whale and blue whale in the Gulf averaged 3 µg/g, while those in blubber biopsy samples from live minke and fin whales averaged 2.5 µg/g (Gauthier et al. 1994). These levels are more than 10–30 times lower than in St. Lawrence beluga (Table 4.2).

Between 1982 and 1985, high concentrations of PCB and DDT compounds were detected in the blubber and organs of stranded, dead beluga whales in the Estuary (Masse et al. 1986; Martineau et al. 1987). Muir et al. (1990) compared a number of organochlorine compounds in the blubber of stranded belugas from the St. Lawrence (1986–1987) to samples collected by Inuit hunters (1983–1987) from five Arctic populations (Table 4.2). Animals from the St. Lawrence, particularly adult males, had the highest concentrations of PCBs, DDT-group chemicals, polychlorinated camphenes (toxaphene), chlordane-related compounds, mirex and dieldrin. PCB, DDT and mirex concentrations were as much as 100 times higher in St. Lawrence males than the average values in males from the Arctic (Table 4.2). By contrast, there were few major differences in organochlorine concentrations among the Arctic beluga populations. Differences in tissue concentrations of some organochlorines between the sexes are usually attributed to elimination by females through lactation, but dietary differences may also be a factor.

During the 1980s, autopsies of over 40 dead, stranded St. Lawrence belugas indicated a relatively high incidence of lesions such as tumours and ulcers within the oral cavity, respiratory system, mammary glands and, particularly, the digestive tract (Béland 1991). There may be a link between the high concentrations of organochlorine contaminants and the tumours and ulcers observed in the St. Lawrence beluga (Béland 1991). Other authors (Masse et al. 1986; Martineau et al. 1987) have implicated PCB and DDT compounds as a major factor in the lack of recovery of the St. Lawrence beluga population, since these

Table 4.2 Mean concentrations (in µg/g wet weight) of organochlorines in blubber of belugas

Chemical	*St. Lawrence Beluga*		*Arctic Beluga**	
	Male	*Female*	*Male*	*Female*
PCB (sum of PCB congeners)	75.8	37.3	2.53–4.91	0.96–2.46
DDT (sum of DDD, DDE and DDT)	101.0	23.0	1.96–6.83	0.67–2.19
toxaphene-related compounds	14.7	6.34	3.83–5.78	1.38–3.74
mirex	1.00	1.11	0.01–0.04	0.01–0.02
dieldrin	0.93	0.56	0.14–0.91	0.10–0.33
chlordane-related compounds (sum of chlordane-related compounds, including heptachlor epoxide)	7.43	3.55	1.75–2.38	0.62–1.84
chlorobenzenes (sum of P_5Bz and HCB)	1.34	0.60	0.32–1.05	0.16–0.29
HCH (hexachlorocyclohexane isomers) (sum of HCH isomers)	0.37	0.24	0.19–0.39	0.15–0.24

Source: Adapted from Muir et al. 1990

**Range, in means, for five Arctic populations*

contaminants have been shown experimentally to affect reproduction in mammals and birds.

Addison (1989) suggested that too few data exist to attribute the apparent reduction in reproductive success of the St. Lawrence beluga population solely to increased organochlorine levels. Stranded animals are not an unbiased sample. Contaminant concentrations fluctuate with changing blubber mass such that concentrations increase with decreased blubber mass (Addison 1989). This has important implications for stranded animals or those in poor condition (Beck et al. 1994). Organochlorine levels are frequently high in stranded animals but this may have more to do with lower blubber mass or older age of the animals than high concentrations.

Two of the major problems with linking organochlorines (e.g., PCBs) with reproductive impairment are the complexity of PCB mixtures—which may produce a variety of effects either singly or in combination—and little understanding of the basic biochemistry of marine mammal reproduction. The causes of pathological lesions found in stranded belugas need to be verified. For example, organochlorine residues in harbour porpoises in the Bay of Fundy were among some of the highest levels in the world (1969–1983), but no gross disorders of the reproductive systems have been observed in 350 autopsies (1969–1988) (Gaskin 1992). Data are needed on how organochlorine contaminants affect the physiology, metabolism, cells and tissues of beluga. Further information is required on contaminants in specific prey species, and the period of exposure to contaminants (Kingsley 1991).

Box 4.5: Organic Contaminants in the St. Lawrence Estuary Food Web

Gagnon et al. (1990) found that, in the MTZ, levels of PCB contamination increased with age in fish, being greater in adult smelt and tomcod than in juveniles or larvae. PCB levels also increased up the food web, with larval fish showing levels greater than those in zooplankton (Figure 4.14; Gagnon et al. 1990). In addition, the pattern of PCB congener contamination within biota was similar to that detected in beluga tissues (Gagnon et al. 1990).

Dalcourt et al. (1992) suggested that benthos do not contribute significantly to the accumulation of contaminants (e.g., PCB, PAH and mercury) within the beluga population; rather, more highly contaminated pelagic species (e.g., smelt, tomcod and eels) may be the major source of organochlorines.

Eels may be the principal carrier for mirex and PCB from the Great Lakes into the Gulf (Cossa 1990). Although levels of most contaminants in eels have recently declined, current levels in eels still represent a source of contaminants to the long-lived beluga (40–50 years). Muir et al. (1990) calculated that belugas would have to eat contaminated eels for only one week per year to attain the current levels of mirex in their blubber. This quantity of eels would also account for as much as 40% of the PCB levels found in blubber of stranded belugas.

Harp seals only spend the winter months in the Estuary, when they feed intensively on capelin and lay down significant reserves of blubber. Using PCB concentrations documented by Gagnon et al. (1990) for capelin in the Estuary, a minimal estimate of the increase in PCB body burden in a seal during 21-to-28-days is 6.5 mg. Concentrations of PCBs in seal blubber is far lower than in beluga blubber because harp seals are resident in the Estuary only a few months of the year and migrate to Arctic waters in the summer.

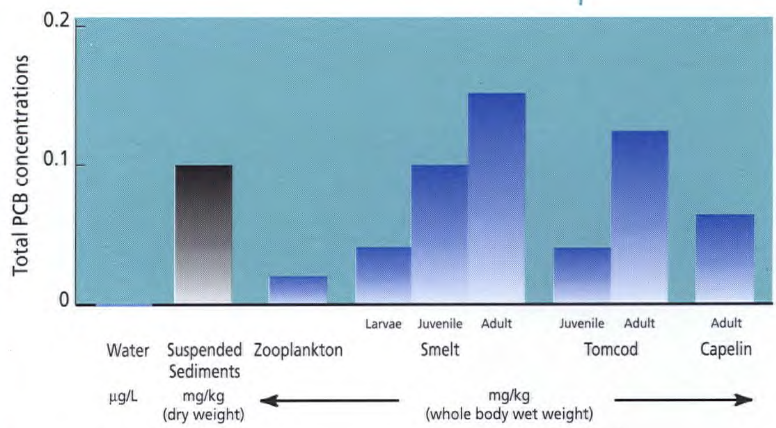

Figure 4.14
Total PCB concentration in selected components of the aquatic food web, MTZ in the Upper Estuary
Source: Gagnon et al. 1990

Chemicals from Biological Sources: Marine Phycotoxins and Bacteria

Marine Phycotoxins

In the past decade or so, there have been increasing reports from Canada and the rest of the world of toxic phytoplankton. It is a matter of debate whether increased frequency of population blooms and the expanding geographic range of toxic algae result from expanding aquaculture activities, general climatological changes or anthropogenic eutrophication (nutrient enrichment) (Smayda 1990).

