BAY OF FUNDY ISSUES
A
SCIENTIFIC
OVERVIEW

Proceedings of a Workshop
January 29 - February 1, 1996
Wolfville, Nova Scotia

FMESP
Fundy Marine Ecosystem Science Project

Editors
J.A. Percy, P.G. Wells and A.J. Evans

Environment Canada
Atlantic Region
Environnement Canada
Région de l'Atlantique

Fisheries and Oceans
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Pêches et Océans
Région de Scotia-Fundy

The
Gulf of Maine Council
on the Marine Environment

Acadia Centre for Estuarine Research

Clean Annapolis
River Project

This publication should be cited as:

Percy, J.A., P.G. Wells, and A.J. Evans (eds) (1997) Bay of Fundy Issues: a scientific overview. Workshop Proceedings, Wolfville, N.S., January 29 to February 1, 1996. Environment Canada - Atlantic Region Occasional Report no. 8, Environment Canada, Sackville, New Brunswick, 191 pp.

Copies may be obtained from:

Environmental Conservation Branch
Environment Canada - Atlantic Region
P.O. Box 1590, Sackville, N.B.
E0A 3C0

Published by Authority of the
Minister of Environment

Catalogue No. CW69-12/8-1996E
ISBN 0-662-25570-4
ISSN 1195-664X

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SUPPORTING AGENCIES AND GROUPS

The Fundy Marine Ecosystem Science Project and the Wolfville Workshop were supported by the following agencies and groups:

Environmental Conservation Branch,
Environment Canada,
Dartmouth, Nova Scotia.

Canadian Wildlife Service,
Environmental Conservation Branch,
Environment Canada,
Sackville, New Brunswick.

Environmental Monitoring and
Assessment Network,
Environment Canada,
Burlington, Ontario.

Fisheries and Oceans Canada,
Bedford Institute of Oceanography,
Dartmouth, Nova Scotia.

Fisheries and Oceans Canada
Halifax, Nova Scotia

Gulf of Maine Council on the
Marine Environment
Augusta, Maine

Acadia Centre for Estuarine Research,
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PREFACE

The Bay of Fundy is an important component of the major functional coastal unit known as the Bay of Fundy - Gulf of Maine - Georges Bank System (FMG). It is renowned for its unique oceanography, abundant marine resources, diverse wildlife (especially seabirds and whales), fascinating history and outstanding natural beauty. The Bay has traditionally been recognized as comprising a number of distinct regions, sometimes named in a confusing fashion. In this report the various subareas are shown in Figure 1 and are named as in Prouse *et al.* (1984: see Chapter 4 references) and are defined as follows:

> ***Upper Bay*** - *Chignecto Bay and Minas Basin, located to the northeast of Cape Chignecto*
>
> ***Inner Bay*** - *From the level of Cape Chignecto to the St. John-Digby line*
>
> ***Outer Bay*** - *From the St. John-Digby line to the mouth of the Bay*
>
> ***Lower Bay*** - *a general term for both the outer Bay and inner Bay together*

The Bay's dynamic environment is continually changing, both naturally and as a result of human activity. Some indicators of marine ecosystem health suggest that undesirable ecological and habitat changes may be occurring in the Bay, and that important parts of the ecosystem are being impaired. Key species (for example: migratory shorebirds and intertidal invertebrates in the Upper Bay) and critical habitats (for example: salt marshes, mud flats) are at risk. Some of these changes are of special significance. For example, the mudflats of the Upper Bay are "Wetlands of International Importance" under the Ramsar[*] Convention and have been designated as a 'Western Hemispheric Wildlife Reserve' for their critical role as habitat for migrating shorebirds such as plovers and sandpipers. The Lower Bay, which is heavily traveled by shipping, is renowned as a summering area for whales, especially the endangered North Atlantic right whale. As a result, certain offshore areas are being considered for designation as Marine Protected Areas. Furthermore, many of the marine resource stocks and their habitats are reduced or threatened, posing severe economic hardships on coastal communities in Nova Scotia and New Brunswick which have long been dependent on the fisheries.

> ***"Some indicators of marine ecosystem health suggest that undesirable ecological and habitat changes may be occurring in the Bay, and that parts of the ecosystem are being impaired."***

These concerns have led to the launching of a new project - the Fundy Marine Ecosystem Science Project (FMESP). The Project's initial goals are to attempt to address five broad questions:

> *a) What is happening in the Bay of Fundy marine ecosystem, with particular emphasis in the Upper Bay?*
>
> *b) Is our knowledge of the ecosystem sufficient to understand what is happening?*
>
> *c) What else do we need to know?*
>
> *d) How are we going to find the answers?*
>
> *e) How can we use the evolving scientific understanding in support of continued management for conservation and protection of the Bay's ecosystem?*

A necessary first activity, underway since March, 1995, was to develop a synopsis of recent Bay of Fundy scientific, technical and anecdotal informa-

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[*] Named after the city in Iran where the Convention was signed in 1971; The Convention is a framework for international cooperation for the conservation and wise use of wetlands and their resources.

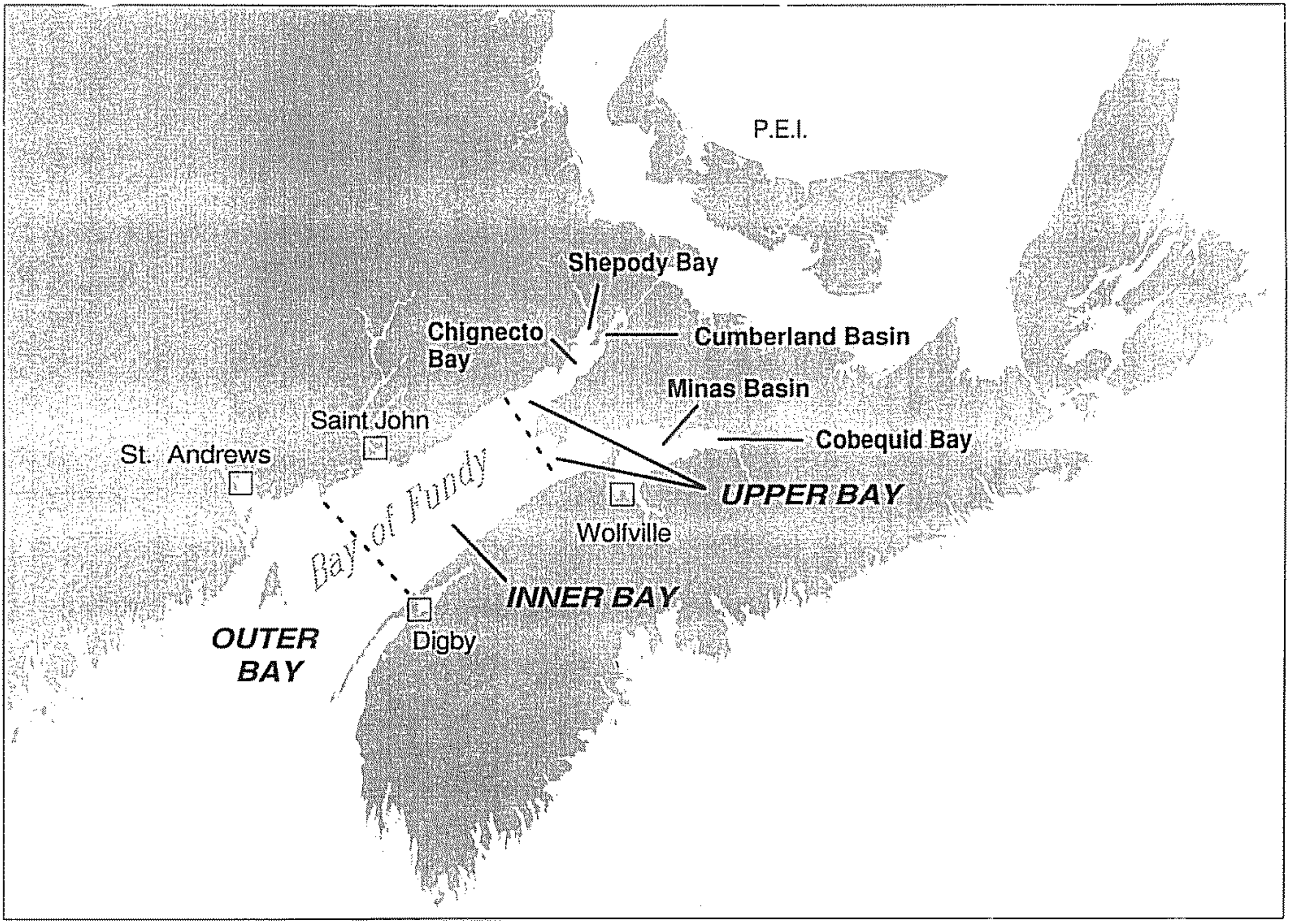

Figure 1 The Bay of Fundy and its principal subareas. *(Map prepared by R. Cranston, Bedford Institute of Oceanography)*

tion. Thus, a draft background paper was prepared by a number of contributors to summarize recent ecological understanding and identify current issues facing the Bay. A supporting bibliography of recent (largely since 1985) scientific literature was also compiled. Following upon this, a Bay of Fundy Workshop, primarily involving the scientific and resource management communities, was held in early 1996 to discuss issues affecting the Bay. The purpose of this Workshop was to bring together Atlantic Region scientists and managers interested in the Bay of Fundy ecosystem to discuss the current state of scientific understanding of the principal ecosystem components and processes. In particular, we hoped to determine whether there was consensus within the scientific community about the scope and ecological significance of recently observed changes in the marine ecosystem The draft background paper served as a working document for the Workshop and as a catalyst for discussion. In addition, a number of conceptual models (Appendix 1) of key biological processes in the Bay were prepared as a framework for the discussions.

The ultimate goal of the Workshop was to seek a consensus on further marine ecosystem research needed on the Bay's natural resources, to identify coastal management and conservation requirements for the Bay, and map out a plan for timely multi-partner, interdisciplinary research and coastal management initiatives. Although questions asked were primarily scientific in nature, it was implicitly understood that further research and/or actions on the Bay cannot be effectively carried out without a cooperative approach involving scientists, resource managers and resource users as well as concerned community groups. Once the state of our scientific understanding has been adequately clarified, it will be essential to expand the discussion to include these other interested parties. It is our hope that such a cooperative approach, involving all stakeholders, can be developed and will ultimately contribute to the conservation and protection of the natural and commercial resources of the Bay and the diverse habitats that sustain them.

> ***"The ultimate goal of the Workshop was to seek a consensus on further marine ecosystem research needed on the Bay's natural resources, to identify coastal management and conservation requirements for the Bay, and map out a plan for timely multi-partner, interdisciplinary research and coastal management initiatives."***

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ACKNOWLEDGEMENTS

The FMESP Steering Committee especially thank the workshop participants (Appendix 3) for sharing their thoughts and concerns about the many environmental issues confronting the Bay of Fundy. We also gratefully acknowledge the important contributions of the numerous reviewers who provided critical comments on various sections of the report.

CHAPTER ONE

FUNDY MARINE ECOSYSTEM SCIENCE PROJECT: SCIENCE OVERVIEW

G.R. Daborn

1.1 Introduction

The Bay of Fundy is a unique coastal environment from almost any point of view. In addition to the extreme tidal range, which has made it an object of scientific interest for more than a century, the Bay lies at the centre of a number of social changes and initiatives that are stimulating regional, national and international recognition. Prominent among these initiatives are those associated with the bi-national Gulf of Maine Council on the Marine Environment, Canada's 'Green Plan' experiments in community-based environmental management under ACAP (*Atlantic Coastal Action Programme*), New Brunswick's Bay of Fundy Project and CLURE (*Commission on Land Use and Rural Environment*) Report, and Nova Scotia's 'Coastal 2000' policy that proposes to devolve decision-making power on environmental and economic issues to local communities. It is clear that a fundamental requirement for all of these efforts is a thorough scientific understanding of the Bay of Fundy ecosystem.

Research on the Bay of Fundy has been episodic, reaching peaks of intensity when practical questions have arisen. Proposals for development of tidal power on a large scale precipitated basic research on the Bay in the 1920's and 1930's, the 1950's and again in the 1970's (Charlier 1982). In each case, these research programs yielded significant increases in understanding of the Bay of Fundy ecosystem. The last major iteration was carried out under the auspices of FESC (*Fundy Environmental Studies Committee*), a sub-committee of the Atlantic Provinces Council on the Sciences, and involved more than 100 scientists from universities, government agencies and the private sector (Gordon and Dadswell 1984). This truly multidisciplinary effort not only developed a substantially better understanding of the Fundy ecosystem, but provided an excellent framework for training of young scientists in coastal zone processes. Tangible results of the research were published widely (*e.g.* Gordon and Hourston 1983, Gordon and Dadswell 1984 and other papers listed in the bibliography); an equally important but less tangible consequence of the 1970's efforts was recognition of, and commitment to, integrated, multidisciplinary approaches to the study of coastal environments. The holistic, cooperative approach adopted by the FESC is an important facet that has contributed to the world-wide recognition that the oceanographic scientific community in Atlantic Canada receives.

> ***"a number of environmental indicators seem to suggest that the Bay of Fundy ecosystem is undergoing changes that are not easily explained on the basis of our present knowledge"***

In the last few years, however, a number of environmental indicators seem to suggest that the Bay of Fundy ecosystem is undergoing changes that are not easily explained on the basis of our present knowledge. Collapses, or extreme population fluctuations, of fisheries resources are not always attributable only to overharvesting; apparent changes in patterns of sediment distribution or properties, and consequent changes in abundance or feeding behaviour of birds and fish, might be explained by a number of phenomena, but it seems that our understanding of the system is insufficient to select between these alternatives; new recognition of the role of saltmarshes and seaweeds challenges notions that such habitats and species can be modified or harvested without system-wide consequences.

For these reasons, the Fundy Marine Ecosystem Science Project (FMESP) was initiated. Supported financially by Environment Canada and the Department of Fisheries and Oceans, the intent of this project is threefold:

1. *To review existing scientific knowledge about the Bay of Fundy system, particularly the information that has been gained in the last decade*
2. *To stimulate discussion within the regional scientific community regarding the reality and significance of the system changes that have been measured or perceived*
3. *If appropriate, to establish the objectives and framework for a new scientific initiative aimed at increasing understanding of the system so that perceived problems can be addressed.*

1.2 Geomorphology

The Bay of Fundy was formed as part of the Appalachian Orogenic event during the Permian (286 -360 million years BP). It is a fault-bounded half-graben, which began to fill with sediments during the Triassic (Stevens 1977); these sediments were subsequently folded and uplifted, and form much of the friable shoreline exposed in the Minas Basin that in places is eroding at rates of > 1 m/y (Amos 1984). Consequently, Minas Basin is principally a sandy estuary, with silts and clays accumulating mainly in sheltered embayments such as the Southern Bight and Avon Estuary. Chignecto Bay, on the other hand, is bordered by Palaeozoic siltstones and shales, which yield finer sediments that are maintained in suspension by tidal and wave action (*ibid.*).

"*The depth of the Bay has changed extensively during the last 14,000 years as the last ice sheets receded, sea level rose, and the land rebounded*"

The depth of the Bay has changed extensively during the last 14,000 years as the last ice sheets receded, sea level rose, and the land rebounded. A principal feature of the post-glacial evolution of the Bay of Fundy has been the depth of water over Georges Bank (Scott and Greenberg 1983): at the lowest point of relative sea level, the emergence of Georges Bank restricted inflow of tidal waters, but as the Bank submerged the Bay became progressively more influenced by tidal forces. Maximum land elevation was reached about 4,000 BP, at which time the inner portion of the Bay was a microtidal estuary or embayment (tidal range *c.* 1m), with an entirely different ecology. With continuously rising sea level, and deepening of the Bay by erosion of the bottom, the macrotidal characteristics of the Bay evolved and continue to increase (Amos 1978, Bleakney 1986, Godin 1992).

1.3 Dynamic relationships

The most notable physical feature of the Bay of Fundy system is of course its tidal regime. Tides range from *c.* 4 m at the mouth of the Bay to an average of 12+ m in Minas Basin. The extreme amplification of the tide with distance up the Bay results from the near-resonance of the Bay of Fundy - Gulf of Maine - Georges Bank (FMG) system with the forcing of the Atlantic tide. Although the natural period of the Bay is about 9 h (Greenberg 1984), that of the FMG system is around 13.3 h, close to the tidal period of 12.4 h (Greenberg 1983). The magnitude of the tidal rise and fall is determined partly by the morphology of the Bay, and partly by variations in the strength of astronomical forces. Tidal range is a variable; it changes in a cyclical manner over periods of 15 and 29 days (the familiar *spring-neap* and *lunar* cycles), and varies seasonally because of the Earth's elliptical orbit around the sun. It also oscillates over longer terms such as the 18.6 year *nodal* cycle, which is associated with variation in declination of the moon's orbit (Greenberg 1983). The largest tides are generally about twice the amplitude of the smallest. The actual rise and fall is also influenced by local atmospheric conditions.

These tidal movements cause strong currents throughout the Bay system, reaching maximum values of *c.* 4 m/s in the Minas Channel. Currents are reversing, rather than rotary, producing marked tidal excursion. A residual, counter-clockwise circulation is found in the main Bay resulting, in part, from the entry of Atlantic tidal water primarily on the Nova Scotia side, but also, in part, from the outflow of the Saint John River on the New Brunswick shore. This feature is of considerable significance to the dispersion of plankton, including larval forms of fish and benthic crustaceans, and of pollutants.

> ***"the mouth of the Bay therefore represents one of two important tidal 'pumps' in which tidal energy is effectively a subsidy supporting biological production processes."***

Frictional effects associated with strong tidal currents result in extensive vertical mixing of the water column in shallower areas of the Bay. Major upwelling zones are found at the mouth of the Bay between Grand Manan Island (N.B.) and Brier Island (N.S.). As in other upwelling areas, vertical mixing of cold, nutrient-rich deeper water with warm surface waters results in higher primary production by phytoplankton; the mouth of the Bay therefore represents one of two important tidal 'pumps' in which tidal energy is effectively a subsidy supporting biological production processes. These upwelling areas are major feeding grounds for marine fish, birds and mammals. Concentrations of whales and seabirds in upwelling areas have given rise to a significant and growing tourism industry in recent decades.

> ***"These upwelling areas are major feeding grounds for marine fish, birds and mammals."***

The link between vertical mixing and biological processes is all-encompassing, and has formed the basis of much research in recent years. Loder and Garrett (1978) showed that sea surface temperature in the outer Bay was strongly correlated with tidal range, and therefore oscillated over long periods, such as the 18.6 years of the nodal cycle. Using this information, Cabilio *et al.* (1987) examined catch records for major commercial finfish species in the FMG system and concluded that stocks of several important species were strongly correlated with the nodal cycle. Evidence for this association was detectable in the landings records despite changes in fishing effort, technology, vessel sizes etc. Catches of northern species such as cod, halibut and haddock tended to rise following years of maximum tidal range, and to be lower when the tides are smaller. They thus show a positive correlation with tidal range, and a negative correlation with sea surface temperature. Two alternate hypotheses were presented to explain the relatively greater success of the northern species: either increased primary productivity caused by greater upwelling of nutrients, or the decreased sea surface temperature resulting from vertical mixing are favourable for growth and survival of larval fish of northern species. Southern species such as herring and menhaden seemed to be more abundant following the trough (*i.e.* years of lowest tidal range) of the nodal cycle. In addition to the vertical mixing hypotheses mentioned above, it is possible that these species, which may be more dependent on estuarine environments during early life, may benefit from enhanced retention in inshore waters during years of low tidal range.