Some toxic algae species have always been present in Canadian waters, albeit in low numbers. Other species may have been introduced through the discharge of ballast water into Canadian waters from ships coming from foreign ports. The presence of toxic algae can have a negative impact on human health and finfish and molluscan aquaculture (Shumway 1990). Their impact on free-living finfish and shellfish populations is less known but it is an active area of research.

There are at least 10 species of phytoplankton (Table 4.3), which can produce toxins (phycotoxins), that are widely distributed in Atlantic coastal waters. Marine phycotoxins are generally classified into three main groups according to their neurological effects on human

Table 4.3 Species of toxin-producing phytoplankton in the Maritimes

ASP-producing species	
	Pseudonitzschia pungens forma *multiseries*
	P. pseudodelicatissima
	P. delicatissima
PSP-producing species	
	Alexandrium funyense
	A. excavatum
	A. tamarense
DSP-producing species	
	Dinophysis norvegica
	D. acuminata
	D. acuta
	Prorocentrum lima

Source: Therriault and Levasseur 1992

consumers of shellfish: diarrhetic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP, caused by domoic acid) and paralytic shellfish poisoning (PSP). Vertebrate marine species are particularly vulnerable to these neurotoxins. Invertebrates such as molluscs, lobster and crab appear to ingest and accumulate phycotoxins with few or no effects.

In 1987, cultured blue mussels from Cardigan Bay in eastern Prince Edward Island became contaminated by the neurotoxin domoic acid. This resulted in 107 cases of ASP poisoning and three deaths in human consumers of the shellfish (Todd 1993). In response to that event, the Department of Fisheries and Oceans conducts research and monitoring programs on toxic algal species and toxin levels in cultured shellfish throughout the Estuary and Gulf (Therriault and Levasseur 1992). The monitoring program has effectively prevented a recurrence of ASP or PSP from cultured and wild mussels, oysters and clams destined for human consumption (Todd et al. 1993) by enforcing temporary closures of shellfish harvesting in affected areas (Figure 4.15).

Domoic acid (ASP) is produced by diatoms in the genus *Pseudonitzschia* (formerly *Nitzschia)*, whose fall blooms primarily occur in the estuaries of northern and eastern Prince Edward Island (Todd 1993 and Figure 4.15). The presence of a hard-to-detect non-toxic form of this diatom greatly complicates monitoring programs (Smith et al. 1990; Bates et al. 1993).

Okadaic acid is one of the principal toxin components implicated in DSP, which is a severe gastrointestinal illness caused by ingestion of shellfish contaminated by dinoflagellates, including several species of *Dinophysis* and the benthic species *Prorocentrum lima.* In Canada, the first conclusive evidence of okadaic acid was in 1989 in the Lower Estuary and Baie de Gaspé (Cembella 1989). Several species of potentially toxic *Dinophysis* may occur throughout the Gulf, particularly in the Baie de Gaspé and Chaleur Bay (Larocque and Cembella 1991). In 1991, *Dinophysis* species occurred in St. Georges Bay and Miramichi Bay (Smith et al. 1994). Although the *Dinophysis* species found in eastern Canadian waters are reputed to be toxic elsewhere in the world, their presence here is not always associated with DSP toxins.

Blooms of two species of *Alexandrium* are associated with PSP, particularly in the Estuary and northern Gulf (Turgeon et al. 1990). In the Estuary, *Alexandrium tamarense* produces among the highest levels of toxin per cell detected in the world (Cembella and Therriault 1989). PSP toxins were first documented in the southern Gulf in 1988, following detection of high levels in mussels in northeastern New Brunswick, including Miramichi Bay. *Alexandrium excavatum* can also occur in very cold ice-covered water in the southern Gulf, where this species was not thought to be prevalent (Worms et al. 1993).

There are indications that phycotoxins may remain in the benthic food web longer than was previously thought. Generally, non-carnivorous mussels and other bivalves show seasonal and annual variation in PSP toxin levels as they accumulate and depurate the toxin. In Miramichi Bay, PSP toxins in the northern moonshell (*Lunatia heros*), a carnivorous gastropod, have been detected every year since 1988, but levels have been steadily declining. Worms et al. (1993) suggested that the northern moonshells

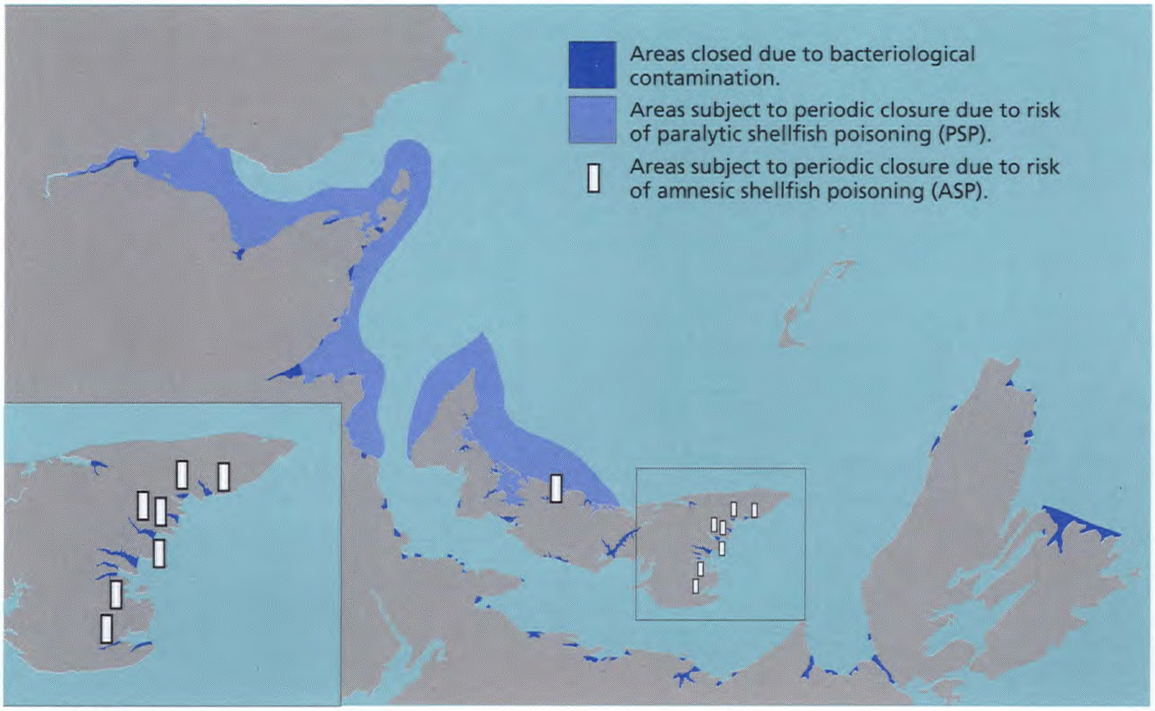

Figure 4.15
Shellfish harvesting areas in the southern Gulf, closed or subject to periodic closure
Source: Environment Canada 1994

accumulated high levels in 1988 and have either a slower depuration rate (years versus months) than most bivalves or have continued to concentrate toxins in their tissues.

Accumulation of PSP toxins is not confined to molluscan shellfish; in the Gaspé Peninsula, Bay of Fundy, and southwestern Nova Scotia high concentrations of PSP toxins have also been found in lobster tomalley (hepatopancreas) (Watson-Wright et al. 1991). In affected areas, Health and Welfare Canada has issued a health advisory on tomalley consumption (Todd et al. 1993).

Copepods, particularly larger specimens, can accumulate domoic acid (Windust and Wright 1991) and PSP toxins (Turiff et al. 1992) with almost no mortality. Therefore, they may act as carriers for the toxin into the pelagic food web. Laboratory experiments have shown that copepods that have accumulated PSP toxins from *Alexandrium* species can cause mortality in larval capelin and herring (Gosselin et al. 1989), mackerel (Robineau et al. 1991a) and five other larval fish species (Robineau et al. 1991b). Species of *Alexandrium* in the Estuary were so toxic that ingestion of a single cell contained enough toxin to kill first-feeding larvae. The potential for survival of larval fish to be threatened only would occur if toxic phytoplankton blooms coincide with larval emergence (Robineau et al. 1991a).

PSP toxins are also lethal to adult fish and have been implicated in herring kills in the Bay of Fundy. Kills of adult fish are sporadic events and appear to have a relatively limited impact on fisheries (Gosselin et al. 1989). PSP toxins were found in the livers of Atlantic mackerel caught at the northern tip of Cape Breton Island, Nova Scotia, during a massive fish kill. However, the evidence is not conclusive that the toxins caused the mortality (Levasseur et al. 1994). PSP toxins have been implicated in several cases of mortality in cetaceans and seabirds elsewhere, but no cases have been documented in Canadian waters (Therriault and Levasseur 1992). For example, Geraci et al. (1989) reported the deaths of 14 humpback whales (in Cape Cod, Massachusetts) that contained PSP-contaminated mackerel in their stomachs. Because no evidence of PSP-producing algae was found in New England waters at the time, the authors suggested that mackerel spawning in the Gulf of St. Lawrence accumulated it there and brought it to the Gulf of Maine in the fall of 1987.

Bacterial Contamination

Approximately 30% of the coast of southern Québec is closed to shellfish harvesting. Also, 61% of the south shore of the Estuary and 43% of the Gaspé Peninsula is closed (Wells and Rolston 1991).

In the Gulf, closures of shellfish harvesting areas are principally the result of bacterial contamination from human and animal wastes and agricultural runoff (Menon 1988). Figure 4.15 shows the coastal areas in the southern Gulf that are closed, either permanently or temporarily, to harvesting shellfish. Although the closure or approval of shellfish harvesting may vary locally from year to year, the overall trend since 1940 has been a steady upward trend in the number of shellfish closures (Machell and Menon 1992). Over a 17-year period (1975–1992), the area closed to shellfish harvesting has increased by an average of 34 km^2/year. Reversing these trends will require improved sewage treatment and improved effluent quality from industries and municipalities throughout the region (Menon 1988).

Uncertainties

This review has not covered all potential contaminants present in the Gulf and Estuary because information is only available regarding a few. Some specific classes of chemicals for which there is very little information include organometallics, most pesticides and polychlorodibenzo-p-dioxins and polychlorodibenzo-furans. Organometallic compounds of concern include organo-arsenic compounds and organotin compounds derived from anti-fouling preparations. Numerous pesticides on the market contain chemicals whose behaviour and toxicity in marine waters are unknown. In addition, there are specific areas of uncertainty:

- lack of quantitative data on the amount of chemicals entering marine waters from the atmosphere, ocean currents, and terrestrial sources (particularly municipal and agricultural runoff) for both the Gulf and Estuary system as a whole and specific locales such as coastal harbours and bays;
- little understanding of chemical, oceanographic and biological processes involved in the transformation of chemicals, particularly of organochlorine chemicals; and
- lack of recent data and the scarceness of existing data prevent time trends from being established for many chemicals in water, SPM, sediments and biota, particularly in areas of local contamination.

Chapter 5

Overall Assessment

Chapter 5 **Overall Assessment**

EACH OF THE PREVIOUS FOUR chapters examine the Gulf and Estuary from the perspective of a single scientific discipline. Nevertheless, when human activities are reviewed for potential environmental effects, cross-disciplinary issues are evident. We are unable to reach unambiguous conclusions about the effects of many of these activities and thus it is difficult to evaluate the appropriate level of concern. In most cases there is enough information to recognize the potential effects of a particular activity but not enough to evaluate the severity of the impact.

The Role Of Environmental Variability

Environmental variability is an issue that is hard to quantify but it certainly ranks as an important concern for all professional scientists. For example, the amount of precipitation determines the fresh water flow into the Gulf, which can influence phytoplankton and zooplankton productivity. This in turn may affect recruitment of catchable fish some years later. Fresh water flow will also affect the salinity in the region between Pointe-des-Monts and Cabot Strait, including the productive Magdalen Shallows. Deep water temperatures and oxygen content are affected by long-term oceanic events in the North Atlantic that propagate into the Gulf by means of the Laurentian Channel. Surface water temperatures are subject to both short-term variations and long-term climate modification. Any of these factors has the potential to change fish distributions, spawning grounds and larval survival. If there are adverse human activities (such as possible over-fishing) along with environmental changes, the cumulative stress on the environment may cause unintended changes to the ecosystem.

The variability and unpredictability in environmental conditions are the backdrop upon which human activities occur. By themselves, some activities may not seem to be a problem but when they occur in a system that goes through large fluctuations, some components of the ecosystem may be vulnerable. The major uncertainty shared by all disciplines is our inability to distinguish between the effects of natural variability and human-induced changes.

Human Activities of Concern

The impact of anthropogenic modifications on the marine environment is the focus of this chapter, and its structure follows that of Table 5.1 in discussing those human activities that cause the greatest concern.

Chemical Contamination of the Gulf and Estuary by Industries

Concentrations of many contaminants in biota and the environment—in water, SPM and sediment—have been declining (e.g., mercury, cadmium, PAHs, PCBs and DDT-group chemicals).

Environmental concentrations of contaminants has declined, probably as a result of regulatory actions:

- improved emission and effluent control at smelting operations;
- active regulation or other ongoing initiatives to control ocean dumping, dredging and pulp and paper mill effluent; and
- complete or restricted banning of the use of some chemicals such as DDT and PCBs.

On the other hand, there are many chemicals for which there are little or no data, such as organometallics and many pesticides and herbicides.

One of the major shortcomings of any data on chemical contamination is that although contaminant levels in biota may be known, the biological effects of these levels are not. These effects are unknown because there is little information on 1) toxic and less-than-lethal effects of many chemicals and 2) important biological data for marine organisms.

The following are the clearest and most important trends available on chemical contamination in living organisms and the marine environment of the Gulf and Estuary.