The same conceptual model of the effects of vertical mixing formed the basis of the ecosystem model developed by Campbell and Wroblewski (1986) for the FMG system. This model suggests that increases in tidal range in the Gulf of Maine resulting from tidal power development in the Bay of Fundy would probably enhance pelagic fish production on Georges Bank, but cause decreases in southwest Nova Scotia, eastern Maine and New Brunswick, where more frequent and persistent fog is also expected to occur (Campbell 1986).

In the inner Bay and the upper bays (Chignecto and Minas Basin), the high tidal range means that waters are generally well mixed in all years. This results in increased turbidity, decreased light penetration, and lower chlorophyll levels in the water column. Huntsman (1952) had concluded that lower primary production limited secondary production in the upper part of the Bay. However, investigations carried out by the Fundy Environmental Studies group have led to a very different sense of the production processes in Minas Basin. Large areas of intertidal zone harbour benthic diatoms that yield up to 38 g C/m^2/y (Gordon 1986). Some of this production is released into the sediments and distributed by the flooding tide, making it available for grazing by filter feeders and bacteria (Gordon *et al.* 1986, Schell and Daborn 1994). In Cumberland and Minas Basins, Keizer *et al.* (1987) concluded that most of the net aerial primary production of low marsh (averaging 215 g C/m^2/y) was exported into nearby waters because of the high tidal energy. Winter ice also removes a substantial fraction of the annual saltmarsh production from the shore for reuse in tidal waters (Gordon and Desplanque 1983). Thus the dynamic action of the tides constitutes a second 'pump' that assists organic production processes in the inner reaches of the Fundy system.

> ***" the mid-summer rise in sediment strength in intertidal muds was a reflection of the arrival of large numbers of migratory birds that feed extensively on Corophium"***

The very tight coupling between tidal forces and production processes is also implicated in the dynamic relationships of intertidal sediments in the macrotidal regions of the upper Bays. In estuaries, intertidal flats often act in a seasonally varying manner, storing sediments such as silts and clays during summer months, and releasing them to the water during the winter (Allen 1982). In recent years, the notion of a dynamic balance between the water and the sediments has arisen, by which sediments are mobilized from the shoreline if the nearby water carries less than its 'equilibrium capacity' (Amos 1995, Amos and Tee 1989); conversely, a water more heavily loaded with sediment than its 'equilibrium capacity' will yield the excess to any space that can accommodate it. This conceptual model is useful in interpreting the effects of anthropogenic modifications to estuaries, especially those that either increase the loading to an estuary (*e.g.* through increased sediment input), or decrease the 'equilibrium capacity' of the water (*e.g.* by constructing dams and decreasing tidal energy), or by modifying the accommodation space within the estuary.

Difficulties in predicting the behaviour of muddy sediments led Amos and Mosher (1985) to examine closely the properties of intertidal muds in Minas Basin. They estimated that these sediments were 80 times less erodible than measures of their grain size would suggest. Subsequently, a field study on Starrs Point mudflat detected a significant increase in erodibility during mid-summer, which was at first attributed to atmospheric effects occurring when the intertidal zone was exposed for long daytime periods (Amos *et al.* 1988). Development of new technologies for measuring sediment properties under in situ conditions, particularly Sea Carousel (Amos *et al.* 1992) and INSIST (*In-situ Simple Sheer Test*, Faas *et al.* 1991), formed the basis of a detailed, comprehensive study of sediment dynamics in the Minas Basin in 1989 (Daborn 1991). The mid-summer changes in sediment strength previously recorded were confirmed. However, investigations of biological processes seemed to suggest that they were linked to food web interrelationships rather than atmospheric effects. Much of the stability of the surface muds is attributable to organic secretions (formally known as extracellular polymeric substances, or EPS - Decho 1990) derived from benthic diatoms. Since diatom biomass is influenced by grazing pressures, particularly by the burrowing amphipod *Corophium volutator*, the abundance of grazers and the strength of the sediments are indirectly linked. The surprising conclusion of this study was that the mid-summer rise in sediment strength in intertidal muds was a reflection of the arrival of large numbers of migratory birds that feed extensively on *Corophium* : *i.e.* a 'cascade' effect involving three trophic levels and affecting an important property of deposited sediments (Daborn *et al.* 1993).

The results of the LISP (*Littoral Investigation of Sediment Properties*; a multidisciplinary investigation of the dynamic properties of estuarine sediments involving more than 30 scientists from 5 countries) study have shed new light on the behaviour of fine-grained sediments in coastal waters, and led to much more comprehensive conceptual models. However, observations by Shepherd *et al.* (1995) suggest that the sediment properties have changed in some important shorebird feeding areas, resulting in localized decreases in the abundance of food sources such as *Corophium volutator*, and possible consequent changes in migratory behaviour of shorebirds. If the observations are valid, explanation of the changes is a critical need.

1.4 History of resource use

The fisheries resources of the Bay, along with its suurounding forests, have been the mainstay of human settlements since the earliest times. Shell middens indicate that shellfish, particularly oysters, quahogs and soft-shelled clams, were important to indigenous peoples. In Maine, evidence from middens suggests that the most important fish species was the swordfish, although there seems to be no similar indication for Canadian waters. With the arrival of Europeans, the abundant coastal and migratory fish populations became more widely known, being described with great enthusiasm by early travelers (Dunfield 1985). Decline of salmon and other migratory fish during the 19th century resulted largely from degradation of spawning grounds as a consequence of extensive dam construction and river modifications associated with agricultural and forestry activities.

"it may be that cyclical oceanographic processes are also implicated in changing absolute and relative abundances of commercially important species. It is essential that we be able to distinguish between natural and anthropogenic effects"

Increasing harvesting of the dominant fish species in the FMG system was accompanied at first by increasingly large fluctuations in stock abundances, followed, in the case of herring, cod, halibut and haddock, by collapse of the stocks. In the Gulf of Maine, fish biomass has apparently remained much the same in spite of these collapses, as cartilaginous fish appear to have largely replaced the formerly dominant bony groundfish. The responses of the fishery have been largely predictable: increasing pressure on other species such as flounder and pollock, with severe impacts on the former species in Mary's Bay and Minas Basin; initiatives to find unutilized resources such as sea urchins, baitworms, periwinkles, rockweed and eels; greater interest in the potential for aquaculture of shellfish and finfish; and attempts to diminish the numbers of fishers and vessels.

Much of our management effort appears to be consumed in reacting to a rapidly changing pattern of resource utilization. However, as the evidence on fish cycles suggests, it may be that cyclical oceanographic processes are also implicated in changing absolute and relative abundances of commercially important species. It is essential that we be able to distinguish between natural and anthropogenic effects.

1.5 History of research

Scientific research on the Bay of Fundy extends back to before Confederation, being an integral part of the activities of the Nova Scotian Institute of Science and the Natural History Society of New Brunswick, both established in 1862 (Johnstone 1977). Investigations of the outer part of the Bay and Passamaquoddy Bay began with the establishment of the Biological Station at St. Andrews in 1899. At first the work of the Station was focused on aspects of fisheries ecology, but with increasing interest in the prospects for tidal power development in Passamaquoddy Bay, the 1930's saw a significant amount of basic research into the ecology of the outer Bay of Fundy, particularly of its fish populations.

A joint Canada-U.S. proposal for tidal power development in the Passamaquoddy Bay - Cobscook Bay region formed the basis for studies of physical processes in the outer part of the Bay during the late 1930's. The scheme actually resulted in some preliminary civil works, including a small village in Maine that was built to provide suitable accommodations for construction workers. When the idea was temporarily abandoned in 1941, attention began to shift toward the head of the Bay. Its revival in 1948 initiated much broader studies, including fisheries. Although the final reports suggested that there would be impacts on several fisheries, especially on some herring stocks (Leim *et al.* 1957) and migratory stocks of cod, halibut and haddock, the International Joint Commission considered it unlikely that these would be of great significance overall (IJC 1959).

In the 1950's and 1960's, the Atlantic Tidal Power Programming Board studied proposals for tidal power development in the Petitcodiac, Chignecto Bay and Minas Basin. Although most of the 23 sites were eventually dropped from consideration as uneconomic, the relatively favourable cost-benefit assessments of sites in Shepody Bay, Cumberland Basin and Minas Basin resulted in these being subjected to much closer consideration. Investigations of surficial geology, tidal dynamics and sediment characteristics were initiated to aid in evaluation of the schemes. In 1976, at the instigation of the Atlantic Tidal Power Review Board, a conference of scientists was held at Acadia University to address the broader issues of potential environmental effects. Because the regions were poorly known ecologically, and had unusually extreme characteristics, very little could be stated with confidence about the possible environmental effects of a tidal barrage.

Following the 1976 meeting, scientists from universities, government agencies, and the private sector came together to form FESC (*Fundy Environmental Studies Committee*), a more-or-less *ad hoc* organization that designed the first comprehensive and coordinated study of the upper Bay of Fundy. After formation, it was 'adopted' as a committee by the Atlantic Provinces Inter-University Council on the Sciences (APICS). The results of its work were presented at a workshop at l'Université de Moncton in 1982, at international meetings (*e.g.* Gordon and Hourston 1983), and summarised in two major technical reports (Gordon and Dadswell 1984, Plant 1985). These represent the starting point for the present review of scientific knowledge on the Bay of Fundy system.

Despite the considerable efforts of more than 100 scientists over six years, several important scientific questions remained unresolved in 1984. Principal among these issues were the long distance effects of a tidal power barrage (*e.g.* on the Gulf of Maine), the effects of turbine passage on migratory fish, and the behaviour of the cohesive sediments that appeared to predominate in areas considered suitable for tidal dam construction. These problems have been examined in scientific research conducted during the last decade, and are reviewed in the accompanying chapters.

1.6 New concerns

One might assume that the extensive efforts of the FESC during the 1970's and 1980's would provide a substantial basis for interpreting phenomena in the Bay of Fundy ecosystem. However, since the last review of our knowledge in 1982 (Gordon and Dadswell 1984) there have been a number of system-scale changes that seriously challenge the adequacy of our scientific understanding. It seems essential at this time to revisit many of our past assumptions, to distinguish between perception and reality, and to determine whether a new major initiative on the Bay of Fundy ecosystem is warranted. Perceived changes and issues include :

1. The dramatic changes to fish stocks in the FMG system present a very different paradigm with which both the scientific and management communities must contend: it is possible that for the foreseeable future the FMG ecosystem will exhibit an entirely different ecology in which slow-growing sharks and skates are the principal biomass components. The present fishing industry is completely out of context with such resources, and scientific knowledge about them is extremely weak. Similarly, the rapid shifts in resource utilization onto species that have been little studied in the Bay - sea urchins, periwinkles, baitworms, for example - or whose ecological role is not well understood (*e.g.* intertidal rockweed beds), presents another major challenge.
2. Rising interest in aquaculture in coastal waters and estuaries challenges our understanding of ecosystem processes. The Habitat Ecology unit of DFO has made major advances through its comprehensive, ecosystem-scale approach in

the L'Etang Estuary, but the demand for information is rapidly exceeding the ability of the scientific community to conduct research and to provide assessments, and political pressures do not permit the luxury of time to repeat studies like that.

3. Oscillations in stocks of migratory fish are commonly attributed to a recent environmental insult in the neighbourhood of spawning grounds or migration routes. For example, changes in age structure of the Annapolis River shad population could be blamed with confidence upon the Annapolis Tidal Generating Station, were it not that somewhat similar declines have been seen in stocks in other rivers.

> ***"Realistically, there are not sufficient resources available to do research on coastal ecosystem issues without recruiting local communities to the cause"***

4. In recent years the potential long-term effects of modifications to rivers and estuaries has become an issue in itself. The Windsor Causeway in Nova Scotia was a focus of early sedimentological work (Greenberg and Amos 1983). Following its construction in 1970, a large tidal flat developed on the seaward side that has grown steadily down the estuary, resulting in significant shoaling in the region of Hantsport, some 9 km away. Because the initial deposits were fluid and unconsolidated, it took 17 years before the first signs of a saltmarsh became visible on high points on the flat. Since then the rapid growth of the marsh and stabilization of the sediment are producing a productive habitat that attracts fish, piscivorous birds, and migratory shorebirds. Similar long-term changes appear to have been induced by causeways on the Petitcodiac and the Annapolis Estuary. In the latter case, the causeway and power project have resulted in rapid erosion of a bordering saltmarsh at Fort Anne National Historic Site (Daborn *et al.* 1995). Many of these long-term consequences are only obvious in retrospect, indicating that our predictive understanding of impacts of modifications to the ecosystem is inadequate.
5. Observations of changes in abundance and behaviour of migratory birds in the upper Bay of Fundy system prompted an examination of biological and sedimentological characteristics of their feeding grounds in Minas Basin and Chignecto Bay (Shepherd *et al.* 1995). There is considerable evidence that sediment grain size distributions and water content are different from earlier surveys in the late 1970's, and that the abundance and distribution pattern of the amphipod *Corophium volutator* have changed as well. These changes might be related to the long-term effects of human intervention in the watershed surrounding these basins, as indicated above. Alternatively, they may reflect a hitherto unrecognized facet of the long term cycles (*e.g.* the 18.6 year nodal cycle) to which the Fundy ecosystem is subject, or have been caused by entirely different factors.

6. The search for single factor explanations of apparent change in itself reflects an inadequate application of scientific knowledge. If we know anything about ecosystems, it must be that they are dynamic and interactive, so that any change in one parameter is likely to have multiple and cumulative effects.

1.7 New initiatives

The context of environmental science has itself changed a great deal in the last decade. It is no longer the sole prerogative of formally trained scientists.

1. Recent initiatives to incorporate resource users into both scientific investigation and management decision-making reflect both the demand for that empowerment and the financial strictures in which governments find themselves.

2. An ecosystem basis for resource management and environmental monitoring is the essence of new initiatives by EMAN (*Environmental Monitoring and Assessment Network*) , the establishment of Ecological Science Centres, and responses to global change. The Fundy Envi-

ronmental Studies Committee took an ecosystem approach from the start because it was logically necessary; it is now de rigeur.

3. Last, but not least, scientific endeavours to understand and monitor ecosystems will be subject to intense public scrutiny and demands for public involvement. Realistically, there are not sufficient resources available to do research on coastal ecosystem issues without recruiting local communities to the cause. The experiments under the Atlantic Coastal Action Plan indicate clearly that local communities can contribute substantially to such efforts, and benefit in manifold ways from greater exposure to scientific thought and applications. It is clearly necessary to pursue our scientific and management endeavours in that context.

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CHAPTER TWO

THE PHYSICAL ENVIRONMENT OF THE BAY OF FUNDY

D.A. Greenberg, B.D. Petrie, G.R. Daborn and G.B. Fader,

2.1 Physical oceanographic processes

(D.A. Greenberg and B.D. Petrie)

Abstract - There has been little new research on the physical oceanography of the Bay of Fundy since the studies of the 1970's and 1980's which were inspired by the possibility of tidal power development. The description of the Bay given at that time still holds. The Bay is forced and controlled by the resonant semi-diurnal tide with the other physical forcing mechanisms adding some variation about the tidally-driven picture. There has been recent work looking into aquaculture issues in the L'Etang Inlet of Passamaquoddy Bay using a numerical model and many observations. A study of long-term variability of temperature and salinity on the Scotian Shelf and in the Gulf of Maine shows that the Bay of Fundy is very much part of the larger picture in the western North Atlantic. A description of all the inlets of the Bay of Fundy was included in a tabulation of basic parameters of coastal embayments done for the Maritime Provinces. A study of long-term variations in the amplitude of tidal constituents at Saint John Harbour shows some intriguing trends that merit further study.

2.1.1 Introduction

In the Bay of Fundy the tides rule. With the tides producing a range at the head of Minas Basin frequently over 14m, at times over 16m, and currents around 6m/s by Cape Split, other physical processes can be considered only as variations around the tidally-driven picture. The summary of the physical oceanography given by Greenberg (1984) describes how the tides mix the water through the head of the Bay and drive much of the residual circulation. Although not as significant as the tides, other physical factors such as waves, storm surges and density effects driven by freshwater discharges, from local heating and cooling, and exchanges with the adjacent seas, cannot be ignored.

> ***"The Bay is forced and controlled by the resonant semi-diurnal tide with the other physical forcing mechanisms adding some variation about the tidally-driven picture."***

Studies (Greenberg 1979) showed how the large tides were due to near resonance of the M_2 tide with the natural period of the Bay of Fundy - Gulf of Maine together. Complicating simple resonance explanations were the natural period of the Bay by itself (around 9 hours) and tidal friction which takes a lot of energy out of the system.

Readers are referred to the above references for details on, and pointers to, research done up to the mid 1980's. A brief summary of selected work that has been done more recently follows.

2.1.2 L'Etang Inlet studies

The L'Etang Inlet has been the site of a booming aquaculture industry. Concern has been raised about the water quality. It was not known how many salmon farms the area could support, or how close together the farms could be, without damaging their environment. The high concentrations of caged fish demand a good supply of oxygen and produce large amounts of waste. The fish waste combined with the excess food on the bottom can deplete the oxygen. An extensive current meter mooring program was undertaken (Trites and Petrie 1993) to help determine flushing/residence times of the inlet. The rough topography and irregular shoreline with many islands made a proper computation using just observations impractical, so the data were also used for calibration and verification of a numerical model (Trites and Petrie 1995, deMargerie *et al.* 1990). Although there were limitations in the model's capabilities, it did help identify areas where there could be maximum impacts from aquaculture practices.

2.1.3 Classification Of Estuaries Project

The Classification of Estuaries Project (Gregory *et al.* 1993) set out to give a basic description of all coastal embayments in the Maritime Provinces from the Baie des Chaleurs to Passamaquoddy Bay including those of Prince Edward Island. The primary purpose of the classification project was to compile baseline information for possible aquaculture sites. The information includes:

1) *geographic parameters - area at high water and chart datum, perimeter, axis length low water volume, maximum depth, width and area at the mouth of the inlet and watershed area;*
2) *oceanographic parameters - mean and large tidal range, mean tidal volume, tidal current at the mouth of the inlet, and an estimate of the flushing time;*
3) *hydrological parameters - monthly mean and standard deviation of the freshwater discharges into the inlet.*

An example listing is shown for Annapolis Basin in Figure 2.1.

This report also includes statistics on temperature derived from The Long-Term Temperature Mooring Program (Loucks and Petrie 1991). It shows that in the Bay of Fundy, for the years in which data were collected, that temperature peaked at 12° - 14°C. in August and September and was at its minimum value of 0° - 2°C. in January to March. (See Figure 2.2).

2.1.4 Historical temperature-salinity observations

Recent analyses of historical temperature and salinity data are available in several forms. Petrie and Drinkwater (1993) have looked at data on the Scotian Shelf and in the Gulf of Maine. They correlated anomalies in the Gulf found over several years with anomalies on the Scotian Shelf and in the Labrador Current. Long-term temperature changes in the Gulf and the mouth of the Bay of Fundy were similar to those on the Scotian Shelf and deep waters of the Gulf of St. Lawrence. These changes were caused by variability of the properties of the water over the continental slope that intruded into the shelf regions. An updated examination of the temperature and salinity differences between the outer and inner Bay of Fundy. (Figures 2.3, 2.4) agrees with the summary of Greenberg (1984) showing fresher water in the central (inner) Bay throughout the year, and warmer water there in summer and cooler in winter than in the outer Bay. Central (inner) Bay profiles show more stratification than might be expected, but this is probably because the central (inner) Bay area (Figure 2.5) straddles the area that Garrett *et al.* (1978) found to divide the stratified and tidally mixed water (Figure 2.6). The Northwest Atlantic Fisheries Organization (NAFO) produces an annual overview of environmental conditions in the Northwest Atlantic. Their review of conditions for 1994 (Drinkwater *et al.* 1995) found that the water was generally warmer and saltier than the long-term mean, reversing the trend of the previous few years where the water was seen to be fresher and colder. NAFO produces many such reports which go unnoticed in the gray literature. Some could relate to the Bay of Fundy, such as the Drinkwater *et al.* (1992) study which looked unsuccessfully for changes in water characteristics that might explain the recent low returns of Atlantic salmon to the rivers of the inner Bay.