Table 5.1 Summary of anthropogenic effects in the Gulf and Estuary

Anthropogenic Activity	*Potential Environmental Effect*	*Evaluation*
Contamination		
industrial and municipal discharges	*Estuary:* Organochlorines—beluga Mirex—beluga, eels	concern
	Mercury—disturbance of sediments, particulate matter	concern
	Lead—sediments	lessening concern
	PAH and PCB—sediment (Baie des Anglais)	concern
long range transport	Organochlorines, mercury, lead	few data
dredging/ocean dumping	Increased availability of contaminants in resuspended sediments	concern for inshore areas only
oil spills	Mortality of seabirds and marine mammals	episodic events, concern for northern and western Gulf
municipal sewage, agricultural runoff, aquaculture operations	Increase in toxic algal blooms: mortality of larval fish and hazards to human health from contaminated shellfish	concern for inshore areas of the Gulf and Lower Estuary
	Bacterial contamination—hazard to human health	concern for humans who eat shellfish, throughout the Gulf
Harvesting		
fishing industry	Mortality and injury of target species; decrease of stock densities to low levels, thus influencing the age structure and genetic composition of stocks, disrupting the food web	concern for all commercial fish species
	Mortality and injury of non-target organisms (benthos, fish, seabirds, cetaceans) primarily by gear used for groundfish and scallop dragging	few data
directed hunt	Mortality and injury of seabirds and marine mammals; threatened populations historically	concern only if directed hunts are resumed
Habitat Alteration		
trawling dredging ocean dumping	Sediment resuspension: decreased phytoplankton productivity, egg and larval fish mortality, damage to gills of adult fish, smothering of benthic organisms or spawning beds of fish	concern for inshore areas only
	Changes to sea bottom: changes in benthic community structure, loss of fish spawning beds	sparse data, concern for inshore areas and heavily fished areas
coastal construction	Environmental changes to habitat of benthic and pelagic organisms and mammals (pupping habitat for grey seals)	sparse data, concern for Northumberland Strait

Estuary

Long-term information on spatial and temporal trends of organochlorine contaminants comes primarily from the seabird egg monitoring program. In 1984, seabirds in the Estuary and Gulf were the most contaminated seabirds at any coastal site in Canada. Between 1984 and 1992, levels of PCB and DDT-group chemicals significantly declined in eggs of Double-Crested Cormorants in the Estuary. Levels of dieldrin and HCH also declined while other pesticides (oxychlordane and mirex) appear to be as prevalent as in the mid-1970s. Current levels of contaminants in cormorants are comparable to those found in the Bay of Fundy but are higher than those in seabirds from Newfoundland, the west coast and Arctic regions of Canada. Levels of organochlorines in seabirds from the Great Lakes are 2–4 times higher than those on the east coast. The seabird data suggest that atmospheric inputs of organochlorines to the open ocean may currently be more important than river inputs to the marine environment.

Organochlorine levels do not now appear to affect the reproduction of seabird populations. In fact, many areas of the Gulf and Estuary have increasing seabird populations, in response to cessation of illegal hunting, collecting of eggs and, most importantly, regulatory controls that have reduced the amount of organochlorines entering the environment.

The reproduction of beluga whales in the Estuary is possibly being impaired by high organochlorine (mirex, PCB and DDT-group chemicals) levels, which have been observed in beluga blubber. Current concentrations of organochlorines in St. Lawrence belugas are representative of a lifetime (as much as 40 years) of accumulation. However, no cause and effect relationship has been established between contaminant levels and reproductive success.

Studies of chemicals in the Estuary's food web indicate that it is pelagic organisms—not benthic ones—that are contaminated. This finding suggests that suspended particulate matter and migratory eels are the primary carriers of contaminants in the St. Lawrence River and, therefore, to marine animals.

Migratory eels had a marked decrease in contaminant concentrations between 1982 and 1994: 56–77% decrease for PCBs, DDT-group chemicals and mirex in their tissues, although levels were still comparatively high.

Lead and mercury levels in the sediments of the Estuary and Saguenay Fjord (which empties into the Estuary) are high because of past industrial emissions (chloralkali and aluminum plants) and present industrial emissions (aluminum plants). Elevated levels of PAH, associated with aluminum refineries and pulp and paper mills, also have been found in the Estuary, particularly near the Saguenay Fjord and Baie des Anglais. Since the highest levels of contaminants in sediments are found trapped in the deeper layers—deposited there in past decades when there were few emission and effluent regulations—it is important that such sediments not be physically disturbed, for example, by dredging. Otherwise, higher concentrations of contaminants will become available for uptake by marine organisms.

Figure 5.1 combines Table 4.2, Figure 4.11, Figure 4.12 and Figure 4.14 to show the relative increase in PCB contamination in the Lower Estuary at higher trophic levels. It is evident that significant bioconcentration is occurring.

Gulf

There are problems caused by contaminants in localized areas of the Gulf (e.g., Chaleur Bay), but these are neither sufficiently severe nor widespread to have resulted in major deterioration of marine resources and amenities in the region. Sewage discharge, mineral processing and pulp and paper mills represent the most common causes of these local problems. The only area of the Gulf that shows strong evidence of anthropogenic degradation is Chaleur Bay, which has received effluents from mine smelting operations. Elevated levels of mercury and cadmium occur in sediments, mussels and lobster. Absence of data prevents assessment of other inshore areas.

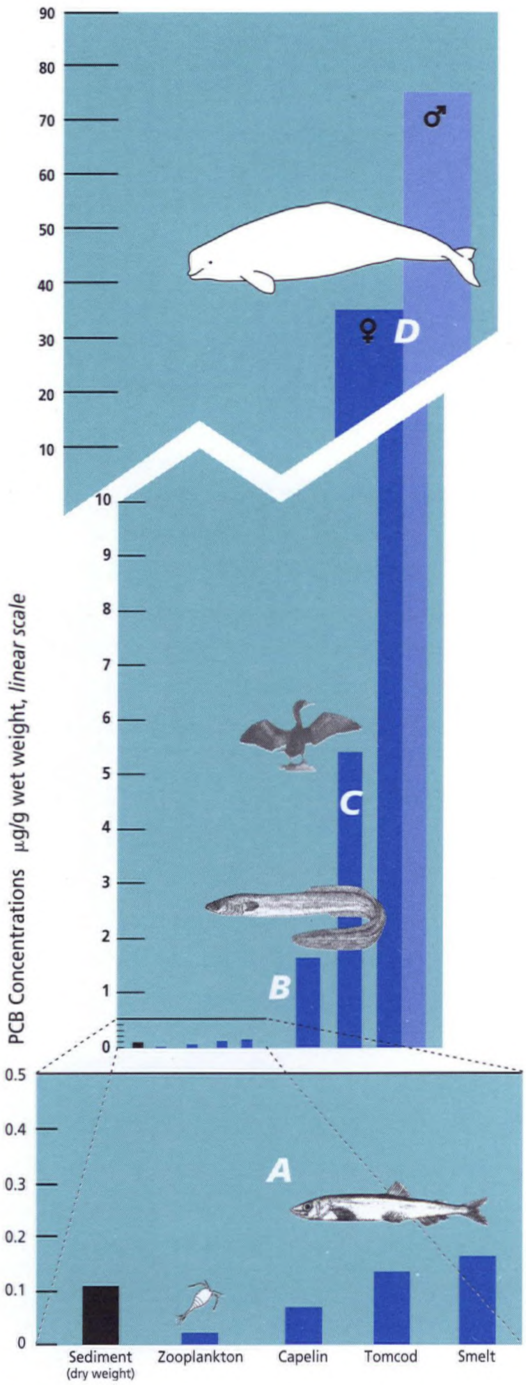

Figure 5.1
PCB concentrations in the food web of the St. Lawrence Estuary

A Total PCB concentrations in sediment, zooplankton and pelagic fish in the Upper Estuary in 1987
Source: Gagnon et al. 1990

B Geometric mean level of PCB in adult migrating eels in the Lower Estuary in 1990
Source: Castonguay et al. 1989; Hodson et al. 1994; C. Desjardins, unpublished data

C Average concentration of PCB in Double-Crested Cormorant eggs in the Estuary in 1992
Source: N. Burgess, personal communication

D Average PCB concentration in male and female beluga blubber from the Estuary in 1986 / 87
Source: Muir et al. 1990

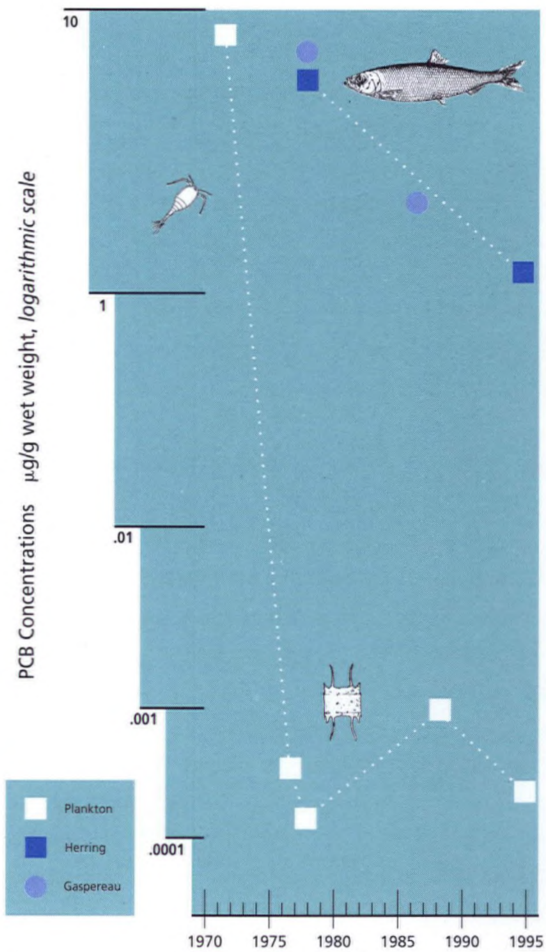

Figure 5.2
Average PCB concentrations (as Aroclor 1254 equivalent) in plankton and fish collected in St. Georges Bay in the southern Gulf
Sources: adapted from Harding et al. in press and G. Harding, personal communication

St. Georges Bay, N.S. in the southern Gulf is probably the most studied coastal region in the Gulf, especially for PCB contamination. Since the early 1970s, there has been a downward trend for PCB contamination in plankton and fish. However, concentrations in plankton have remained relatively constant and low since 1977. This has been attributed to local atmospheric deposition from sources far away. Figure 5.2, a combination of Figure 4.9 and Figure 4.10, shows the relative increase for PCB concentrations in biota.

Chemical Contamination by Long Range Atmospheric Transport

Long range transport of chemicals is a worldwide problem. Evidence suggests that in the open areas of the Gulf, atmospheric deposition of some chemicals (e.g., mercury) may be equal to all other inputs combined. The continued presence in the Gulf of chemicals long banned from use in North America and Europe (e.g., DDT) is attributed to their environmental persistence and continued low inputs from atmospheric transport of chemicals carried to North America from countries where such chemicals are still in use or where controls are lax.

Chemical Contamination by Oil Spills

Petroleum hydrocarbon discharges from industries in the Estuary and Gulf are hundreds of times less than what they once were and substantial improvements in water quality have occurred. As of 1988, the major source of hydrocarbons in the Gulf has been the inflow of adjacent North Atlantic ocean water.

Oil spills, occurring as unpredictable and episodic events, pose the single largest threat to seabird populations, particularly if a spill occurs near a breeding colony or during migration. The most concentrated colony areas for seabird breeding in the Gulf are in the north and west. These areas are also feeding grounds for harp seals and whales. Populations in those areas would be the most vulnerable to an accidental oil spill.

Chemical Contamination by Municipal Sewage, Agricultural Runoff and Aquaculture Operations

Untreated municipal sewage, sometimes combined with industrial sewage and pesticides from land runoff, have not been quantified in either the Gulf or Estuary. The long-term trend is one of deteriorating inshore environments as evidenced by an increase in the number and total area of shellfish beds that have been closed to fishing because of health concerns to humans who eat shellfish.

Excess nitrogen from agricultural runoff, municipal sewage, and wastes generated at agriculture and aquaculture farms has been implicated in the increased incidence of toxic algal blooms, particularly in PEI. Although monitoring has effectively prevented any further incidents of human poisoning from phycotoxins by shellfish consumption, the distribution of various toxic algae species has been increasing. Larval fish are potentially vulnerable to toxic algal blooms, but there is no evidence that blooms have had an impact on larval fish survival.

Effects of Harvesting

In the past, fisheries managers ascribed relatively few biological effects to exploitation. However, recent studies show that the effects of exploitation include changes in the genetic composition of exploited populations, habitat destruction, and disruption of food web or species interactions. Biological evidence indicating that groundfish stocks were in trouble was available before the recent fishery closures. Particularly clear was the evidence of changes in distribution of cod and redfish stocks in the Gulf, reduced growth in cod, the disappearance of young year-class redfish and mortalities that exceeded quotas as early as 1987.

A solid understanding of fish biology, biological effects of exploitation, and environmental effects on fish recruitment needs to be fully incorporated in the future management of fish stocks.

In the past, unregulated hunting of seabirds and whales led to drastic population reductions and, for seabirds and whales, elimination of some species from the Gulf and Estuary. Some seabird species have recovered, although not to their former numbers. The St. Lawrence beluga has not recovered. If direct hunting is resumed, it can be expected that population reductions in the hunted species will be significant.

Habitat Alteration

Trawling, Dredging and Ocean Dumping

Dredging and ocean dumping occur only at minor levels in the Gulf and Estuary, but they can enhance the effects of coastal wave action, increase suspended sediments in the waters, release contaminants from sediments, accelerate coastal erosion and cause permanent alterations to the seabed. As a result, fish spawning areas may be lost or made uninhabitable for benthic organisms, including commercially important groundfish and crustaceans. On the other hand, the expanding use of preliminary assessments for permitting ocean dumping activities should result in adverse effects being reduced.

Fish trawling has some of the same effects as dredging and dumping, albeit probably not at the same intensity on any one local area. Degradation of habitat by fishing activities and its potential effects on the food web and future recruitment of fish stocks has only recently begun to be studied.

Coastal Construction

The lack of baseline data on the biological and physical systems and their interaction in inshore areas seriously undermines the ability to predict the impact of coastal construction projects. Apart from oceanographic understanding and location of commercial fish, most coastal areas of the Gulf and Estuary lack historical data that document the variability of the system against which changes due to coastal construction can be compared.

An example of this deficiency in our knowledge is that a major coastal modification project—the 13-km bridge linking Prince Edward Island and New Brunswick—has proceeded under the umbrella of tight environmental monitoring because the ultimate effect of the bridge on major components of the benthic food web, phytoplankton productivity, fish spawning and recruitment is uncertain.

Resource Use Conflicts

Human activities in any ecological system, marine or others, can lead to habitat loss and environmental degradation. At intense levels of use, this can lead to conflicts in using the same marine environment as a recreation area, food source and for dispersal of liquid, gaseous and solid wastes.