> ***"Long-term temperature changes in the Gulf and the mouth of the Bay of Fundy were similar to those on the Scotian Shelf and deep waters of the Gulf of St. Lawrence."***

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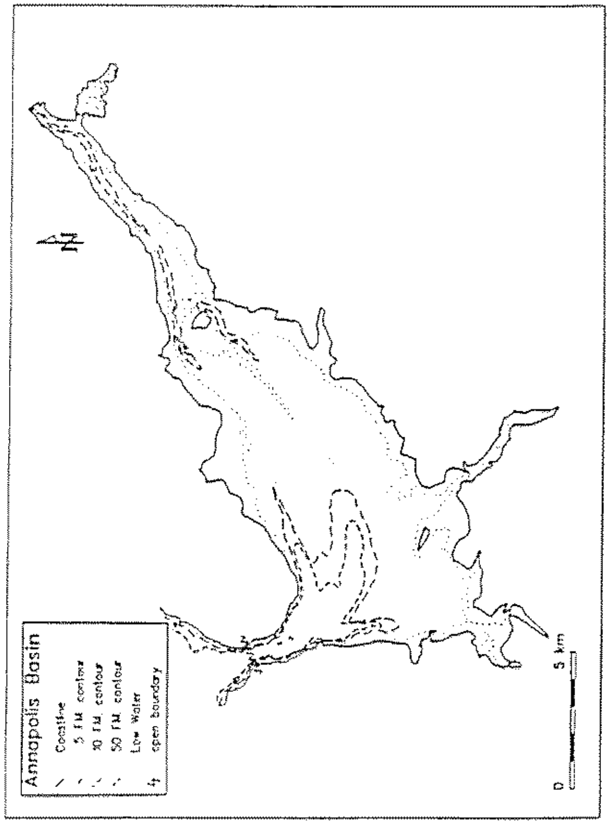

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ANNAPOLIS BASIN

Zone 4Xr
Chart 4396
Bay ID..CF

Area (CD)	66.5 km^2	Area (HW)	96.2 km^2
Perimeter	100.2 km	Volume (CD)	612.0 $10^6 m^3$
Axis Length	25.8 km	Maximum Depth	94.2 m
Section Width	0.7 km	Section Area	25526.0 m^2

Tidal Range		Tidal Volume	Tidal Current	
Mean	Large	Mean tide	Mean	Peak
6.80 m	9.30 m	553.2 $10^6 m^3$	0.97 m/s	1.52 m/s

Flushing time	19.2 hr
Tidal/Freshwater volume ratio	455.46

Watershed Area 2408.4 km^2

Freshwater Discharge m^3/s (Standard Deviation)

Jan	61.8 (42%)	May	62.2 (51%)	Sept	14.4 (101%)
Feb	68.4 (50%)	June	32.9 (71%)	Oct	31.8 (89%)
Mar	99.2 (41%)	July	21.3 (85%)	Nov	52.9 (60%)
Apr	103.2 (35%)	Aug	20.5 (122%)	Dec	83.4 (42%)

Figure 2.1 The Classification of Estuaries Project entry for Annapolis Basin (From Gregory *et al.* 1993).

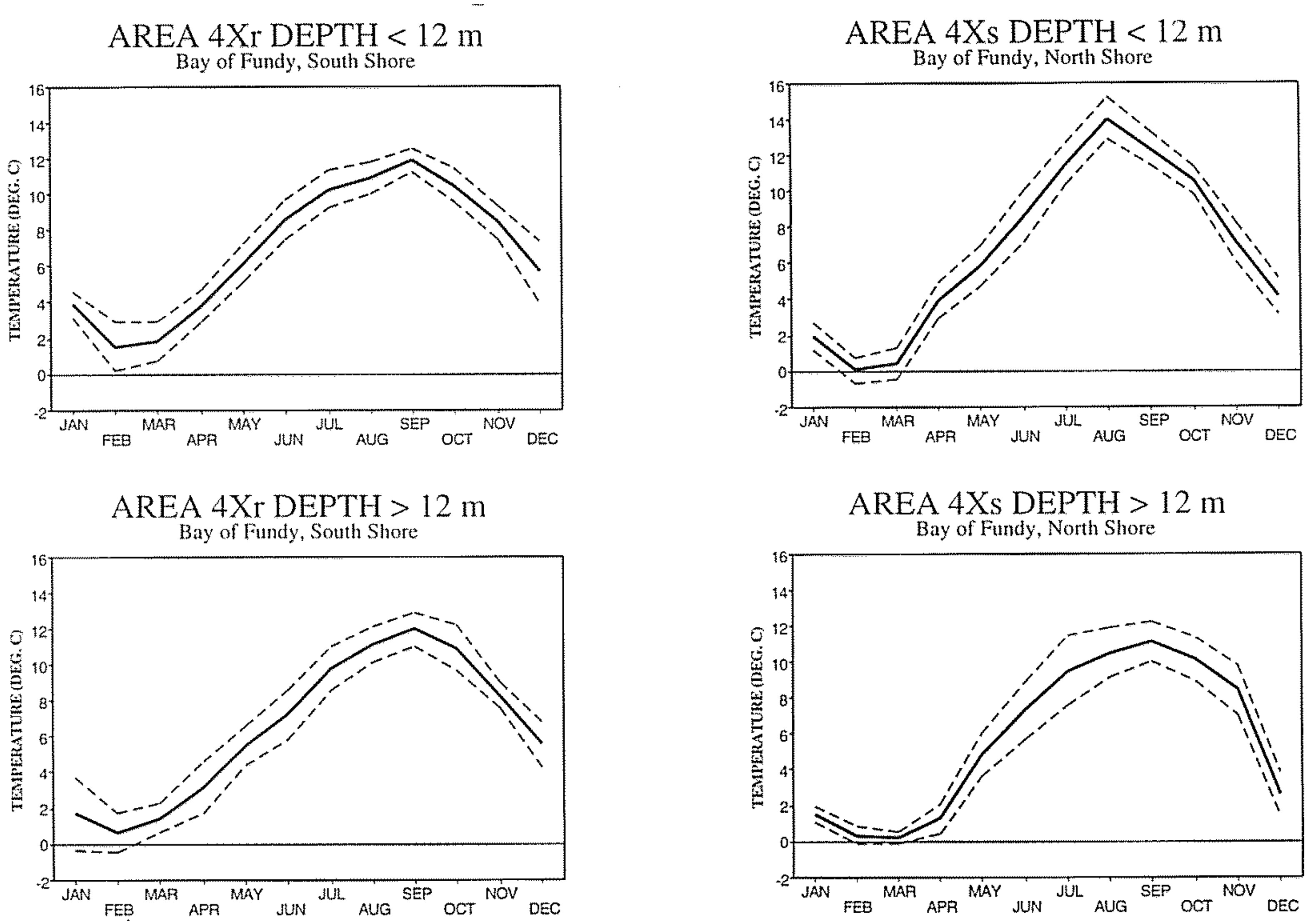

Figure 2.2 The temperatures observed in the Bay of Fundy, where the solid line represents the monthly mean temperature and the broken line ± 1 standard deviation (From Gregory *et al.* 1993).

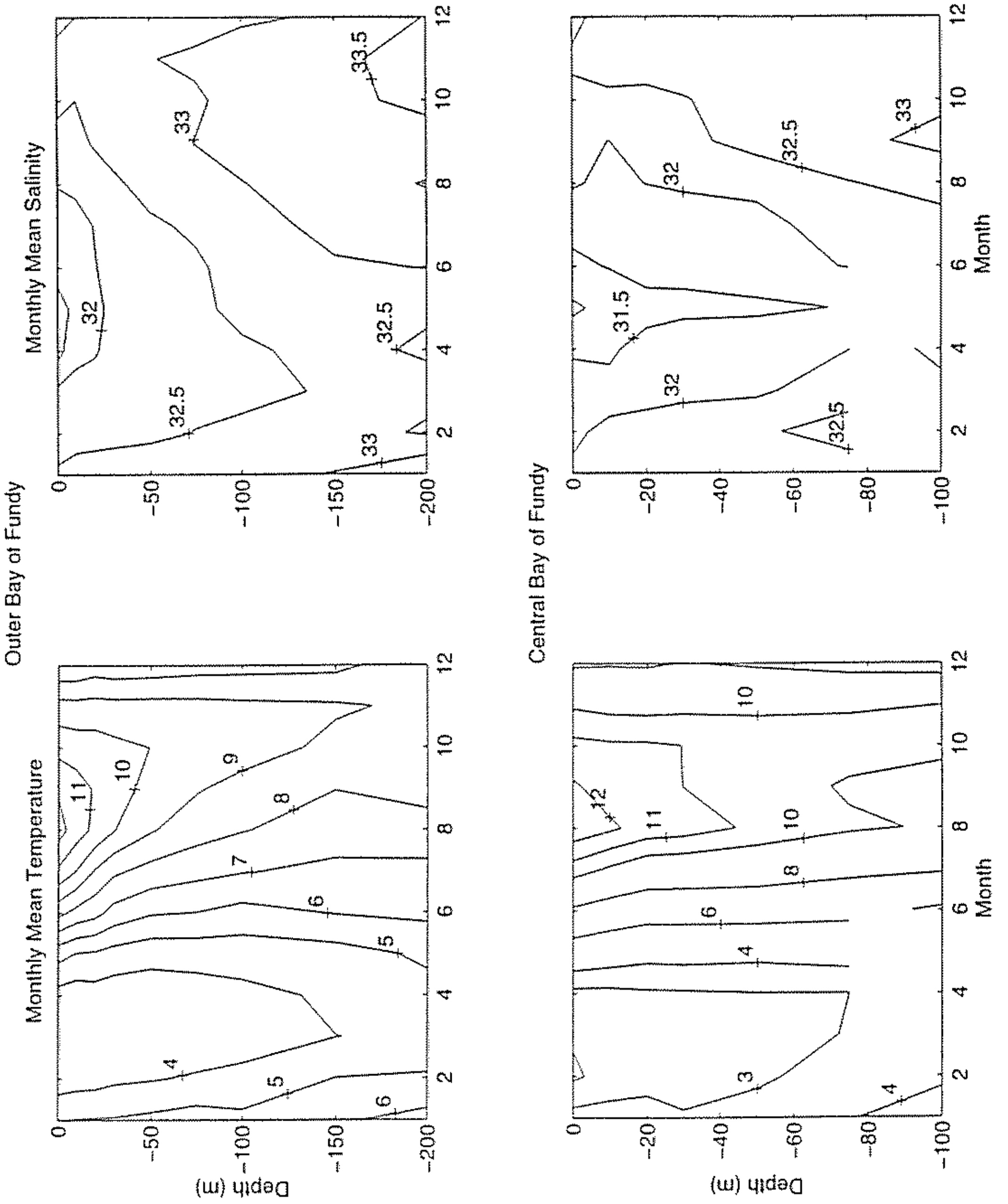

Figure 2.3 The monthly mean temperature and salinity in the inner (central) and outer Bay.

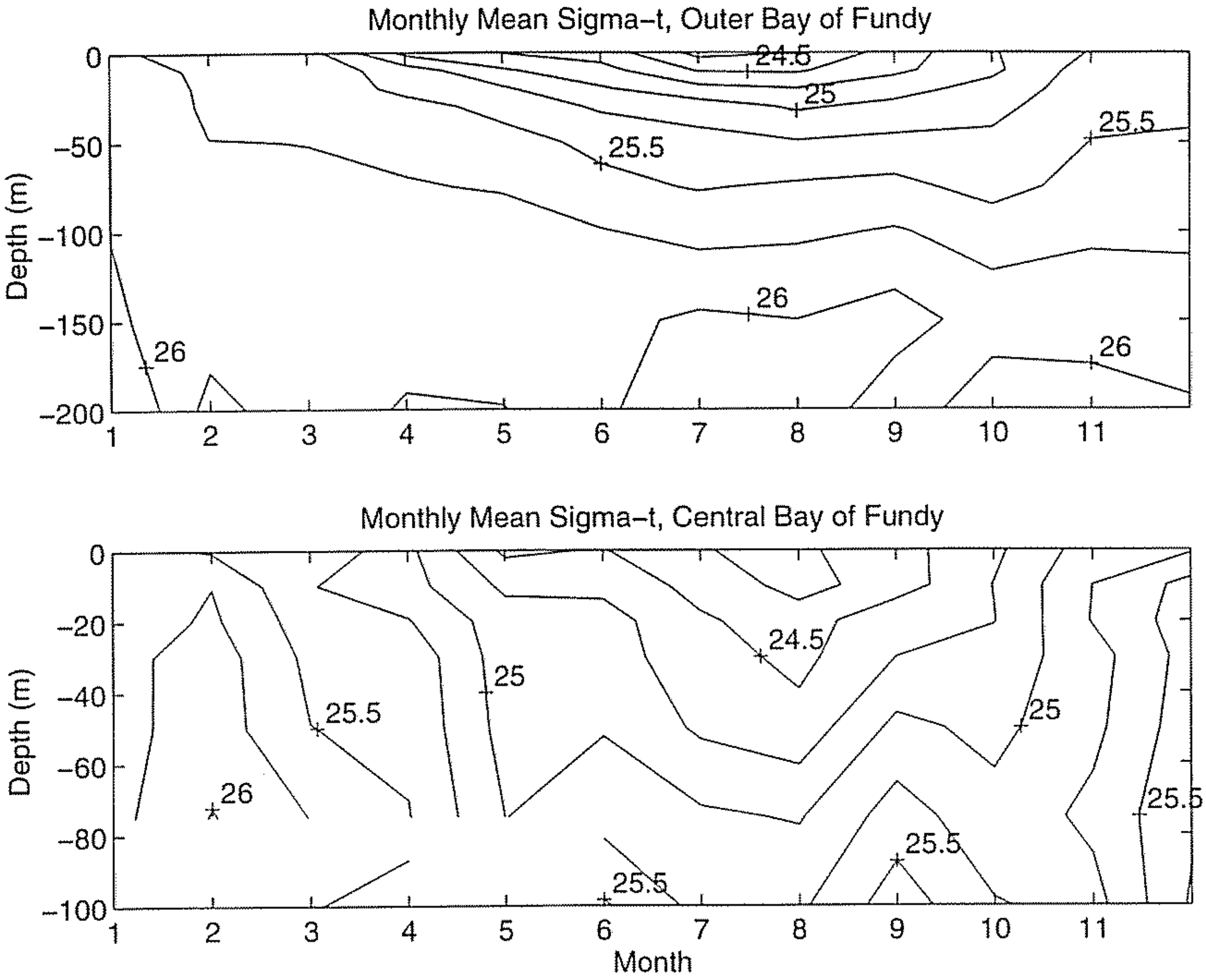

Figure 2.4 The monthly σ_t *(density)* in the inner (central) and outer Bay

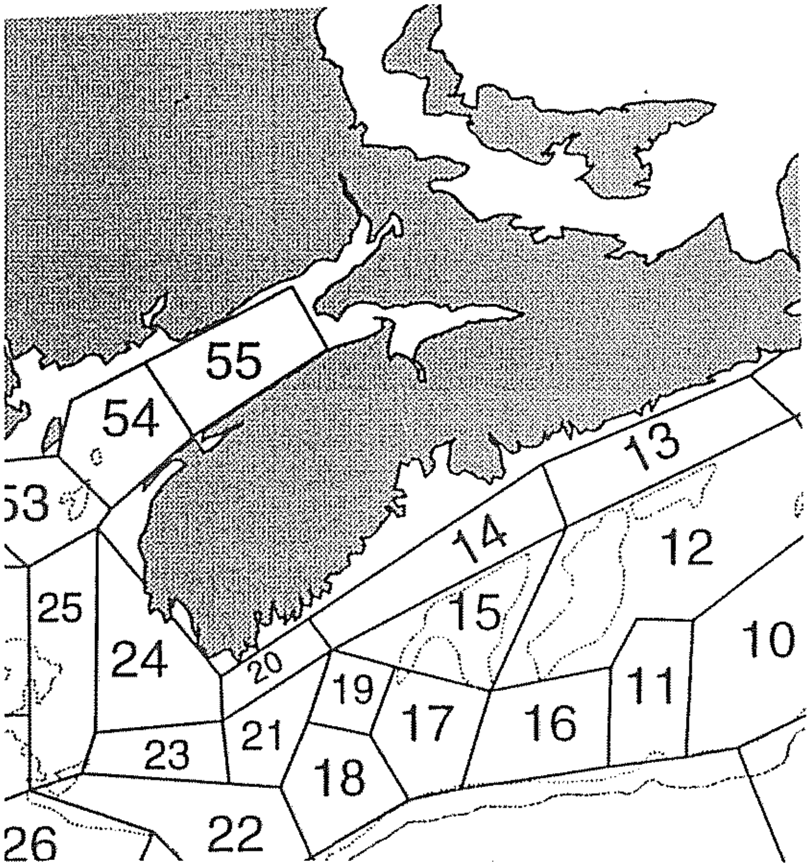

Figure 2.5 The regions corresponding to the inner (central, area 55) and outer (area 54) Bay of Fundy for the results shown in Figures 2.3 and 2.4.