In fact, a common theme throughout Chapters 1–4 and in Table 5.1 is the conflicting uses made of inshore areas. Industrial facilities use air and water to disperse waste products of their operations. Many coastal cities and towns use nearby waters to dilute human and industrial wastes; these same areas (e.g., Miramichi Bay and Chaleur Bay) also are subject to occasional coastal construction, and sporadic dredging and marine dumping. All these activities can conflict with the fishing industry and with recreational activities. In the past, little attention has been paid to these conflicts of use but responsible environmental stewardship requires that all users, both direct and indirect, of the waters of the Gulf and Estuary cooperate so that the ecosystem remains healthy and sustainable for future generations.

Recommendations for Further Research

The actions needed to help protect the Gulf and Estuary from further degradation are mostly in the realm of scientific studies to eliminate areas of critical uncertainty. The lack of fundamental information hinders our ability to predict the effects of human activities such as coastal construction, commercial fishing and inputs of chemical contaminants.

- Dredging and raw sewage discharge can conflict with commercial fisheries and recreation in inshore areas. Therefore, inshore areas require more detailed studies by multidisciplinary teams of scientists: oceanographers, biologists, fish scientists and marine chemists. Such studies will expand our knowledge of local physical, biological and chemical oceanography and aid in resolving use conflicts in inshore areas. Important nursery areas for commercial fish (e.g., Belledune Harbour, Chaleur Bay and St. Georges Bay, NS) are potential candidates for such studies.

- Mercury, PCBs and DDT-group contaminants are coming under control due to regulations and use restrictions beginning in the 1980s. However, new contaminants, such as chemical plasticizers and newer pesticides, are little studied and their effects need to be closely examined.

- Local sources of contaminants have declined in the region due to regulatory controls and, thus, long range atmospheric transport may now be the dominant source for some contaminants. Atmospheric transport is a much harder problem to solve because of transjurisdictional issues. More study is required, both by scientists and policy makers, to determine 1) the long-term effects of chronic, low-level contamination and 2) the appropriate regulatory response.

- Establishing ecological objectives for protecting marine life is hindered by lack of data on the marine toxicity of specific chemicals, particularly organochlorines. Thus, greater effort needs to be given to toxicological issues.

Glossary

Abundance
A measure of the total number of individuals of a species within a defined group (population) or area (stock).

Adsorption
The retention of gases, dissolved chemicals, or ions on the surface of particles. These particles may occur in water, sediments or biota.

Age class
All fish in a stock that are the same age, such as all three-year olds.

Anadromous
Fish such as Atlantic salmon that live in the sea and migrate to fresh water to spawn.

Anoxic bottom waters and sediments
Waters that are near the sea floor and bottom sediments whose oxygen content has been depleted by high levels of decomposition and biological activity.

Bathymetry
The science of measuring ocean depths to determine sea floor topography.

Benthic
The sea bottom environment, regardless of depth, and the organisms that inhabit that environment (see **benthos**). The benthic zone, along with the pelagic zone, is one of the two major divisions of marine ecosystems.

Benthic fish
Fish—such as flounder, cod and stingrays—that spend much of their life at or near the sea bottom.

Benthos
Plant and animal organisms that live on or in sea bottom sediments. Benthos can include benthic fish as well as true bottom dwellers such as shellfish and sea worms (see also **epifauna** and **infauna**).

Bioaccumulation
A general term describing the ingestion and retention of chemical substances by organisms, either from the environment or by consumption of food.

Bioavailable
The portion of the total amount of substances present in the environment that can be assimilated by organisms.

Biological cycling
The continuous transfer of energy and material between different organisms. For example, plankton are consumed as food by a prey species such as capelin, which in turn become food for higher-level predator species such as cod. The cod in turn becomes food for higher-order predators or for planktonic scavengers or detritovores (zooplankton that consume detritus) when it dies.

Biological production
The production of organic matter by the organisms in a specific area.

Biogeochemistry
In a given geographical area, the specific interactions between biota and chemicals in the soils, rocks, waters and atmosphere.

Biomass
The total mass of a species or group of species within a defined area. In fisheries, the area is often defined as the region inhabited by a particular fish stock, and the biomass is measured in metric tonnes per stock.

Bioturbation
The movement and mixing of sediments by animals—such as polycheates (marine worms) and shrimp—that burrow in and ingest sedimentary material.

Catadromous
Fish such as American eels that live in fresh water and migrate to the sea to spawn.

Classification
The systematic grouping and naming of plant and animal organisms according to physical characteristics; also known as taxonomy. The smallest group which is regularly distinguished is the species. Species are grouped into genera, genera into families, families into orders, orders into classes, classes into phyla (animals) or divisions (plants), and phyla or divisions into kingdoms, the highest taxonomic ranking.

Chloralkali
Industrial facilities that produce chlorine and caustic soda (NaOH) by the electrolysis of sea water.

Chlordane
Chlordane is used to control a variety of insects and insect larvae on ornamentals, vegetables, bulbs, strawberries, lawns and turfs. It is also used to control wood-boring insects in housing and other buildings. Oxychlordane is a persistent and toxic metabolite of chlordane and is the major metabolite produced by mammalian systems.

Chlorobenzenes
See **HCB**

Compositional features (of sediments)
The nature and relative proportions of the chemical and mineral components that make up the main physical constituents of particular bottom sediments.

Community
An assemblage of organisms characterized by a distinctive combination of species occupying a common environment and interacting with one another.

Conduction
Heat transfer from one region to another because of differences in temperature. This transfer of heat is not accompanied by transfer of matter, rather it occurs by molecular collisions.

Coriolis Force
The tendency for moving objects to turn counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere due to the earth's rotation. Local phenomena can modify this tendency.

Diadromous
Fish that migrate between salt and fresh waters.

DDT, DDE, DDD
Dichlorodiphenyltrichloroethane, a chlorinated organic compound once used extensively as an insecticide, but banned during the 1970s in Canada and the United States. While not hazardous to humans under normal circumstances, DDT is a persistent environmental poison that is toxic to fish and seabirds. DDT decomposes to produce the degradation products (metabolites) DDD (dichlorodiphenyldi-chloroethane) and DDE (dichlorodiphenyldi-chloroethylene), which also exhibit environmentally damaging effects.

Degree of tissue contamination
The relative amount of a tissue, such as liver or kidney, within an organism that has been detrimentally affected by a toxic chemical.

Demersal species
Fish that live at or near the bottom of the sea. Also, sometimes used as a synonym for benthic fish.

Density front
The boundary between two adjacent masses of ocean water with different densities that cause these water masses to behave separately. A tidal front is a density front that occurs between nearshore and offshore waters and is produced when the density of the shallower nearshore water is altered through mixing by tides.

Detritus

Unconsolidated sediments composed of both inorganic and dead and decaying organic material. Detritus is the basic food for planktonic animals known as detritovores, which break down the material and re-introduce it into the food web.

Dieldrin

A contact insecticide. Its use was generally restricted in Canada in 1975 to be used only for termite control. It is a persistent contaminant.

Dioxins

A family of 75 related chemical compounds formally called polychlorinated dibenzo-p-dioxins that are principally formed as by-products in the manufacture of other chemicals. Sources include municipal incinerators, wood waste, slash burning, fuel wood burning, motor vehicles, some herbicides, the wood preservative pentachlorophenol (PCP) and sewage sludge. Some compounds are hazardous to humans, even at low concentrations.

Drainage basin

The land area over which surface water and groundwater is carried by the natural slope of the land to streams, rivers, bays, gulfs, seas and oceans. Streams have the smallest drainage basins and oceans have the largest.

Echolocation

The use of reflected sound to determine the shape, size and location of objects. Many marine mammals, including toothed whales, minke whales, seals and walruses, use echolocation to navigate through dark or clouded waters. The physiological mechanisms used to produce, receive and process the sounds used in echolocation are often highly sophisticated, particularly in whales.

Ecosystem

The physical environment, along with organisms (biota) inhabiting that space. Processes that determine the characteristics of a particular ecosystem are the birth, growth, reproduction and death of biota season-to-season, year-to-year and over decades and centuries. The interactions between species and between species and the physcial and geological environments determine how matter and energy cycle and flow through the system.

Entrainment

The waters contained by a large body of water often have different physical properties.The physical forces can be different from subregion to subregion. Entrainment refers to the occasions when a large amount of water having particular properties (e.g., temperature and salinity) is trapped or carried within an even larger mass of water that has different properties. The entrained mass can be carried large distances, both vertically and horizontally.

Epifauna

Bottom-dwelling animals (benthos) that live on the surface of the sea floor, such as scallops, crabs, lobster and shrimp; also known as epibenthos.

Estuary

The area of a coastal river that is affected by the tides of the ocean into which the river flows and where fresh and salt waters meet. Estuarine flow refers to the general tendency for the surface waters to be fresh (how deep the surface is depends on the estuary) and flowing out of the estuary while the bottom flow of water is saline and into the estuary. It is because the saline water is denser than the fresh water that saline water is found near the bottom of the estuary.

Eutrophic

Waters that are abundant in nutrients and have high rates of productivity frequently result in oxygen depletion below the surface layer of a water body.

Fate

Disposition of a material into various environmental compartments (e.g., sediment, water, air, and biota) as a result of transport, transformation and degradation.

Fauna
The animal population of a specific environment.

Fecund / Fecundity
In fish, this term denotes how prolific the females are, as measured by the average number of eggs laid per breeding cycle.

Fishable stock
The part of a stock that is available to be fished. The fish must be big enough to be caught and must live in places where fishermen work to be part of the "fishable stock."

Fisheries management
The application of regulations such as catch quotas and licensing to limit a fishery to meet specific objectives. Fisheries management objectives are often defined in terms of government policy.

Flora
The plant population of a specific environment.

Food web
The interrelationships between the different food chains found in a particular locality. Whereas food chains are simple linear relationships, food webs are more complex and encompass both predator/prey and predator/predator relationships between trophic levels.

Furans
Formally called polychlorinated dibenzofurans, they are a similar group of compounds as dioxins. There are about 135 types of furans, and they are formed by the same processes as dioxins.

Grain-size distributions
The percentages (by weight or count) of mineral particles of different sizes in particular sediments. These particles and their sizes include clay (less than 2 µm), silt (2–64 µm), sand (64 µm– 2 mm), granules (2–4 mm), gravel (4 mm–6 cm), cobbles (6–25 cm) and boulders (greater than 25 cm).

Gyre
A circular movement of water formed by wind activity, upwellings or currents, especially when the latter pass obstructions or when two adjacent currents run counter to each other. They play an important role in the transport of dissolved substances, heat and momentum.

Habitat
The natural environment of a plant or animal organism.

Habitat degradation
The physical or chemical harm done to natural areas that are important to an animal population for feeding, breeding or nesting. The source of harm can be local, such as siltation that occurs during construction of shoreline facilities, or more distant, such as the transport of toxic materials to the sea from terrestrial runoff.

HCH
Hexachlorocyclohexane or benzene hexachloride is a synthetic chemical compound used as an insecticide. Hexachlorocyclohexane is a mixture of eight related compounds, but only one, lindane, has significant insecticidal activity. The principal sources of lindane are its direct and indirect application, agricultural runoff and industrial discharges, primarily in western Canada. Long range transport is the principal mechanism by which it reaches the marine waters of Atlantic Canada.

HCB
In the past, hexachlorobenzene (HCB) was used 1) as a fungicide and a wood preservative, 2) in dye and electrode manufacturing, and 3) as an additive in pyrotechnical compositions. At present it is not produced as a product but may be produced inadvertently as a waste product in chemical manufacturing. HCB is a concern because it is widespread in the environment and occurs in food for human consumption. The St. Lawrence-Great Lakes system is a critical region for HCB contamination because of the numerous

chlorine plants located in the region.

Heat budget
The balance or imbalance between the amount of heat received by an area from solar radiation and the amount that an area loses through processes such as evaporation, re-radiation and reflection. The heat budget for a given area varies daily and seasonally. On an annual basis, higher latitudes such as those of Atlantic Canada locally lose heat but it is replaced by heat originating from equatorial latitudes via winds and ocean currents.

Heptachlor epoxide
Occurs as a result of the breakdown of heptachlor by organisms. Heptachlor is a pesticide that is not registered for use in Canada. There is no available information on how much is imported. Heptachlor epoxide is generally resistant to chemical and biological transformations in the aquatic environment. It is generally toxic to aquatic life, but its toxicity varies greatly from species to species.

Infauna
Bottom-dwelling animals (benthos) that spend most of their lives buried in sea floor sediments, such as sea worms, clams and oysters; also known as endofauna.

Internal tides
A phenomenon that occurs below the surface of the water where and when the water is stratified. Internal tides appear when the positions of the different layers of water, which have different densities in the water column, begin to undergo a regular, wave-like oscillation.

Intertidal zone
The marginal area between the high water mark and the low water mark; it is periodically flooded by tides.

Level of exposure
The degree to which biota are exposed to chemicals in the environment. The exposure is not only dependent on the chemical concentrations in the environment but also on biological variables: the exposed species and individuals, properties of the habitats in which species dwell and the life cycle of a species (e.g., birth, juveniles, adults and time of breeding).

Limit of detection
The smallest concentration of a particular substance that can be determined by a specific chemical analysis. The limit of detection will vary for different methods of analysis, and is particularly important in determining which methods to use to analyze substances that occur at very low concentrations.

Lipid tissue
Animal tissue made up primarily of organic substances such as fats, oils and waxes; commonly known as "fatty tissue".

Lipophilic
Having an affinity for fats, oils and waxes.

Metalliferous sulphide deposits
Deposits of sulphur compounds that contain large concentrations of metals.

Mirex
Mirex is used for control of various ant species as an insecticide, flame retardant in plastics, and smoke generator in pyrotechnics. It is an ingredient in anti-fouling paints, rodenticides and antioxidants. Its use was primarily in the U.S. portion of the Great Lakes. In 1978, the importation, manufacturing and processing (which would lead to its dispersion) was prohibited in Canada. Its main source is release during manufacturing processes, particularly of kepone by two manufacturing and processing plants in the U.S., which discharge into tributaries of Lake Ontario.

Natural weathering
The disintegration and decomposition of rock into smaller particles by natural physical,

chemical and biological processes.

Organochlorines
Chemical compounds that are made primarily of carbon, hydrogen and oxygen but also that contain the element chlorine (Cl). Many of these organic chlorinated compounds, such as dioxins, furans, many insecticides, DDT and PCBs, are toxic or carcinogenic.