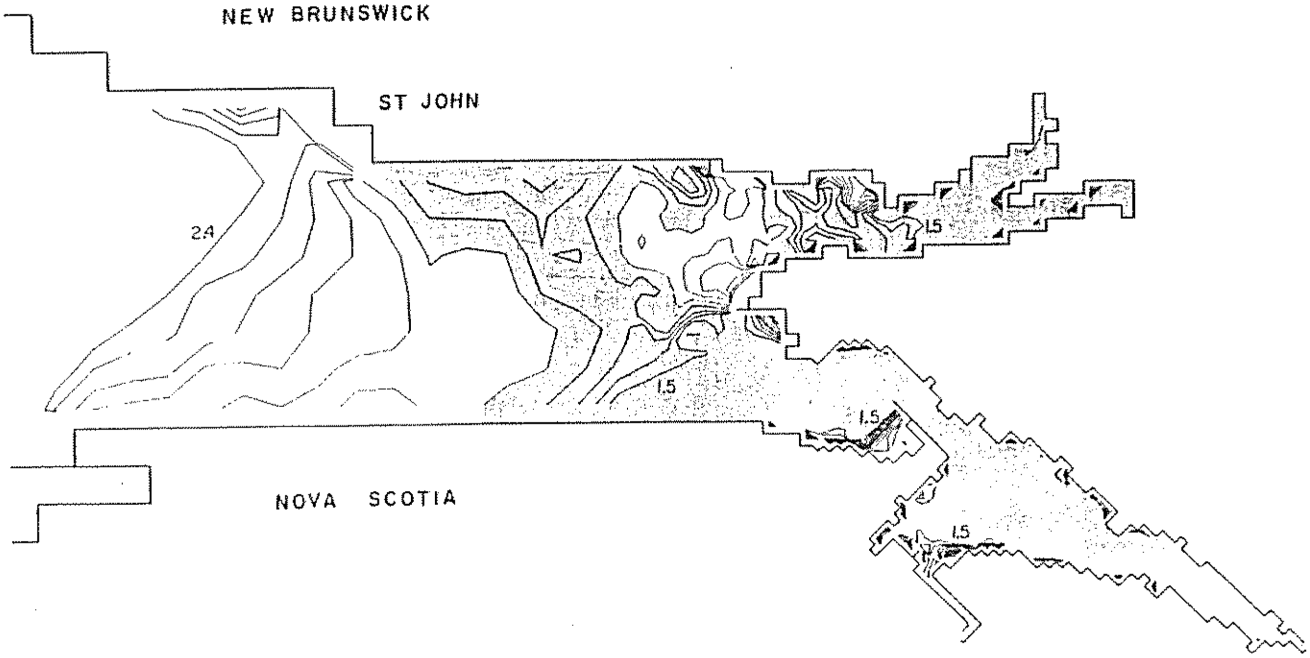

Figure 2.6 The well-mixed area (shaded) and stratified area of the Bay as determined by Garrett *et al.* (1978)

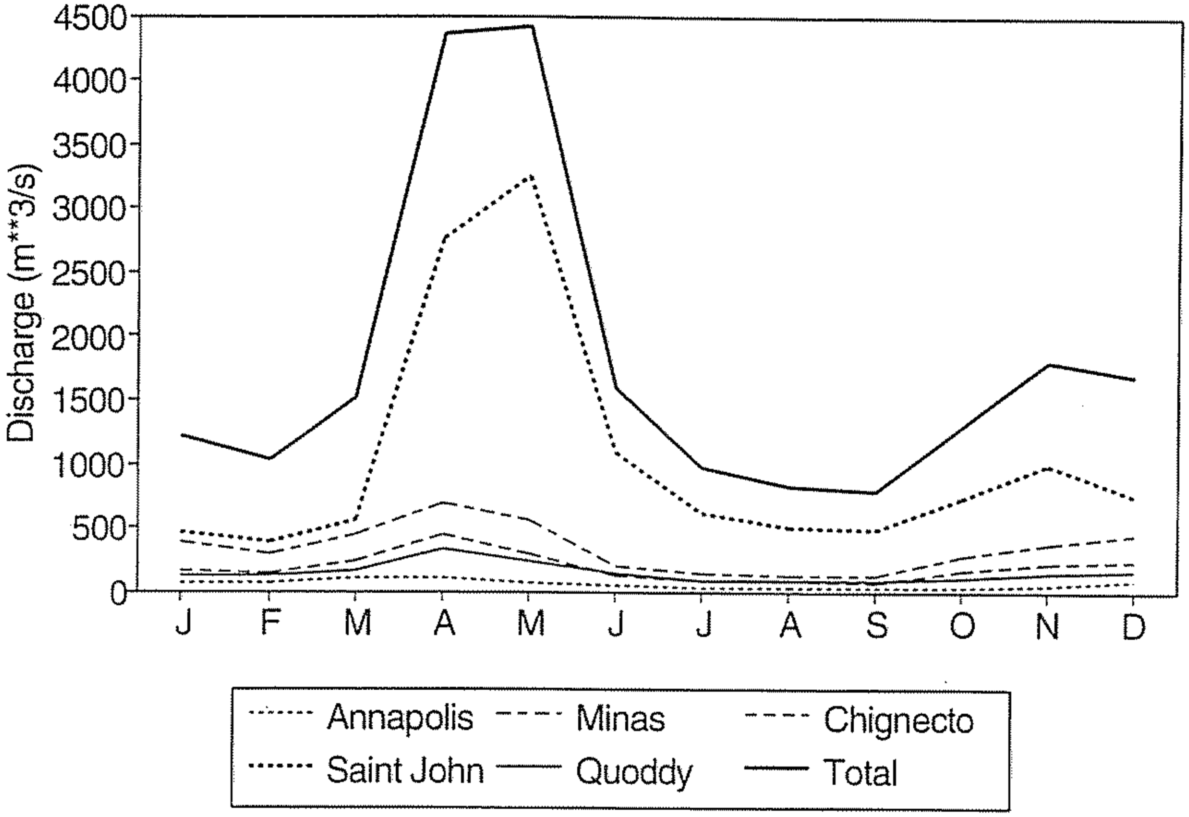

Figure 2.7 The monthly average freshwater discharge into the Bay of Fundy from the major sources.

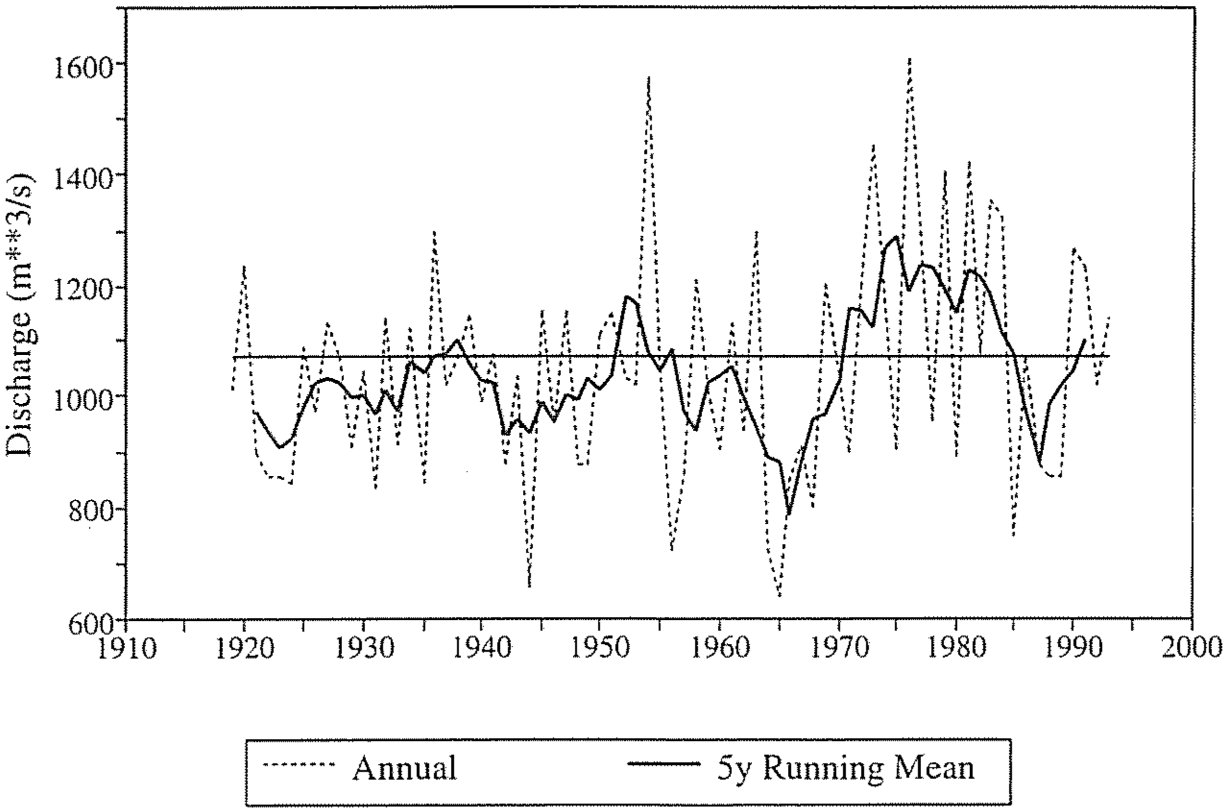

Figure 2.8 The annual discharge of the Saint John River (1919-1993) and the five-year running mean.

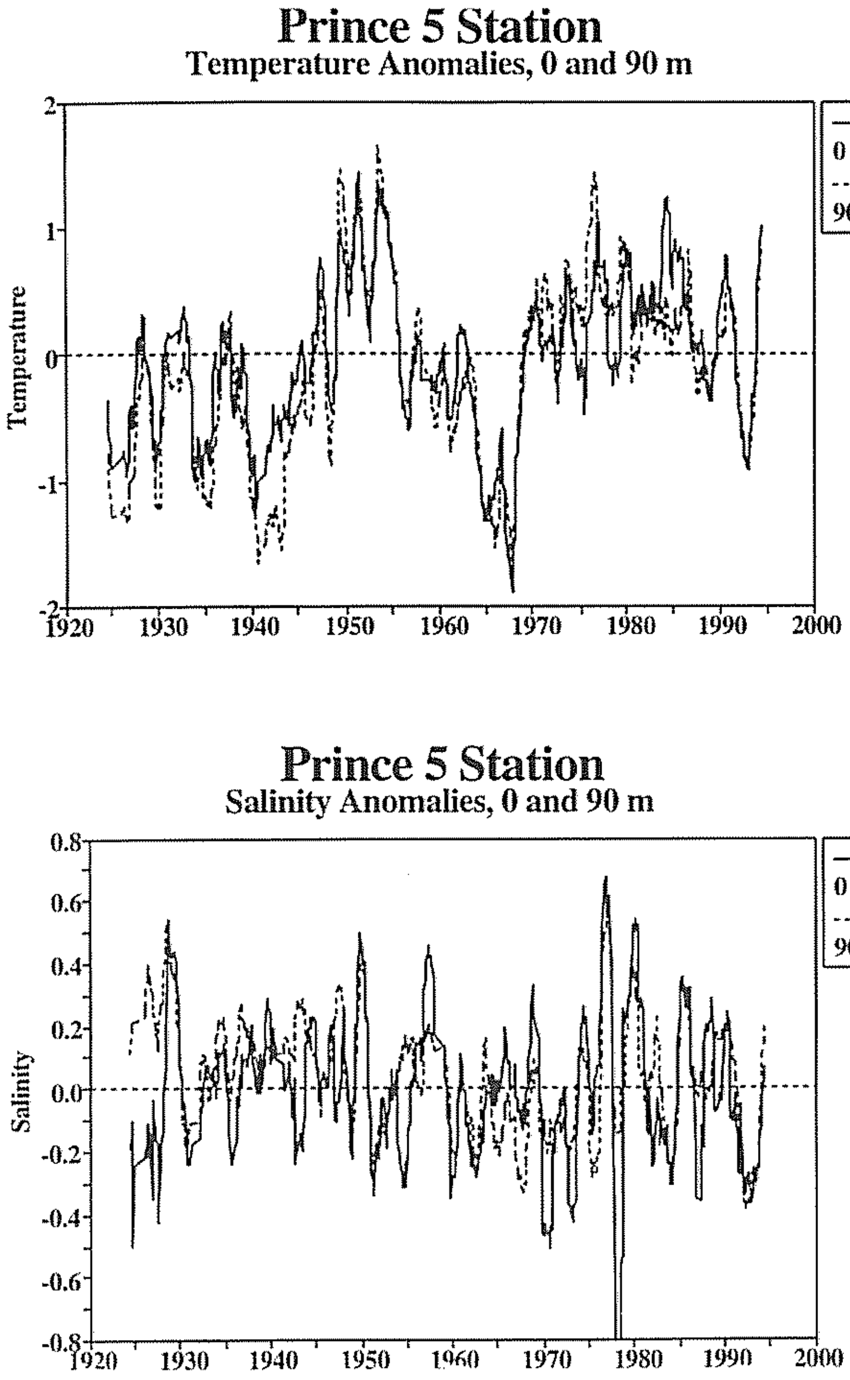

Figure 2.9 The differences from the annual average salinity and temperature at the surface and 90 m from Prince 5 station from 1924-1994. The uniformity of the data from 0 and 90 m are consistent with the area being tidally well-mixed, except as seen in 1978 where the freshwater runoff in one month gave rise to the strong anomoly difference noted in that year's average.

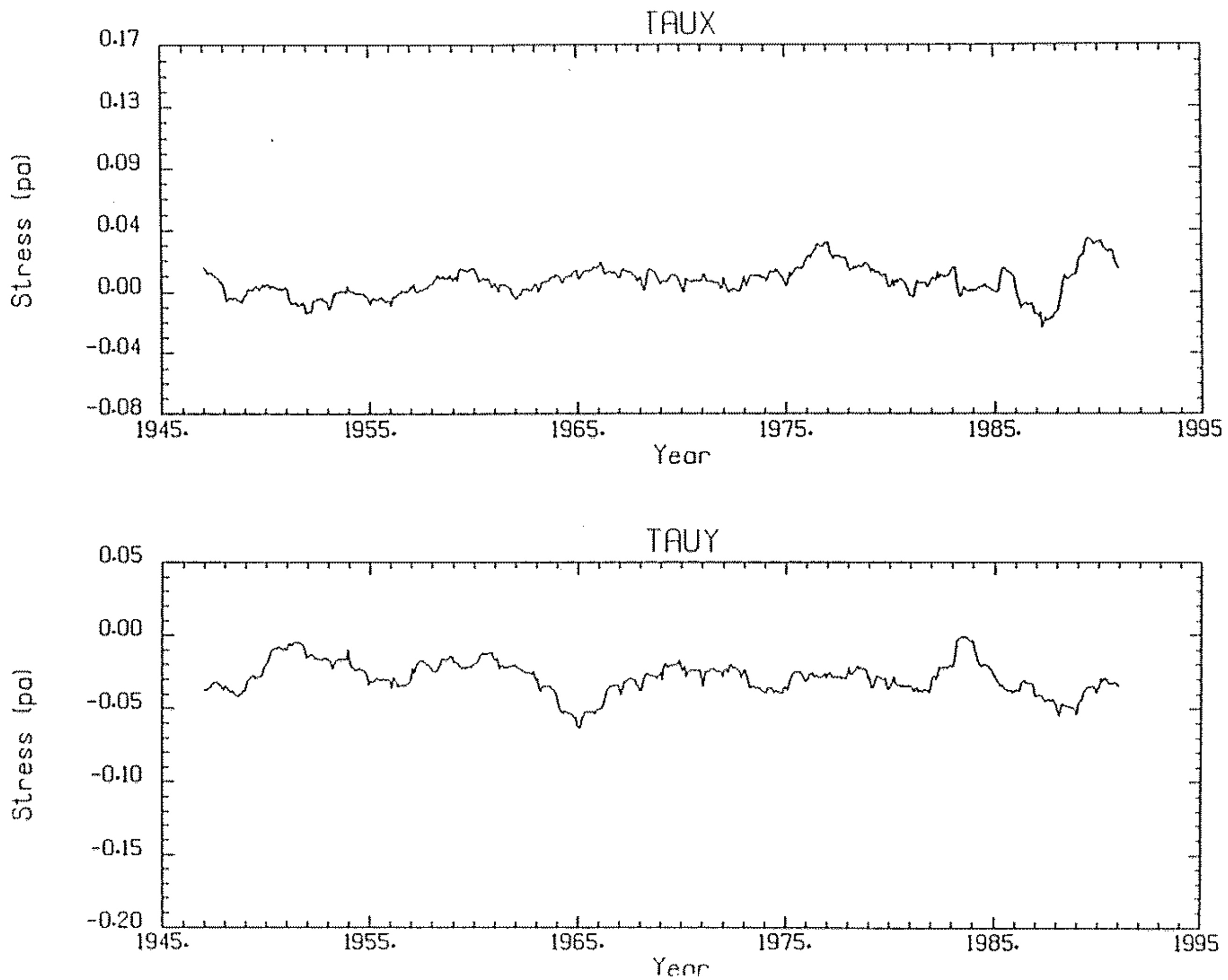

Figure 2.10 The monthly mean geostrophic wind stresses from grid point 20 (44° 48' N, 64° 24' W (Drinkwater and Pettipas 1993). τ_x is resolved along 45° (positive to the NE) and τ_y is resolved along 315° (positive to the NW).

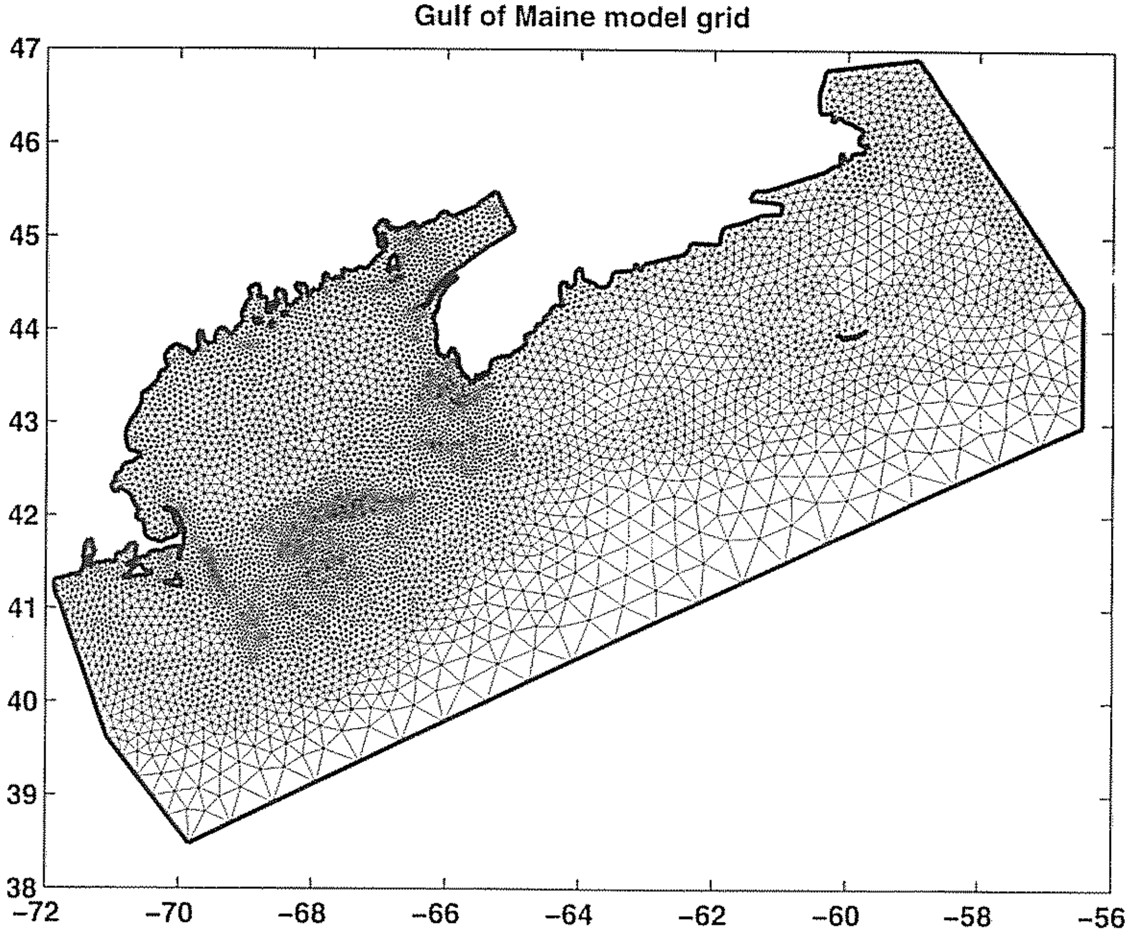

Figure 2.11 A typical finite element model grid showing how variable resolution permits better defining of some regions while still including the influence of distant regions in the same model. In this case interest was focussed on Georges and Browns Banks.