Organotins
Chemicals with 1 to 4 carbon atoms covalently bonded to the tin atom. It is used as a powerful biocidal agent (mainly as tributyltins) against a wide spectrum of fouling and boring organisms. They are widely used in marine anti-fouling paints and as preservatives, plastic stabilizers and lubricants. Organotins leach easily into the marine environment where they have a high toxicity to most marine organisms.

Oxychlordane
See **chlordane**.

PAHs
Polycyclic aromatic hydrocarbons, a group of organic compounds produced by the burning of fossil fuels. Sources include thermal power plants, coke ovens, sewage, wood smoke and lubricating oils. Many PAHs are highly carcinogenic.

PCBs
Polychlorinated biphenyls, a class of synthetic chlorinated organic compounds once widely used primarily as insulation in electrical equipment. These compounds are highly carcinogenic and have been shown to disrupt reproduction in gulls and other higher animals. See **PCB congener**.

PCB congener
Any of over 209 possible configurations of PCBs differing only in the number or position of the chlorine atoms in their molecular structure.

Partitioning processes
The chemical process by which compounds may be found dissolved in water or bound to suspended particulate matter. Sometimes the concept is extended to include incorporation into biota and sediments. The partitioning depends on many properties of the marine waters, among them being the water temperature, salt content, pH value and amount of organic matter.

Pathological lesion
An abnormal or harmful change in the structure of an organ or tissue caused by disease.

Pelagic
Pertaining to the marine aquatic environment at all depths, but excluding bottoms and shores (benthic and littoral zones). The pelagic zone, along with the benthic zone, is one of the two primary divisions of marine ecosystems.

Persistence
When applied to environmental contaminants, the tendency for a chemical to remain in the environment for a long time before it breaks down into inert and generally innocuous substances.

Photosynthesis
The process by which chlorophyll-containing organisms such as algae, plants and some plankton use the energy of sunlight to produce new organic material (carbohydrates) from inorganic carbon dioxide and water.

Plankton
Minute plants and animals that drift in the sea and are the basic food source for many marine mammals and commercial fish. Plankton include a vast group of organisms.

Population
A closely associated group of individuals of the same species that occupy a common area, such as cod on the Grand Banks.

Population biomass
The total mass of a single species that occupies a common area or space.

Primary production
The amount of new organic matter produced from inorganic material by organisms using photosynthesis.

Productivity
The rate at which a population, species or ecosystem produces new individuals over a specific time period.

Recruitment
The entry of maturing juvenile fish into the adult (sexually mature) portion of the population that can be harvested. Frequently, the range of juvenile fish is geographically different from the adult population.

Resuspension
The transfer of dissolved contaminants and contaminated particles from sediments to the overlying water through chemical processes (oxidation and reduction reactions). Resuspension may be enhanced by processes such as physical mixing or bioturbation.

Salinity
The measure of the amount of salt in a body of water. Fresh water is usually about 0.2 parts per thousand (by weight) and ocean water, 35 parts per thousand. It is measured by comparing the conductivity of a sample of water to the conductivity of a known standard. The "practical salinity unit" is used in this text and has the same numerical value as the old measure of parts per thousand except in very saline or very dilute waters when the difference is, at most, 0.06 units.

Schooling behaviour
The gathering together of fish species into large dense groups for feeding, protection and reproduction. Even if the total population of a schooling species decreases due to fishing, natural predation or environmental change, the density of fish within a given school generally remains substantially unchanged. It is thus possible to harvest large quantities of a fish species whose total overall population may be declining.

Seabird colony
A large, densely populated grouping of seabirds living in close proximity during their annual nesting period.

Sediment
Matter that settles to the ocean bottom; it comprises muds, clays, shells and remains of living organisms.

Spawning biomass
The sexually mature portion of a fish population that is ready to reproduce. In some species (e.g., haddock), spawning adults congregate into a distinct group referred to as a spawning aggregate.

Species
A taxonomic grouping of plants or animals of common ancestry that closely resemble each other and can produce fertile offspring.

Stratification
The separation of a body of water into vertical layers (strata) that have differing densities due to variations in temperature, salinity and (to a lesser degree) pressure. Stratified marine systems of this type are generally characterized by warmer, less dense waters on top and colder, denser waters on the bottom.

Subtidal zone
The area of sea bottom between the low tide level and the continental shelf; also known as the sub-littoral zone.

Suspended particulate matter
The relatively fine particles (primarily clay, silt, small organic and inorganic debris, plankton and microscopic organisms) that drift with water currents and only slowly settle out to form the sediments that underlie rivers, bays, gulfs and oceans.

Sustainable yield
The portion of a fish population that can be harvested continuously without impairing its ability to renew itself through reproduction and recruitment. The sustainable yield also can be defined as

the annual increase in biomass (growth and recruitment) within a stable population.

Taxon (taxa)
A general grouping of organisms of a similar type (see also **classification**).

Tidal front
See **density front**.

Toxaphene (CHB)
Toxaphene is a complex mixture of chlorinated camphene and bornane derivatives. It has a typical chlorine content of 67–69%. Toxaphene was widely used as an insecticide and replaced DDT in many agricultural uses, but its use is now prohibited in both Canada and the U.S. Long-range transport is the primary mechanism by which it reaches areas where it has never been used, such as the Arctic.

Toxicity
The capacity of a substance to produce biochemical or anatomical damage to an organism. Chronic toxicity is biochemical or anatomical damage caused by long-term exposure to low or moderate levels of a toxic substance. Acute toxicity is a poisonous effect caused by short-term exposure to high levels of a substance, resulting in significant biochemical or anatomical damage or death.

Toxicological effects
The impacts of a chemical substance on the health of individual organisms or groups of organisms.

Trophic level
A portion of the food chain in which all organisms obtain food and energy in essentially the same manner.

Turbidity
A decrease in water clarity, thus preventing penetration of light. It results from the presence in water of suspended particulate matter such as clay, silt, small organic and inorganic debris, plankton and microscopic organisms.

Ultra-basic rock
Igneous (volcanic) rock that contains a very low (<44%) silica content.

Upwelling
The rising to the sea surface of cold, dense subsurface water. Upwelling can occur where two currents diverge or where surface water is displaced by physical forcing. Upwelled water, in addition to being cooler, is also often rich in nutrients, so that regions of upwelling are generally also regions of rich fisheries. Tidal upwelling occurs when tide-induced currents flow away from the coastline, displacing surface waters.

Vertical mixing
The transport and distribution of properties such as temperature, salinity and chemical composition between surface and subsurface waters by forces such as waves, tides and currents. Vertical mixing is generally most intense in the surface layer of water and can be inhibited by strong stratification.

Volatile anthropogenic chemicals
Man-made chemical compounds that evaporate readily at ordinary temperatures. Detrimental environmental effects have been attributed to some of these compounds, such as DDT-group chemicals and PCBs.

Water column
The volume of water between the sea surface and sea bottom. The term is used to refer to vertical differences in temperature, salinity or chemical composition within a body of water.

Whelping area
An area where marine mammals such as seals and walrus gather to give birth to their young.

Year class
All fish in a stock that were spawned in the same year, such as all those spawned in 1990. Also called a cohort.

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Chapter 3
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Chapter 4
Occurrence of Chemicals

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Personal Communications for Chapter 4

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Geographic Index

Subject Index

(page numbers, table numbers, boxes and figure numbers in **bold** indicate major discussions)

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