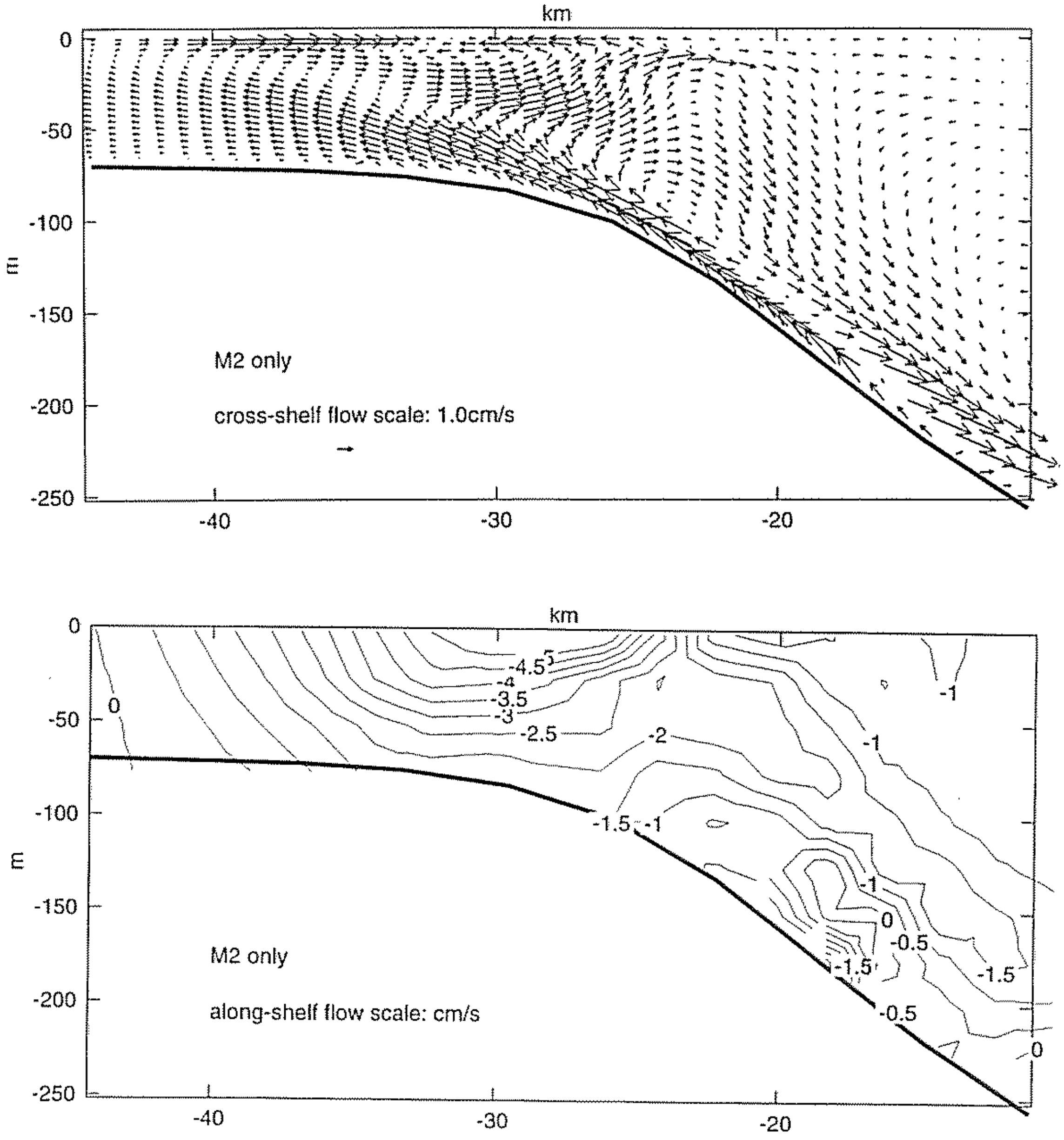

Figure 2.12 A vertical slice from a finite element model (Y. Shen, pers. comm.) illustrating the vertical structure of the tidal currents on Georges Bank.

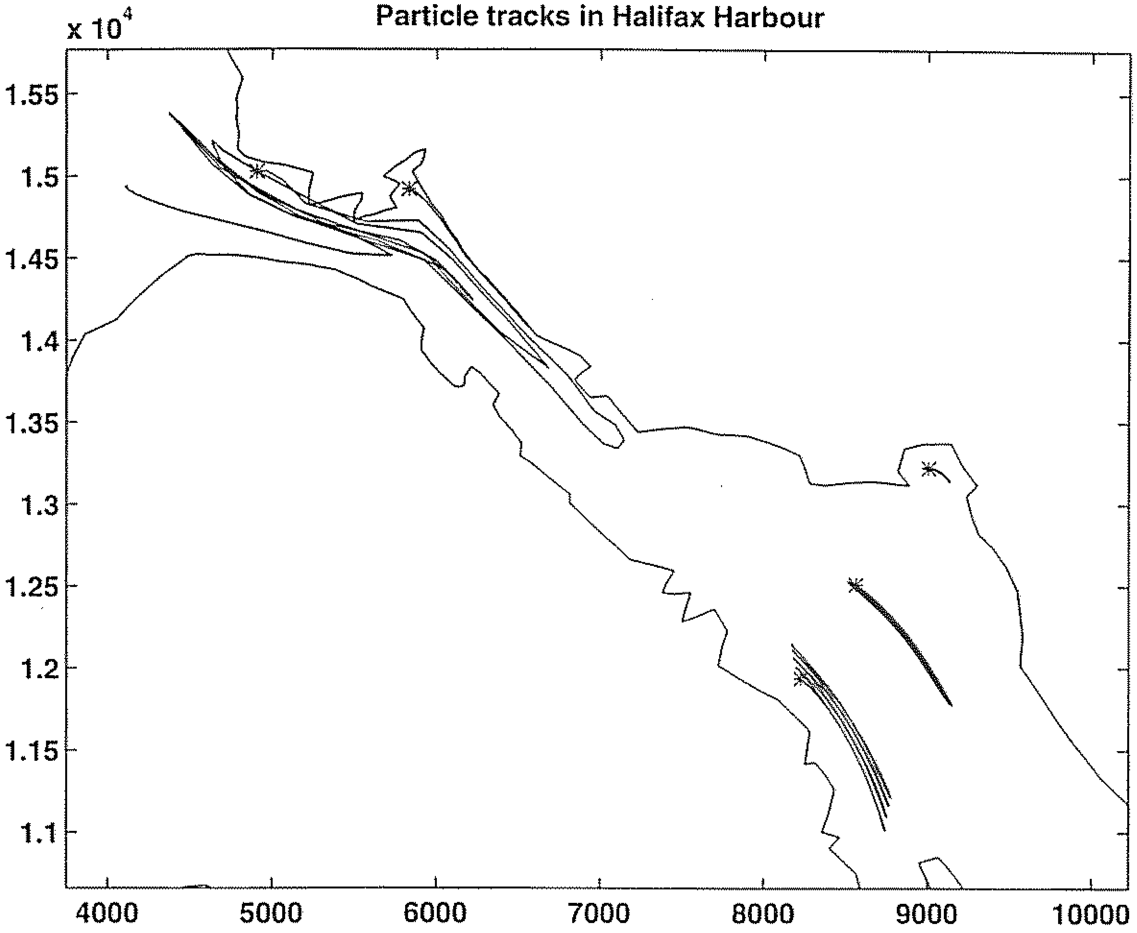

Figure 2.13 The paths traced by particles in the velocity field of Halifax Harbour M_2 tidal and tidally-driven mean currents.

2.1.5 Tidal variations

Godin (1992) analyzed long records of sea surface elevation at Saint John, New Brunswick and determined that the amplitude of the M_2 tide was increasing at a rate of 10-15 cm/century, while the S_2. and N_2 components appeared to be decreasing. He felt this could be the result of changing resonance from rising sea level or the redistribution of sediments at the head of the Bay. However, a study of how sea level change is related to tidal amplitude (Scott and Greenberg 1983) estimated a 1.5% increase in tidal amplitude for each 1 m increase in sea level which, with the present estimates of mean sea level rise (15-30 cm/century), would translate to an increase in tidal amplitude increase of only 1-2 cm/century. A study of the possible effects of tidal power barriers (Greenberg 1979) indicated changes in tidal amplitudes of similar magnitudes to those found by Godin (1992) might occur only with major installations dwarfing any change in geometry caused by sedimentation patterns. Given these results, more study would probably be helpful in sorting out magnitudes and causes of the changing amplitude of the M_2 tide. It would be useful to analyze other stations in the Bay of Fundy - Gulf of Maine system looking for similar trends, and to use a modelling approach to investigate the possible processes.

2.1.6 What has changed recently?

Plots of the monthly mean discharge of freshwater into the Bay of Fundy show that the Saint John River dominates the freshwater input (Figure 2.7). A time series of the annual discharge from the Saint John River (Figure 2.8) indicates the runoff from recent years is within the range observed since 1920. Long-term observations of temperature and salinity (Figure 2.9) taken at the Prince 5 station, just north of Grand Manan Island, show variations for recent years from the long-term means also within the bounds of those observed in the past 70 years. Similarly, wind stress analyses (Figure 2.10) from 1946-1991 (Drinkwater and Pettipas 1993) show nothing unusual in the recent years of the records. The only indications of recent anomalies in the physical oceanography of the Bay of Fundy are in the Godin (1992) study of the tidal amplitude of Saint John.

> ***"records of sea surface elevation at Saint John, New Brunswick [indicated] that the amplitude of the M_2 tide was increasing at a rate of 10-15 cm/century............ [possibly] the result of changing resonance from rising sea level or the redistribution of sediments at the head of the Bay"***

2.1.7 A new generation of numerical models

Since the earlier Fundy models were developed (Greenberg 1979), modelling techniques have developed significantly, keeping in step with the increasing computer power necessary to run them. Studies focussing on the Gulf of Maine (Werner *et al.* 1993) have used a linear harmonic model with a fixed density field to look at the currents driven by tides, wind, density and upstream boundary elevation in examining the movement of cod and haddock around Georges Bank in their early life stages. Full time-stepping models capable of predicting evolving density fields in tidal and atmospherically forced flows are now being developed and used (Naimie 1995, Lynch *et al.* 1995a, b). The three-dimensional finite element techniques used in these computations allow for variable resolution, giving the capability of focussing-in on areas of interest (Figures 2.11, 2.12). The analysis techniques available include tracking particles (Figure 2.13) as well as following changing concentrations transported by model-predicted flows. Turbulence generation, dissipation and advection comprise one of the fundamental pieces included in the model computations.

> ***"modelling techniques have developed significantly, keeping in step with the increasing computer power necessary to run them."***

Further development and testing of these models, already underway, is necessary before they can be confidently applied to the challenging dynamics of the Bay of Fundy. In particular, the capability of simulating the flooding and drying of shallow areas, the convergence of the non-linear solutions in extreme currents and current shears, as well as the transport algorithms, will be severely tested in these waters.

2.1.8 Future work

At the FMESP Workshop (January 29-February 1, 1996) there was a need identified for more work in physical oceanography. The dynamics of the sediment in both bedload and suspended form were seen to be critical to the chemical and biological processes in the Bay, while the current regime was critical to sediment dynamics. Evidence in recently observed sediment patterns suggest that there is a trend toward more tidal energy in Minas Basin and less in Chignecto Bay. Taken with the analysis of Godin (1992), this could indicate a change in the geometry of the Bay possibly around Cape Split, which earlier modelling work (Greenberg 1975, Greenberg 1977) showed to be important to the tidal dynamics of the full system. The present picture of the mean circulation is incomplete and poorly resolved, being based on scant observations and coarsely resolved models (Tee 1977, Greenberg 1983) including only tidal forcing. The mean currents are critical to many processes in addition to suspended sediment transport, including pollutant transport and the movement of fish eggs and larvae.

There was a consensus at the workshop that the new generation of models could help in the understanding of these issues. A comprehensive study could include the following parts:

> *The development of a detailed three-dimensional finite element model for the Bay of Fundy tides, including verification and testing.*
>
> *The computation of mean currents driven by tides, river runoff, meteorology and bounding seas.*
>
> *The correlation of the model bottom stresses with bottom sediment to predict and delineate bedload stresses*
> *An evaluation of suspended sediment transport by tides and mean currents.*
>
> *A further analysis of Bay of Fundy and Gulf of Maine tide gauge records to confirm the trends indicated by Godin (1992).*
>
> *A model investigation of whether changing geometry (scoured bottom, eroded or infilled coasts, mean sea level rise) could lead to a significantly changed tidal regime.*
>
> *Other studies of the transport of waterborne materials affecting the Bay.*

A model such as the one proposed above could have applications to many issues besides those identified as important in the Workshop. Other uses might include aquaculture water quality, oil spill trajectory modelling, search and rescue, storm surge prediction and currents for navigation. Some of these applications could involve further refinement and development of the model and others could piggyback on the computations for studies already identifed.

2.1.9 Conclusions

The picture of the Bay of Fundy as a tidally dominated system is still valid. Recent work has added to insights on general trends and to site specific knowledge. With the exception of the tides, the observations of physical oceanography over the past few years seem to be within the range of the variability found in long-term observations. If the trends in the tides predicted by Godin (1992) can be validated, they will have a major impact on the coastal environment of the Bay. The newer generation of models now available could help in some aspects of studying the Bay.

"With the exception of the tides, the observations of physical oceanography over the past few years seem to be within the range of the variability found in long-term observations."

2.2 Sedimentological processes

2.2.1 Sediments: intertidal and benthic

(G.R. Daborn)

2.2.1.1 Introduction

Considerable research has continued on the sediments of the Bay of Fundy since the studies of the early '80's in Cumberland Basin (*e.g.* Amos 1978, 1984, 1987, 1990, Amos and Alfoldi, 1979, Amos *et al.* 1991, Anon. 1995, ten Brink 1994). Physical studies, crucial to interpreting other physical and chemical problems and processes, have addressed transport of fine-grained sediment in Chignecto Bay (Amos 1987) and suspended sediment in Cumberland Basin (Amos and Tee 1989), *in-situ* erosion measurements on fine-grained sediments in Minas Basin and Annapolis Basin (Amos *et al.* 1992), the influence of subaerial exposure on intertidal sediment properties (Amos *et al.* 1988), and the evolution of deposition of sediments in Chignecto Bay (Amos *et al.* 1992). These studies have identified sources, sinks and transport of sediment, worked out mass balances for input and losses, determined that Minas Basin is a "sand-particle" basin in contrast to Chignecto Bay (a "muddy estuary"), and described some of the key properties (shear strength to water content) of intertidal sediments on mudflats from high water to low water that influence sediment movement and eventual fate.

> ***"Minas Basin is a 'sand-particle' basin in contrast to Chignecto Bay (a 'muddy estuary')"***

Research on deposited and suspended sediments in the Bay of Fundy formed a significant part of the work of the Fundy Environmental Studies Committee during the 1970's, following on pioneering work by Middleton, Dalrymple and Knight and their students on the sandy deposits of Cobequid Bay (Amos 1984, Dalrymple *et al.* 1990). It was evident, however, that this early work in the innermost part of Minas Basin had little applicability to some other parts of the Fundy system where more cohesive sediments dominated. Greenberg and Amos (1983) attempted to model suspended sediment behaviour for the regions likely to be directly affected by tidal power development, but found that models based upon known parameters, especially those controlling re-suspension, produced intuitively incorrect predictions. It became evident that problems in making predictions were particularly acute where sediments contained significant amounts of clays, such as in the western parts of Minas Basin.

2. 2.1.2 Minas Basin studies

Amos and Mosher (1985) examined closely the properties of muddy intertidal sediments from the southern bight of Minas Basin, and found them to be far more resistant to re-suspension than standard models of sediment behaviour predicted. These silty clays were as much as 80 times less erodible than expected, leading to the conclusion that representative measurements of sediment properties needed to be made *in situ* wherever possible. A subsequent seasonal study of the Starrs Point mudflat in Minas Basin by Amos *et al.* (1988) showed that intertidal sediment bulk properties varied considerably in both space and time, although more in the latter than the former. In mid-summer, there was a dramatic change in shear strength from 4-5 Pa to c. 42 Pa (as measured by a Torvane pocket shear vane). Correlations between shear strength and sediment properties or biological phenomena suggested that the principal factor causing the seasonal change in shear strength was prolonged daytime exposure to air and associated evaporation during neap tides. However, anomalous results - such as increases in water and organic content and decreases in bulk density - that coincided with increasing shear strength, were not adequately explained. This was attributed to the low precision of sampling : most measurements were based on samples that extended over the uppermost 10 mm, whereas it was concluded that significant changes leading to increased shear strength occurred in the top 1-2 mm. Traditional measurement techniques that integrate strength over depths of several centimeters may be up to 3 orders of magnitude different from the real strength at the surface (Amos 1995). Poisoning experiments carried out as part of this study showed that elimination of the biota by spraying with a biocide modified the pattern of deposition and erosion : treated sites accumulated less, or eroded more than untreated sites (unpubl. data).

The inadequate techniques for measuring sediment properties *in situ* led to development of the 'Sea Carousel', a field-deployable flume designed for study of erodibility of deposited sediments (Amos *et al.* 1992), and 'INSIST', Harold Christian's device for measuring shear strength under varying loads, and calculating natural cohesion of surficial sediments (Daborn, 1991, Faas *et al.* 1991). Using the same Starrs Point mudflat, an intense study of sediment properties was carried out over a three week period in July and August 1989. Entitled LISP (*Littoral Investigation of Sediment Properties*), the study involved more than 30 scientists from 16 institutions in five countries. Field work was centered around the date (25 July) when low tide occurred at noon; *i.e.* when subaerial exposure would be maximal. Shear strength and erodibility were measured at three stations using several *in situ* devices, including 'Sea Carousel', 'INSIST' and Paterson's Cohesive Shear Tester (Paterson, 1989). Bulk sediment properties were again measured frequently, current velocities and heat flux between sediment, water and atmosphere were monitored continuously, and experiments on biological processes were carried out.

The mid-summer changes in shear strength observed earlier were again recorded during the neap tides of late July. However it was apparent that these changes also coincided with the arrival of large numbers of migratory shorebirds, and the apparent disappearance from the exposed sediments of the burrowing but vagile amphipod, *Corophium volutator* (Daborn *et al.* 1993). Biological investigations showed corresponding increases in sediment chlorophyll, carbohydrate and organic matter, suggesting that increased shear strength was related to higher production by epipelic diatoms resulting from decreased grazing by *Corophium*. Poisoning treatments resulted in winnowing away of fine sediments and the appearance of rippled bedforms that were not evident in biologically active sediments. The conclusion was that the accumulation of fine sediments in surficial layers of the mudflat was itself a result of biological processes (Faas *et al.* 1991). Enclosure and exclosure experiments provided evidence that behaviour of *Corophium* changed with the arrival of shorebirds, and that sediment chlorophyll (a measure of diatom abundance) increased when abundance of *Corophium* declined (Daborn 1991).

> ***"the accumulation of fine sediments in surficial layers of the mudflat was itself a result of biological processes"***

The LISP study has provided clearer insight into the complex factors affecting behaviour of intertidal sediments, and demonstrated the feasibility of obtaining more accurate and representative *in situ* measurements. It also provided opportunities for comparison of different field techniques, and for contrasting results between *in situ* measurements and those derived from analysis of sediments transported to a distant laboratory, as has usually been done in the past. Grant and Daborn (1994) found little similarity in sediment behaviour of cores inhabited by *Corophium volutator* that were subjected to varying shear stress in a laboratory flume. After transportation from field to laboratory, much of the initial induced erosion was attributed to tube-cleaning activities of the amphipod. Success of the LISP 89 study has led to a similar exercise (LISP-UK 1995) on the Humber Estuary, in which a comprehensive conceptual model patterned after the LISP 89 results formed the basic hypothesis regarding controls on sediment behaviour.

The *in situ* techniques, particularly 'Sea Carousel', have since been widely used to investigate intertidal and subtidal sediment deposits in estuaries, coastal waters and lakes. Studies in the Miramichi Bay, for example, indicate that organic content plays a significant role in determining the stability of submersed cohesive sediments, particularly by affecting retention of water (Amos *et al.* 1992). In the upper Bay of Fundy, measurements of sediment erodibility using 'Sea Carousel' were made in Cumberland Basin to assist with development of a numerical model of sediment behaviour known as CUMBSED (Amos and Tee 1989).

2.2.1.3 Annapolis Basin studies

In contrast to the turbid waters of the upper Bay of Fundy, the Annapolis Estuary has relatively low concentrations of suspended sediments, mostly in the 20 - 40 mg/L range (Daborn 1991). Concerns over declines in soft-shell clams (*Mya arenaria*) in the basin led to extensive studies of deposited sediment grain size and clam distribution during the late 1980's (Rowell 1991). The LISP study confirmed that in Thorne Cove, which had experienced significant changes in clam abundance, deposited sediments were highly over-consolidated at depth, but covered by a soft and unconsolidated veneer of fine sediments (Daborn 1991).

In 1991, observations indicated that an extensive saltmarsh along the Annapolis Estuary shore of Fort Anne National Historic Site was eroding rapidly, leaving the embankments of the Fort extremely vulnerable to the action of waves and ice. A series of studies aimed at determining causes of the disappearance of the marsh indicate that the process began in the early 1960's, at the time of construction of the Annapolis tidal dam (Daborn *et al.* 1992, 1993b, 1995). It seems probable that construction of the dam was responsible for lowering the suspended sediment load of the estuary (*i.e.* the water contained less than its equilibrium capacity for sediment - *cf.* Amos 1995), causing sediment to be withdrawn from the saltmarsh. Since the Fort Anne site is the only saltmarsh in the Annapolis Estuary that is apparently severely affected, this conclusion is still somewhat uncertain.

2.2.1.4 Sediment issues

Recently, observations have indicated that the sedimentary characteristics of relatively well-studied intertidal zones, such as Starrs Point in Minas Basin and Peck's Cove in Cumberland Basin, may have undergone, or be undergoing, significant changes (Shepherd *et al.* 1995). Repeats of intertidal surveys carried out originally in 1977-79 showed that both water content and sediment composition were different in 1994 at all sites, and that these changes were accompanied by changes in important fauna, particularly *Corophium volutator*. In Chignecto Bay, *Corophium* densities were significantly lower at Grande Anse and Peck's Cove, whereas in Minas Basin polychaetes were significantly more abundant in 1994 than 1977-9. Minas Basin sediments showed increased proportions of sand. Changes in invertebrate abundances were accompanied by changes in foraging behaviour and abundance of migratory shorebirds. So far there is no clear explanation for these observations.

2.2.2 Marine aggregate assessment and sediment transport (G.B. Fader)

2.2.2.1 Mineral Development Agreement Project

The Geological Survey of Canada (Atlantic) is involved in an assessment of the aggregate (sand and gravel) potential of the Scotian Shelf and Bay of Fundy (Fader and Miller 1994). This project is conducted through the Canada-Nova Scotia Cooperation Agreement on Mineral Development, commonly known as the MDA-3. Marine mining does not occur in Canada at this time, however, many European countries, and others, are actively mining their seabeds and providing aggregate for the construction industry. Up to 20% of the aggregate needs of the United Kingdom and Japan are met through marine mining. Industry has expressed an interest in marine mining for aggregates off the coast of southeast Canada.

2.2.2.2 Scots Bay Sand Wave Field

In the Fundy region, marine geological and geophysical surveys have been conducted in Scots Bay, over what is commonly known as the "Scots Bay Sand Wave Field", and in the inner Bay of Fundy extending from the Digby area to the Minas Channel. A large field of sand waves was identified, mapped and studied by Fader *et al.* (1977) in the inner Bay, and these bedforms were the target of surveys conducted from the CSS Hudson in 1995.

Miller and Fader (1990) studied the Scots Bay Sand Wave Field from the CSS Navicula and identified a large deposit containing up to 35 million cubic metres of coarse sand and fine-grained gravel, calculated on the basis of high-resolution seismic reflection data. The deposit appears concentrated by a large current gyre that occurs to the southwest of Cape Split. It consists of megaripples superimposed on sand waves that overlie a lag gravel developed on thick layers of glaciomarine/lacustrine sediments. Fishing is not regularly conducted on the large sandy bedforms because of very strong currents and associated sediment remobilization. Fishing trawl marks, however, occur on the gravel lag seabed surrounding the sand wave field. Fader and Miller (1991) proposed that new stable habitat (gravel lag) could be created at the seabed through the removal of the sand wave field and exhumation of the underlying gravel substrate.

2.2.2.3 Resource potential

Preliminary results from the aggregate assessment program indicate that substantial resources occur in the Bay of Fundy and on areas of the Scotian Shelf. As of January 1996, no immediate development plans are in place for aggregate mining. It is, therefore, important at this early stage to assess the potential impact of such a removal program. The environmental effects of seabed mining must be carefully assessed. However, in the case of the Cape Split Sand Wave Field, aggregate extraction may indeed be beneficial, with the enhancement of seabed habitat along with the provision of valuable aggregate resources.

2.2.2.4 Multibeam bathymetry

In 1994, Larry Mayer and John Hughes Clark of the University of New Brunswick, conducted a multibeam bathymetric survey of areas of the inner Bay, from the Canadian Hydrographic Service vessel FGC Creed. Following the earlier research of Fader *et al.* (1977), they conducted surveys over previously identified areas of sand waves. The images produced from the multibeam bathymetric data display water depth, shaded relief and backscatter. The backscatter images are similar to sidescan sonar mosaics but with less resolution (approximately 2 m). They provide a remote method of assessing seabed sediment type. The shaded-relief images are spectacular (see Figure 2.14 for example), and reveal the true morphology of the seabed with a resolution of 2 m horizontally and decimetres vertically. The images resemble aerial photographs of land areas. When integrated with high-resolution seismic reflection and sidescan sonar data, together with seabed and subsurface samples, they can be interpreted to produce an understanding of sediment distributions, dynamic features and ancient and modern processes.

2.2.2.5 Margaretsville Dunefield

A preliminary interpretation of the multibeam bathymetry and data collected on CSS Hudson Survey 95-030, provides considerable insight into geological conditions of erosion and deposition on the floor of the inner Bay off Margaretsville (Figure 2.14). The stratigraphy consists of a thick glaciomarine mud, overlying bedrock, which is interbedded with tills deposited during the last Wisconsinan glaciation of the area, approximately 18,000 years BP. The glaciomarine sediments are overlain by a thin veneer of lag gravel. Across this delicate gravel veneer, sand is in transport in the form of sand ribbons, megaripples and sand waves. The larger sand waves range in height from 4 to 12 m, are up to 0.75 km in length, and occur in depressions. By virtue of their large size and orientation normal to current flow, it appears that the sand waves may locally induce erosion, concentrated at their ends. A comparison of the 1994 and 1995 data indicates that their crest positions have not substantially moved during the time interval. However, on high-resolution sidescan sonograms, the ends of the bedforms can be seen migrating out of the scoured depressions, suggesting that they are enlarging. Erosion of these local depressions around the flow-transverse sand waves is a complex process, and one that results in local perturbation of bottom currents and a dissipation of energy through frictional effects.

> ***"Preliminary results from the aggregate assessment program indicate that substantial resources occur in the Bay of Fundy and on areas of the Scotian Shelf."***

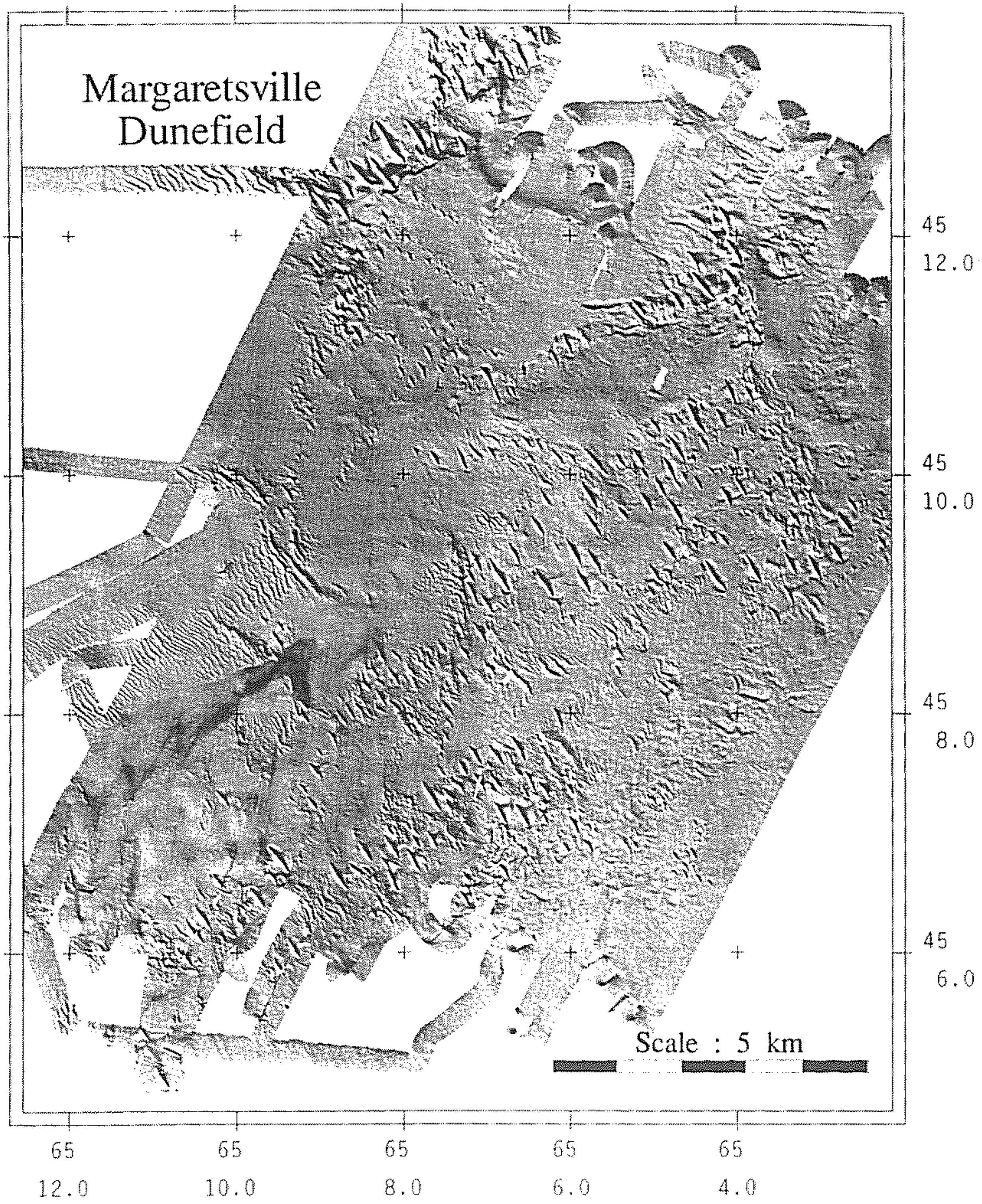

Figure 2.14 Shaded relief image of Margaretsville Dunefield, Bay of Fundy.

2.2.2.6 Seabed erosion

Other areas of the seabed, not directly associated with the sand waves, appear to be eroding through the lag gravel and into the subsurface glaciomarine mud. Flute-like depressions appear to form locally and coalesce into large areas of eroded seabed toward the inner Bay of Fundy. These depressions also contain megaripples. Flutes are triangular-shaped erosional bedforms. They are deepest at their upstream apex end, and flare upward toward the seabed and outward toward the inner Bay of Fundy. The shape of these bedforms indicates erosion from the currents moving from the southwest to the northeast, that is, up the Bay of Fundy, parallel to its axis. Large quantities of fine-grained silt and clay are removed through the process of flute formation and the sand-sized particles appear to largely remain in the depressions where they are formed into meggaripple fields, as a residual product of selective glaciomarine sediment erosion.

"It is possible that this fishing activity is breaking through the thin and fragile lag gravel surfaces, facilitating erosion of the underlying muds."

2.2.2.7 Bottom fishing impacts

Large areas with bottom fishing marks (trawling and scallop dragging) can be seen on the sidescan sonar data, preserved on gravel bottoms of the inner Bay of Fundy. It is possible that this fishing activity is breaking through the thin and fragile lag gravel surfaces, facilitating erosion of the underlying muds. This hypothesis remains to be assessed.

2.2.2.8 Sediment transport

Although at first glance the sand waves appear to be symmetrical, suggesting equal current velocities during ebb and flood tides, other bedforms (comet marks, sand ribbons and ramps of sand on the eastern sides of large sand waves) suggest dominant sediment transport notheastward, toward the inner Bay. This understanding of net sediment transport may explain the problems associated with an apparent accumulation of fine-grained sediment and changes to mud flats in Minas Basin and Cobequid Bay. The changes may be directly related to erosional processes on the seafloor to the west, with subsequent transport of materials to the east.

An overall assessment of the new multibeam bathymetric and seismic reflection data suggests that the energy in the inner Fundy system is increasing, possibly in response to tidal amplification as resonance is approached. If this is true, then some of the lithologic and depositional changes observed in the inner Fundy system could be attributed to natural variation as opposed to anthropogenic effects. On the other hand, the role of sediment supply from bottom fishing related erosion has not been quantified. In either case, the quantity and transport of fine-grained sediment to the inner Fundy area, and its eventual fate, is not completely understood. The dyking of the inner Fundy areas and continued damming and bridge construction presents barriers to these fine-grained sediments, which would, in the absence of the dykes, normally be deposited in the marshes.

2.2.2.9 Future research

A better understanding of the processes of erosion, sediment transport and deposition is needed for the inner half of the Bay of Fundy. Such studies should not only be confined to Minas Basin and Cobequid Bay, as in the past, but must include the entire Bay. A first step in this process would be the collection of regional multibeam bathymetry, which would provide a geomorphological seabed model. Repetitive surveys, using this technology, would enable a rapid quantified evaluation of changes in erosion and deposition. The multibeam bathymetry can also be interpreted to provide process information regarding the formation of bedforms and sediment transport pathways. The interpretation of the multibeam bathymetry must, however, be based on subsurface information provided by high-resolution seismic reflection profilers and calibrated with accurately positioned seabed and subsurface samples.

"A better understanding of the processes of erosion, sediment transport and deposition is needed for the inner half of the Bay of Fundy"

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CHAPTER THREE

THE CHEMICAL ENVIRONMENT OF THE BAY OF FUNDY

P.G. Wells, P.D. Keizer, J.L. Martin, P.A. Yeats, K.M. Ellis, and D.W. Johnston

3.1 Introduction (P.G. Wells)

This chapter discusses recent data and information on the chemical oceanography and chemical environment in the Bay of Fundy, updating and expanding upon Keizer *et al.* (1984) and Wells and Rolston (1991), among others. Its purpose, in the context of the Workshop objectives, is to answer three questions:

> *1) What is our recent knowledge base and understanding of the chemical processes and overall environment in the Bay?*
>
> *2) What is of general public interest regarding our understanding of the Bay's chemical environment?*
>
> *3) What suggestions do we have for new interdisciplinary research to better understand the processes in, and manage the living resources of, the Bay's ecosystems?*

It is hoped that this overview contributes to an understanding of the fate and effects of nutrient and toxic chemicals in the bay, and provides a benchmark for future research, monitoring, assessment and management initiatives in this portion of the Gulf of Maine ecosystem. This review also complements the recent excellent and exhaustive synthesis on the Northeast Shelf Ecosystem of Sherman *et al.* (1996).

3.2. The water column, and water and sediment quality

3.2.1 Inorganic nutrients (P.D.Keizer)

Information on the concentration of plant nutrients in the Bay of Fundy is almost entirely restricted to inlets around the Basin. There is no published information of concentrations in the open Bay. As part of their work in the upper reaches of Cumberland Basin, Keizer and Gordon (1985a) collected data in the open Bay, but this has not yet been published.

There is a large amount of published nutrient data for Passamaquoddy Bay. As a result of the chronic occurrence of PSP toxins in that area, the Department of Fisheries and Oceans (DFO) has regularly monitored locations in and at the mouth of the Bay. This monitoring in recent years includes the determination of plant nutrients at 3 depths in the water column. At the same time, the growth of finfish aquaculture in the Bay has caused concern about the fate and effect of wastes from that industry. Several studies have been conducted in the area to determine the fate of nitrogen released as metabolic fish wastes and uneaten food. These studies provide information of nutrient dynamics at a variety of temporal and spatial scales in various parts of the Bay of Fundy (Hargrave *et al.* 1993a, b, Wildish *et al.* 1993). In addition Strain *et al.* (1995) used existing data to evaluate the relative importance of various nutrient sources in the L'Etang Inlet estuarine system. Using a box-model to estimate flushing and exchange, they concluded that net-pen culture of fish in the area was a significant contributor to nutrient loading in the L'Etang Inlet.

There also is a large amount of unpublished nutrient data for Annapolis Basin. However, a technical report describing some of this information is now prepared (Keizer *et al.*, 1996, in press). Nutrient data from 3 depths in the water column at one site are available for 5 years with 26 sampling

"the growth of finfish aquaculture in the Bay has caused concern about the fate and effect of wastes from that industry"

times per year. This site was part of the national DFO phytoplankton monitoring program which collected data to determine the species of phytoplankton, particularly potentially harmful phytoplankton species, present in Canada's coastal waters.

There is information on plant nutrient concentrations in seawater in Cumberland Basin (Keizer and Gordon 1985a, b, Keizer *et al.* 1989). While some of the data are for samples collected in mid-channel, most of the data are for samples collected over tidal cycles on the intertidal mud flats. Among other findings, it was estimated that "there was a net import of dissolved nitrate and silicate into Cumberland Basin from Chignecto Bay during early summer, and at all other times there was a net export" (Keizer *et al.* 1989). In Minas Basin, Walker *et al.* (1981) studied the net transfer of materials between the Kingsport Marsh and the open Basin. The data from this study include time series of nutrient concentrations on 9 different dates.

> ***"while there is little or no published information about nutrient concentrations in the open Bay of Fundy, there is a great deal of information from some of its coastal embayments"***

In summary, while there is little or no published information about nutrient concentrations in the open Bay of Fundy, there is a great deal of information from some of its coastal embayments, *e.g.* Passamaquoddy Bay, and Annapolis, Cumberland and Minas Basins. There is also a considerable body of nutrient data collected at various intertidal sites throughout the Bay of Fundy as part of studies of sediment and salt marsh interactions with the tidal waters of the Bay. The only anomaly, in what is a typical northern temperate seasonal variation in nutrient concentrations, is the relatively high concentrations of ammonia found in the waters in and around Passamaquoddy Bay, in the vicinity of finfish culture operations and the fish plant at Blacks Harbour. There is reason for concern about the effects of these elevated nutrient concentrations on the sustainability of other coastal resource uses.

3.2.2 Organic nutrients (P.D.Keizer)

Studies of sources and concentrations of organic matter in waters of the Bay of Fundy focus on natural and anthropogenic inputs. In an early study, Walker *et al.* (1981) measured particulate and dissolved organic carbon in the Kingsport Marsh in Minas Basin. Recently, various DFO scientists (Cranford *et al.* 1987, Gordon and Cranford 1994, Gordon *et al.* 1985, Schwinghamer *et al.* 1983) studied the importance of salt marshes as a source of particulate carbon. In the most recent study, Gordon and Cranford (1994) concluded that Bay of Fundy macrotidal salt marshes may have the greatest export potential of organic matter of any salt marshes in the world, and warrant futher study. Other recent studies focused on anthropogenic inputs, in particular those from the fish processing plant in Blacks Harbour, N.B. (Wildish and Zitko 1991) and from the finfish aquaculture industry in Passamaquoddy Bay (Hargrave 1994, Strain *et al.* 1995). Data on dissolved and particulate organic carbon concentrations in the open Bay was collected by Keizer and Gordon (1985a) in the upper reaches of Cumberland Basin, but this information remains unpublished.

In summary, there is information available on the dissolved and particulate organic carbon concentrations in many parts of the Bay, and there seems little need for further synoptic information. However, in some areas such as Passamaquoddy Bay and Annapolis Basin, there is reason for concern about their assimilative capacity for organic inputs.

3.2.3 Nutrient dynamics (P.D.Keizer)

Investigations of the sources and sinks of plant nutrients in the Bay are few. Anderson (1986) determined that buried salt marsh detritus enhanced nutrient exchange between sediment and overlying waters. Keizer *et al.* (1989) reported seasonal variations in nutrient concentrations in Cumberland Basin and Chignecto Bay and sediment/water exchanges on intertidal sediments. They concluded that, despite the low primary productivity and rigorous physical environment, biological activity still had a measurable impact on nutrient concentrations in the Basin. More recently, Hargrave *et al.* (1993b) investigated the seasonal changes in benthic fluxes of dissolved oxygen and ammonium in organically enriched sediments under finfish culture sea cages in Passamaquoddy Bay. They found elevated rates of oxygen uptake and ammonium release, negative redox potentials, reduced number of polychaetes, and high (>100mM) sulphides in sediment pore water under the pens, showing significant localized impacts of fish aquaculture.

"It is essential that one or more measurable environmental indicators be defined that will permit an assessment of the various impacts of nutrient loading"

Keizer and Gordon (1985a, b) reported, based on a detailed study of nutrient concentrations in Cumberland Basin and the upper Bay of Fundy, that the Basin exported nutrients for most of the time of their observations. They speculated that the effects of winter ice and storms or hurricanes would have a much greater impact on nutrient exchanges than processes acting during less severe weather. Walker *et al.* (1981) were unable to conclude anything about the transfer of materials from the Kingsport Marsh due to the high variability in their data.

Research clearly is required to determine methods for defining acceptable nutrient loadings to specific areas of the Bay of Fundy. It is essential that one or more measurable environmental indicators be defined that will permit an assessment of the various impacts of nutrient loading.

3.2.4 Plant pigments and phytotoxins

(J.L. Martin)

The chronic presence of toxins responsible for paralytic shellfish poisoning in coastal areas at the mouth of the Bay of Fundy has stimulated a great deal of research directed at predicting the occurrence of PSP toxins. A monitoring program has been conducted at sites in and at the mouth of Passamaquoddy Bay since 1987. There is a large amount of data for chlorophyll a concentrations at these stations. Chlorophyll data also exist for most samples referred to in Section 3.2.1.

The shellfish toxicity data since 1943 for PSP in the Bay of Fundy represents the longest database in the world for this type of information. There is some indication that PSP toxicity, which results in the closure of most of the shellfish harvesting areas in the Bay of Fundy every year, has highs and lows that may correlate with the 18.6 year lunar cycle. Blooms of the causative organism, *Alexandrium fundyense*, generally occur offshore and then are advected inshore over a period of 1 to 2 weeks. PSP toxicity and *A. fundyense* blooms were not strongly correlated with water temperature, salinity or nutrient concentrations.

During 1988 and 1995, domoic acid was detected in shellfish from the southwestern Bay of Fundy. The organism responsible, *Pseudonitzschia pseudodelicatissima*, has been observed annually since 1987 and cell concentrations correlate with domoic acid production.

Blooms of potentially harmful marine algae are a world-wide concern. There is a debate as to whether there has been an increased frequency of such blooms. Certainly there is an increase in the number of incidents reported. Regardless, this is a serious problem, affecting both traditional fisheries and marine aquaculture, that requires continued study. It is critical that the processes which control the formation of a toxic bloom are understood so that either mitigative actions can be taken or an early warning can be provided to fishers.

"PSP toxicity, which results in the closure of most of the shellfish harvesting areas in the Bay of Fundy every year, has highs and lows that may correlate with the 18.6 year lunar cycle"

3.2.5 Metals (P. A. Yeats)

One fairly broad survey of metal concentrations in sediments from the Bay of Fundy, excluding the Minas Basin, has been published (Loring 1979, 1982). This survey produced results for Zn, Cu, Pb, Co, Ni, Cr, V, Ba, Hg, As, Se and Be from 83 sites, and included chemical partitioning of the 'bioavailable' component of the total metals. The results showed that the levels of metals are, except for local anomalies, at or near natural levels for unpolluted coastal sediments. Higher concentrations of Cr, V and Ni found in the vicinity of Grand Manan Island and along the coast of Nova Scotia are related to bedrock exposures. Higher concentrations of Cd, Cu, Zn, Pb and Hg were also seen near the dredge dispersal site off Saint John and in the major sediment deposition area in the Quoddy region.

> ***"the levels of metals are, except for local anomalies, at or near natural levels for unpolluted coastal sediments"***

Smith *et al.* (1981) and Ellis *et al.* (1984) reported the results of four surveys of dissolved Fe, Mn, Al, Co, Ni, Cu, Zn and Cd distributions in the western part of the Bay of Fundy. The distributions for all four surveys are generally rather uniform with little difference in concentration from one survey to another. Average concentrations are all quite low and similar to those found in other 'clean' coastal waters. The most noticeable feature in these distributions is the negative correlation between metals (Fe, Mn, Al, Co and Ni) and salinity for surface samples from one springtime cruise, that is related to high freshwater discharge from the Saint John River. Cadmium and lead concentrations in particulate matter (seston) from the Quoddy region of the western Bay of Fundy have been reported by Showell and Gaskin (1992). These results also indicate that metal concentrations in the Bay are not elevated.

3.2.6 Radionuclides (K.M. Ellis)

3.2.6.1 Introduction

Sources of artificial radioactivity in the Bay of Fundy include atmospheric fallout from nuclear weapons tests, fallout from the Chernobyl accident in 1986, as well as effluent from the Point Lepreau (N.B.) Nuclear Generating Station (NGS), Canada's first reactor located on a marine coastline. The 660 MW CANDU reactor which became operational in 1982 uses the Bay of Fundy for cooling water and releases low level radioactivity regularly into the Bay and atmosphere. As a result of the reactor operation, two environmental programs have operated since 1978 in the Bay of Fundy by the Department of Fisheries and Oceans at Bedford Institute of Oceanography (BIO) and by the New Brunswick Electric Power Commission (NBEPC). The reports by BIO (Smith *et al.* 1981, 1982, Ellis *et al.* 1984, 1990, 1992, Nelson *et al.* 1985, 1986, 1988) and NBEPC (Sutherland 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995) provide much detailed information on radioactivity levels in the lower Bay of Fundy.

Radioisotopes most commonly measured are ^{137}Cs, ^{90}Sr, plutonium isotopes and tritium. ^{137}Cs and ^{90}Sr are fission products, each with a 30 year half life, which remain in solution in seawater. Plutonium isotopes, ^{239,240}Pu and ^{238}Pu, are long-lived (half lives of 24,400 and 86.4 years respectively) and particle-reactive, therefore associating with particles and accumulating in sediments. Tritium (^{3}H), a radioactive isotope of hydrogen with a 12.3 year half life, is released from Point Lepreau at substantially higher levels than other radionuclides as a result of neutron activation of heavy water, D_2O, which is used as a reactor moderator. The accepted unit of radioactivity is the Bequerel (Bq) which stands for a disintegration per second.

3.2.6.2 Seawater

The levels of ^{137}Cs in the lower Bay of Fundy are similar to activities measured in surface waters of the Atlantic Ocean and have decreased from average values of 3.8 Bq/m^3 (= 0.7) in 1979 to 2.62 Bq/m^3 (= 0.32) in 1993 (K. Ellis, unpublished data), consistent with the decay of radioactive fallout since the period of most intense nuclear testing in the late 1950's and early 1960's (Ellis *et al.* 1992). ^{137}Cs/^{90}Sr ratios have remained relatively constant at 1.1 ± 0.2 (Ellis *et al.* 1990), typical of coastal values (Kupferman *et al.* 1979). Levels of ^{239,240}Pu measured in 1981, 1984, 1985 and 1987 (Nelson *et al.* 1988, Ellis *et al.* 1992), have remained constant, ranging from 0.02 to 0.04 Bq/m^3 with 20 to 74 % of plutonium on particles. They also report extremely low activities of ^{238}Pu (0.3 mBq/m^3 to 1.4 mBq/m^3). There is no evidence of reactor contribution to the ^{137}Cs, ^{90}Sr or plutonium signal in the Bay of Fundy. Tritium levels have been measured in water in the lower Bay of Fundy throughout the BIO monitoring program. Levels are close to the detection limit of 3 kBq/m^3 and show no increase in activity since 1979. Occasionally, however, higher activities of tritium (up to 505 kBq/m^3) were measured within 1 km of the reactor outfall during periods of tritium release (Nelson *et al.* 1986). These levels do not constitute a significant radiological hazard.

3.2.6.3 Sediments

Inventories of ^{137}Cs, ^{239,240}Pu and naturally occurring ^{210}Pb in sediment reflect the degree of accumulation of fine-grained particles, with highest inventories observed in the Quoddy region, near approaches to Passamoquoddy Bay, and lower inventories near the reactor outfall where the sediments are made up of coarser-grained material (Ellis et al. 1990). There is no evidence of increased inventories as a result of reactor releases. The Quoddy region appears the most favourable region for the accumulation of particle-reactive radionuclides. Profiles of ^{210}Pb and ^{137}Cs and plutonium isotopes measured in the lower Bay of Fundy sediment provide evidence of sediment mixing due to biological activity (Ellis *et al.* 1984).

> ***"The Quoddy region appears the most favourable region for the accumulation of particle-reactive radionuclides"***

3.2.6.4 Air

Deposition of atmosphere radionuclides from nuclear tests, accidents and releases from Point Lepreau constitutes a potential source of radioactivity to the Bay of Fundy. Continuous monitoring of air particles, moisture and gaseous phase at several locations near Point Lepreau by BIO and NBEPC showed no contamination of ^{137}Cs or artificial radioactivity as a result of the reactor but did reveal fallout from a Chinese nuclear test in 1980 (Ellis and Smith 1987) and the major Chernobyl (U.S.S.R.) accident in 1986 (Smith and Ellis 1990). Tritium activities in this environment have increased since the reactor startup. Activities are highest closer to the reactor and in the summer, when humidity levels are highest. Air levels at the tip of Point Lepreau have increased from pre-operational yearly averages of 0.07 Bq/m^3 before 1982 to 1.1 Bq/m^3 in 1990 (Ellis *et al.* 1992). Occasionally, levels of up to 0.12 mBq/m^3 have been observed at Musquash, located 20 km northeast of the reactor. Air samples from Digby, N.S., have not revealed enhanced levels of radioactivity, indicating that minimal transport of reactor effluent occurs across the Bay of Fundy.

3.2.6.5 Marine biota

Marine plants and animals have been analyzed for radionuclides in the vicinity of the Point Lepreau reactor and near Digby, N.S., in order to assess the movement of radionuclides across the Bay of Fundy since 1979. Seaweed (*Fucus vesiculosis, Ascophyllum nodosom, Laminaria spp., Chondrus crispus, Rhodymenia palmata*), plankton, molluscs (periwinkle (*Littorina littorea*)), scallops (*Pectin maximus*), blue mussels (*Mytilis edulis*), horse mussel (*Modiolus modiolus*)), crustacea (amphipods (*Gammarus oceanicus*)), lobster (*Homarus americanus*) flesh and hepatopancreas, green crab (*Carcinus maenus*)) and fish, including salmon from aquaculture facilities in addition to many other species, have been analysed for radionuclides on a routine basis. ^{137}Cs and tritium were the only isotopes detected in these samples and with the exception of tritium levels in a few samples collected near the reactor outfall, activities were within pre-operational ranges, showing no contribution from the operation of Point Lepreau. ^{137}Cs activities in seaweeds have remained low, ranging from < 0.6 to 1.5 Bq/kg. ^{137}Cs levels in plankton samples range from < 0.6 to 2.3 ± 1.8 Bq/kg in samples collected from 1980 to 1984 (Nelson *et al.* 1986). Cesium-137 levels in molluscs were found to be close to or less than the detection limit of 1 Bq/kg. All crustacean samples contained levels of ^{137}Cs less than 2 Bq/kg. Levels of ^{137}Cs in fish and harbour seal (*Phoca vitulina*) were less than 2.5 Bq/kg (Smith *et al.* 1981, Nelson *et al.* 1985). Tritium levels in most samples reflect the tritium concentrations of the surrounding water and range from < 2 to 8.6 Bq/L (for instance, Nelson *et al.* 1985). Levels of tritium in marine organisms near the reactor outfall were found to be higher (up to 283 kBq/L, Nelson *et al.* 1986) than baseline levels (3 Bq/L) and reflect tritium releases from the reactor. Elevated levels are rarely measured in marine biota at distances greater than a few kilometres from the reactor outfall.

3.2.6.6 Terrestrial and freshwater environments

^{137}Cs levels in lake and stream water samples in the vicinity of Point Lepreau have remained low (<3 Bq/m^3) since 1979 (Smith *et al.* 1981, Ellis *et al.* 1992). Tritium activities in freshwater samples have increased from pre-operational levels of 4.2 to 10.6 kBq/L (Ellis *et al.* 1984) to average values near the reactor of 34 kBq/L in 1990, with occasional spikes of up to 162 kBq/L as a result of releases from Point Lepreau NGS (Ellis *et al.* 1992). Levels are highest in water collected near the reactor and at locations downwind from the reactor.

> ***"Elevated levels [of tritium] are rarely measured in marine biota at distances greater than a few kilometres from the reactor outfall"***

A wide variety of plants and animals has been analyzed as part of the Point Lepreau monitoring programs with ^{137}Cs and tritium being the only artificial radionuclides detected. Exceptions were the measurement of short-lived radionuclides ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{141}Ce, ^{144}Ce and ^{54}Mn after a Chinese nuclear test in 1980 (Smith *et al.* 1982, Ellis and Smith 1987) and ^{134}Cs, ^{136}Cs, ^{103}Ru, ^{132}Te, ^{132}I and ^{140}La after the Chernobyl accident in 1986 (Nelson *et al.* 1988, Smith and Ellis 1990). Samples of blueberry (*Vaccinium sp.*), alder (*Alnus rugosa*), ground lichen (*Cladonia sp.*) and arborial lichen (*Usnea sp.*), collected and analyzed since the early 1980's, provide a time series for ^{137}Cs activities. Radioactivity levels in these samples have decreased as a result of the radioactive decay of previously deposited material and decreased inputs from the atmosphere owing to the cessation of nuclear testing. For example, ^{137}Cs levels in blueberry dropped from 63 Bq/kg in 1982 to 17 Bq/kg in 1989, alder from 18 to 14 Bq/kg, ground lichen from 124 to 51 Bq/kg and arboreal lichen from 34 in 1984 to 21 Bq/kg (Ellis *et al.* 1984, 1992). ^{137}Cs levels in aquatic and terrestrial animals have remained within pre-operational levels. Freshwater fish and frog activities in 1990 were all less than 20 Bq/kg (Ellis *et al.* 1992) while pre-operation levels ranged from 5 to 49 Bq/kg (Ellis *et al.* 1984). ^{137}Cs activities in muskrat (*Ondatra zeibenthicus*) present at higher levels in muscle and organs (35 - 101 Bq/kg) than in bone (5 - 8 Bq/kg; Nelson *et al.* 1985). No increase in ^{137}Cs levels in organisms has been observed as a result of releases from Point Lepreau. Tritium levels in terrestrial plants such as blueberry and alder leaves, bullrushes and conifer needles have increased from baseline levels of < 1.8 Bq/L to 6.0 Bq/L since startup of the Point Lepreau NGS. Levels since 1982 vary greatly (< 2 to 526 Bq/L, Ellis *et al.* 1990, 1992) and reflect the activities measured in air because of the rapid uptake of atmospheric moisture by these plants. Highest levels were measured in samples collected close to the reactor. A time series of tritium levels in conifer needles at three locations since 1987 showed wide variability (< 1 to 526 Bq/l) and good correlation with variations in atmospheric tritium levels (Nelson *et al.* 1988, Ellis *et al.* 1990, 1992). Tritium levels in aquatic and terrestrial animals have remained low (<16 Bq/L) and are largely unaffected by the reactor operations (Nelson *et al.* 1986).

3.2.6.7 Birds

In samples collected in the lower Bay of Fundy in 1980, ^{137}Cs activities of 4 to 18 Bq/kg in terrestrial-feeding birds such as starling (*Sturnus vugaris)* and song sparrow (*Melospiza melodia*) were higher than levels of <4 Bq/kg found in marine-feeding species such as eider duck

(*Somateria mollisima*) and cormorant (*Phalacrocorax carbo*). These differences reflect the ^{137}Cs levels in their food, with higher activities measured in the terrestrial vs the marine food chains (Smith *et al.* 1982). No increase in ^{137}Cs activity was observed in any samples as a result of emissions from the Point Lepreau NGS. (Nelson *et al.* 1988).

3.2.6.8 Chernobyl

Radionuclide effluent was released to the atmosphere during the Chernobyl (U.S.S.R.) nuclear accident on April 26, 1986. The releases were characterized by the presence of several short-lived isotopes such as ^{131}I, ^{132}I, ^{132}Te ^{103}Ru and ^{134}Cs, as well as ^{137}Cs. Chernobyl releases were first observed in air samples at Point Lepreau on May 7, 1986, and were gone by mid-June. Elevated levels in terrestrial biota collected in the summer of 1986 revealed Chernobyl radionuclides which all completely decayed by 1988. In general, marine samples collected in the summer of 1986 contained no measurable Chernobyl fallout, with the exception of a few seaweed samples, one clam sample (*Mya arenaria*) and a sediment sample which contained small amounts of ^{131}I, ^{103}Ru or ^{134}Cs (Nelson *et al.* 1988, Sutherland 1987).

3.2.7 Organochlorines, organometals, and other persistent toxic substances

(P.G. Wells)

3.2.7.1 Water

No published information was found on the concentrations of organochlorines or organometallic compounds in the water column of the Bay of Fundy. Based on their known physico-chemical properties, however, it can be surmised that such levels would be very low. Such compounds (PCB's, dioxins, HCH, *etc.*) would be present in the aqueous phase for short periods of time after release from a variety of sources, as a number of such compounds are found in tissues (*e.g.* seabirds, marine mammals) (see Section 3.3) and sediments (*e.g.* Saint John ocean disposal site), and imposex is occurring in Bay gastropod molluscs, indicating exposure to water-borne and/or particulate-borne organotins (N.Prouse, 1997, pers. comm.). It also is well-known from studies of peat bogs that some high molecular weight chlorinated hydrocarbons (PCB's, toxaphene, DDT) are entering local watersheds through atmospheric transport (Rapaport and Eisenreich 1988), providing a source to local coastal waters.

3.2.7.2 Sediments

It would be expected that trace persistent contaminants occur in a variety of sediments throughout the Bay of Fundy, due to many industrial, municipal and land-based sources (*e.g.* the pesticide spray program since the 1940's) around the Bay, but data from research and monitoring programs are surprisingly scarce. According to Larsen (1992), in Capuzzo (1995), trace metals, chlorinated pesticides, PCB's and PAH's are found in sediments and biota throughout the Gulf of Maine ecosystem, but the data base on which this is based is largely for coastal Maine and points south.

A thorough geochemical survey of metals in sediments was conducted in the Bay of Fundy by D. Loring in the 1970's and summarized in 1981 (Loring 1981); levels of Zn, Cu. Pb, Co, Ni, Cr and V in surficial sediments are known and mapped, and areas of medium and high concentrations (*e.g.* Cd, Pb identified; also see Section 3.2.5 by P. Yeats). Concentrations and areal distributions of selected trace metals (Cu, Zn, Pb, Cd, Mo, Ni, Mn, Hg) in surficial sediments of Saint John Harbour were described by Ray and McKnight (1984); concentrations of all metals were low (Cu 16, Zn 53, Pb 24, Cd 0.16, Mo 3, Ni 16, Mn 296, Hg 0.04 µg/g), Hg and Cd being well below permissible levels set by the Ocean Dumping Control Act (now CEPA, Part VI). Heavy metal (Zn, Cu, Pb, Cd) concentrations in sediments in two areas in Annapolis Basin and Peck's Cove were "at natural background levels" (Prouse *et al.* 1987). A very valuable synthesis of data representing Ca^{+2}, Al and toxic metal inputs to the Bay of Fundy from surface water sources around the Bay is being completed (Pol 1996); this should greatly assist interpreting metal concentration data for water, sediment and biota.

Based on the current Gulf of Maine Mussel

Watch program, a wide range of metals and organics are found in blue mussels (*Mytilus* spp.) in the lower Bay of Fundy, reflecting water, sediment and food contamination (Harding, pers. comm., Gulf of Maine reports 1992-1996). This was verified by Mucklow (1996). The ocean dumping (disposal) site off Saint John has been throroughly characterized for the regulated metals and organics (Tay, pers. comm.). Little has been measured in Petitcodiac River basin and Shepody Bay (O'Neill, pers. comm.).

3.2.7.3 Research and monitoring needs

Hence, there is a need to measure some well-known toxic substances in the water column (dissolved and on particulates), and in the underlying surface sediments, as well as to determine the impact of localized organic loading on the sequestering of selected hydrophobic and lipophilic organic contaminants and trace metals and their subsequent deposition to surface sediments.

3.2.8 Industrial, food processing and fish plant wastes (P.G. Wells)

Considerable information is available from the regulatory agencies (Environment Canada and provincial departments of environment) on composition and loadings of effluents from the many food and industrial plants around the Bay of Fundy's perimeter. Food and fish processing plants discharge effluents high in BOD and suspended solids; there have been guidelines in place for them since the late 1970's. Effects are generally localized and non-persistent if effluent quality improves. The many industrial plants (from refineries to power plants), largely localized in the Saint John area, emit many kinds of deleterious wastes, some regulated and some not, into the water column. Their quality generally is well known, and some are now regulated and improved, and some are not. Most of the data appear to be unpublished.

> ***"There is a need to measure some well-known toxic substances in the water column .... and in the underlying surface sediments, as well as to determine the impact of localized organic loading"***

3.3 Chemical contaminants in food chains and tissues (P.G. Wells)

3.3.1 Introduction

The Bay of Fundy has received industrial, municipal, agricultural, forest and airborne contaminants for decades. In particular, the pesticides sprayed extensively on New Brunswick forests since WWII have left a major signature of DDT and other chlorinated pesticides in various compartments of the Bay's ecosystems, and large-scale industries such as the pulp mill and refinery and attendant operations at Saint John have caused local impacts and wide-spread contamination of air and waters. The Bay is surrounded by many point-sources of contaminants, from homes (*e.g.* sewage) to fish plants (*e.g.* fish offal and BOD wastes) to river discharges (Saint John, Petitcodiac). The Bay also receives air-borne materials from the north-east USA and central Canada, dredging spoils from harbours, spills from industry and shipping, and chemicals in migrating species such as fish and seabirds. Point sources are well documented (Eaton *et al.* 1994, Wells and Rolston 1991, Thurston 1990, DOE, unpubl. data, Tay, DOE, pers. comm.). As well, it is acknowledged by the Gulf of Maine Council of the Marine Environment that "the greatest threat to the health of the Gulf comes from long-term effects of introducing persistent toxic materials to marine waters" (GOMCME 1996), and that the health of the Gulf is threatened by cumulative impacts of multiple stressors, and contaminants that include toxins, nutrients, pathogens and atmospheric chemicals (Pearce and Wallace 1995, Pearce *et al.* 1992). A recent critical synthesis of contaminants information for the Bay of Fundy and its bays, estuaries and tributaries, with these considerations, is clearly overdue.

The Bay of Fundy, as part of the larger Gulf of Maine system, clearly is contaminated (*i.e.* exposed to toxic substances). However, there is relatively little published evidence to date of pollution (*i.e.* adverse impacts occurring to marine species, habitats or man's use of living resources due to contaminant exposures). The largest sign of contamination and pollution, using the GESAMP (United Nations) definitions, is the many closures of shellfish areas each year, due to elevated bacterial levels and PSP outbreaks. Most intertidal shellfish beds now are closed each year, reducing jobs and food sources for local communities. As the research summarized below shows, there are many signals in the Bay that biota are accumulating contaminants into their tissues, and relatively little reported research on the significance of such chemical burdens to fish and wildlife and their supporting habitats.

Recent research on chemical contaminants and mixtures in the food chains of the Bay of Fundy has focused on zooplankton, selected invertebrates, fish, birds and mammals. For this summary, pertinent research published since the early 1970's has been considered, as it was given little detailed attention in previous reviews. Federally, toxics research is centered at St. Andrews (Garnett 1985), Moncton, Sackville (N.B.) and Halifax/Dartmouth, and is largely focused on lower Bay fisheries issues (*e.g.* water quality at hatcheries, effects of aquaculture on bottom habitats, effects of specific effluents and chemicals, chemical concentrations in shellfish tissues, and impacts of accidental oil spills). Chemical and biological monitoring has taken place frequently at the Saint John Ocean Disposal Dump Site under CEPA (Tay and Doe, pers. comm.); through the CWS Seabird Contaminants Monitoring Program at selected sites in the lower Bay (Pearce *et al.* 1989, since the early 1970's, Burgess, pers. comm.), and through the recent Gulf of Maine Monitoring Program at sites such as at Digby Harbour (*i.e.* the Gulf Mussel Watch, since 1991, Mucklow, 1996). Some laboratory intercalibration exercises regarding organochlorine residues in biota have been conducted (Phillips and Hargrave 1992). Phytoplankton toxins in the food chain are found frequently (*e.g.* PSP) and monitored annually (these are considered above in Section 3.2.4).

Recent general research summaries of interest are Garnett (1985), Wells and Rolston (1991), Phillips and Hargrave (1992), Pederson (1994), Thurston and Larsen (1994) and Sherman *et al.* (1996). Most recently, Thurston (1990) and Thurston and Larsen (1994) give brief summaries of contaminant levels and related problems that have been measured in the Bay of Fundy.

> ***"The Bay of Fundy..........clearly is contaminated........... However, there is relatively little published evidence to date of pollution"***

3.3.2 Seston and plankton

Showell and Gaskin (1992) examined the partitioning of cadmium and lead within seston of the Quoddy region, as a way of studying the association of these metals with SPM (suspended particulate material) in a coastal environment. They showed that cadmium was associated with the organic detrital component of the seston, in contrast to lead that was partitioned between organic detritus, suspended clays and phytoplankton. Hence lead could easily enter the food chain, at the level of herbivorous copepods, a concern due to already elevated levels (in plankton) in the Quoddy region. This was the only reported study on plankton and contaminants found in this literature survey (circa July 1995).

3.3.3 Benthic invertebrates

Recent studies on invertebrates include scallops (Ray and Jerome 1987), soft-shell clams (Prouse *et al.* 1988), mussels (Harding *et al.* 1994), amphipods (Kierstead and Barlocher 1989, Napolitano and Ackman 1989, Napolitano *et al.* 1992), lobsters (Charmantier *et al.* 1985, Prouse 1994), benthic infauna (Wildish and Thomas 1985), and mixed invertebrates (Hutcheson 1983). Contaminants studied include various metals (copper, zinc, cadmium, lead); organics (PCP's, PCB's, OC's in general, PAH's); industrial effluents (*e.g.* potash brine); contaminated sediments (*e.g.* from Saint John Harbour); and mixed contaminants (*e.g.* from the Mussel Watch program, and associated research with *Mytilus spp.*).

Scallop tissue (muscle, mantle, gill, other) levels of copper, zinc, cadmium and lead were determined at 3 sites - one off Digby and two (one a control site) in Passamaquoddy Bay - where commercial fisheries exist (Ray and Jerome 1987). Levels were highest in the viscera; copper and zinc levels reflected uncontaminated areas; and cadmium levels were similar to Chaleur Bay (northern New Brunswick) sites. Metal burdens were often correlated with size, and with the exception of Georges Bank, levels were not elevated in areas away from industrial activity. Cadmium in Georges Bank scallops is considered natural (J.F. Uthe, pers. comm.). Stewart and Arnold (1994) also state that "scallops from relatively pristine areas such as Georges Bank and other offshore areas south of Nova Scotia and in the Gulf of Maine can have relatively high cadmium concentrations" and that such concentrations relate to natural levels and effects of starvation (Uthe and Chou 1987).

A mortality study of the soft-shell clam *Mya arenaria* in Annapolis Basin (Prouse *et al.* 1988) showed that there were "no significant amounts of chlorinated pesticide residues or PCBs in clam tissues" from two intertidal sites at Oak Point in the Basin. A current study with mussels (*Mytilus spp.*) is also providing metal and organics information for molluscan tissues in the Basin (L. Mucklow, pers. comm.), as part of a wider Gulf of Maine/Bay of Fundy Mussel Watch (G. Harding, pers. comm., Crawford *et al.* 1994).

Several studies have recently been conducted on amphipods in the Bay. A study of the effects of pentachlorophenol (PCP) on amphipods living in a tidal stream of the Bay (Kierstead and Barlocher 1989) showed the high acute toxicity of this common substance (4-day LC50=371µg/L) and its effect on respiration and caloric content (energy accumulation), especially at low salinities. Concern persists about PCP due to its long persistence in aquatic sediments, and common occurrence near or down-stream from wood-preserving plants. Napolitano and Ackman (1989) analyzed amphipod (*Corophium volutator*) tissues in Minas Basin and found no organochlorine pesticides (DDT, Dichlorodiphenyl-trichloroethane or derivatives) or PCB's in lipid extracts, and low hydrocarbon levels (possibly of petroleum hydrocarbon origin due to the isoprenoid phytane). A second study has also been reported (Napolitano *et al.* 1992).

Various invertebrates and lobsters (*Homarus americanus*) were the focus of studies on potash brine effluents. Hutcheson (1983) determined that waste brine solutions were acutely lethal to polychaetes (52.5% 4-day LC50's) and blue mussels (>55% for lethality and reduced gill activity). Charmantier *et al.* (1985) determined the sensitivity of lobster larvae and post-larvae to potash brine discharged from the Denison Mine, Sussex, N.B.; they found that the brine was lethal but at high levels (4-day LC50's of 1-2 g/L for stages I to III, and 2.25-3 g/L for stage IV and juveniles) and potentially sublethal at levels above 1.5 g ore/L sea water (sw)). They concluded local effects on lobsters were possible in the immediate vicinity of ore discharges. Guidelines for potash brine in seawater were set at <1g ore/L sw.

3.3.4 Fish

Studies have focused on mercury and organochlorines in herring (Zitko 1981; Braune 1987, Rosenthal *et al.* 1986); effects of organic pollution from salmonid aquaculture (Wildish *et al.* 1990a, b); levels of pesticides and other industrial chemicals in some sports fish (Prouse and Uthe 1994); and various fish (Zitko *et al.* 1974, Ray *et al.* 1984).

Zitko (1981) measured levels of PCBs and DDT, respectively, in herring muscle from the Bay of Fundy, finding levels of 0.3 µg/g and 0.5 µg/g wet weight, respectively. A pollutant accumulation model worked well at predicting total mercury burdens for 3 to 5 year Atlantic herring from a sampled field population in the Quoddy region of the Bay, and may be used for "predicting whole fish mercury concentrations in commercially valuable herring" (Braune 1987). Levels of mercury in a sample of Bay of Fundy herring caught in weirs on the New Brunswick coast were 5-15ppb (Braune 1987, in Stewart and Arnold 1994). Eggs from field-caught (Grand Manan Island) herring were fertilized and incubated, and their viability (percent fertilization, percent viable hatch, egg volume, yolk sac volume of hatched larvae, and total larval length) plotted with the corresponding ovarian concentrations of four contaminants (PCB's, HCB, alpha-HCH, PCBz) (Rosenthal *et al.* 1986); in very few cases, the viability was correlated with OC tissue residues (in other fish).

Wildish *et al.* (1990b) described activities to monitor the Bay of Fundy salmonid mariculture industry during 1988-89. Phytoplankton, plant nutrients (total phosphate, inorganic nitrate, silicate), redox potential, dissolved oxygen and salinity were measured, "as a means of determining the extent of environmental changes (site-specific benthic effects caused by faeces and waste food, nutrient enrichment of seawater caused by microbial breakdown of wastes) caused by the salmonid mariculture industry". It was concluded that marine phycotoxins were having no effect on salmonid culture in 1988-89, that nutrients (silicate, nitrate) decreased at the time of phytoplankton blooms as expected, and that other sources of nitrates were present (*i.e.* sewage, fish processing effluents). Anaerobiosis of the sediments was demonstrated at one net-pen site during the summer months, perhaps being terminated by sulphide poisoning in the fall. Wildish *et al.* (1990a) presented an environmental research and monitoring plan, together with methods, for managing the organic pollution produced by the salmonid mariculture industry in the Bay of Fundy. Problems caused by other chemical contaminants and disease transmission were not considered. A number of key variables were identified "as indicators of environmental well-being"; they included "dissolved oxygen; salmonid mortalities, growth and food conversion rates; phytoplankton monitoring to determine bloom episodes; and benthic monitoring to determine the incidence and extent of mariculture sludge buildup". Methods were exhaustively described for these variables.

Prouse and Uthe (1994) described pesticide and industrial chemical concentrations in the tail tissue of some sports fish species (striped bass, Atlantic salmon, rainbow trout, American eels) and whole tissue of clams (soft-shelled clams) from New Brunswick and Nova Scotia sites, focusing on the Saint John River basin and Annapolis Basin. Samples were analyzed for total mercury; chlorinated phenols, catechols, guaiacols, and associated derivatives; chlorinated benzenes; organochlorine pesticides; selected chlorinated biphenyls; organophosphorus pesticides; carbamate pesticides; triazine herbicides; and chlorophenoxyacid herbicides. Mercury was present at measurable concentrations in all samples, as high as 0.89 mg Hg/kg, but usually below 0.5 mg Hg/kg. Seven other compounds were found in measurable concentrations, just above detection levels, in eels and striped bass; all others were undetected. Pentachlorophenol was detected at measurable concentrations in American eels in the Salmon River, N.S., near a wood preservation plant. Clams from Annapolis Basin had undetectable pesticides and PCB's. The analyses were conducted by private labs, and "instances of low recoveries and the presence of interferences rendered many results questionable" (Prouse and Uthe 1994).

Ray *et al.* (1984) reported mercury and PCB's concentrations in muscle, liver, kidney and gonadal tissues of striped bass from the Annapolis and Shubenacadie Rivers. Relatively high levels of mercury (0.06-0.79 μg/g in various tissues) were considered to reflect natural sources. Levels of PCB's (0.02-1.4 μg/g), the highest (1.4 μg/g) being in the gonads of fish from the Annapolis River, are generally low, but in the Annapolis River might be implicated in a lack of recruitment of striped bass in this river and estuarine system. Finally, in an earlier study, Zitko *et al.* (1974) measured pentachlorophenol in six fish species from the Bay of Fundy, detecting it at trace levels (<0.5-10.8 ng/g wet weight) in relatively clean areas.

3.3.5 Seabirds

There have been a number of contaminant monitoring studies (Elliott *et al.* 1992, Furness and Greenwood 1993, Gilbertson *et al.* 1987, Noble and Burns 1990, Norstrom 1988, Pearce *et al.* 1989, Pearce and Peakall 1979, Zitko 1974, 1976, 1978, Zitko and Choi 1972, Zitko *et al.* 1972) and specific research studies (Boersma *et al.* 1986, Braune and Gaskin 1987, Moccia *et al.* 1986) on seabirds in the Bay of Fundy, most since the mid-1980's. The CWS seabird biomonitoring program has been running since 1968, an exemplary scientific effort of vision and endurance!

Zitko's monitoring and analytical studies on OC's in seabirds broke new ground in the early 1970's. Polychlorinated terphenyls (PCT) were detected in eggs (0.1 µg/g) and fatty tissues (1.4 µg/g) of herring gulls (*Larus argentatus*) from the Bay, but were not detected from eggs and fatty tissue of double-crested cormorants (*Phalacrocorax auritus*) from the same area (Zitko *et al.* 1972). "Relatively high levels of PCB and p-p'-DDE were found in eggs of double-crested cormorants (*P.auritus*), herring gulls (*L. argentatus*), and black ducks (*Anas rubripes*), from Fatpot Island (The Wolves, outer Bay of Fundy) and from Hospital Island (Passamaquoddy Bay, collected in 1971" (Zitko and Choi 1972). Five years of monitoring data on chlorinated hydrocarbons also were reported (Zitko 1976), finding relatively low levels of 7 compounds (hexachlorobenzene 0.016-0.017 µg/g; PCB's (as Arochlor 1254) 5.23-14.3 µg/g, p,p'-DDE 1.92-9.70 µg/g, dieldrin 0.041-0.297 µg/g, p,p'-DDD 0.020-0.113 µg/g, p,p'-DDT 0.023-0.167 µg/g and mirex 0.058-0.113 µg/g, all mean wet weight values) in eggs of cormorants from the Bay. At the end of the '70's, Pearce and Peakall (1979) reported on mercury and OC concentrations in eight species of seabirds from the Bay of Fundy, Gulf of St. Lawrence and the open Atlantic. "Only in cormorants were DDE residues high enough to cause, through eggshell thinning, local population declines".

Gilbertson *et al.* (1987) described a number of seabird contaminant studies, including those of CWS's seabird contaminant monitoring program that included three sites in the lower Bay of Fundy (Manawogonish Island, N.B.; Kent Island, N.B.; and Machias Seal Island, N.B.). In this program, eggs of the double-crested cormorant, Atlantic puffin and Leach's storm petrel were sampled every four years, for DDE, dieldrin, HCB and PCB's. DDE and PCB's declined markedly in concentration between 1972 and 1984 at these sites, but appear to have reached a plateau at low ppm levels (also see Pearce and Peakall 1979, Pearce *et al.* 1989). In general, contaminant residue levels (*e.g.* PCB's) are lower at the Bay of Fundy sites (2-5ppm) than in the St. Lawrence Estuary (9-10ppm) (Noble and Burns 1990). However, this pattern varies with species and chemicals; for example, there was no difference for dioxins and furans for double-crested cormorants at the two locations (concs. <<50 ppt) (Noble and Burns 1990), but PCB's (and possibly toxaphenes) in three species (storm petrel, double-crested cormorant, Atlantic puffin) varied in concentration and composition (Norstrom 1988).

"The CWS seabird biomonitoring program has been running since 1968, an exemplary scientific effort of vision and endurance!"

In a summary paper on the CWS contaminants in seabird eggs program, Pearce *et al.* (1989) concluded that there were declining levels of most of 8 measured chemicals (PCB's, DDE, dieldrin, HCB, oxychlordane, heptachlor epoxide, HCH and mirex) in the Bay of Fundy colonies of storm-petrels, cormorant and Atlantic Puffin between 1968 and 1984.

Elliott *et al.* (1992), in the most recent paper on this CWS program, discussed patterns and trends of organics in seabird eggs from 1968 to 1990. They stated: "DDT was used extensively for spruce budworm control in the forests of New Brunswick; cessation of this use has resulted in an ongoing decline in mean DDE concentrations in the food chains of the Bay of Fundy". PCB concentrations have also sharply declined, to ongoing stable levels. Dioxin levels in cormorant eggs are much lower (<20ng/kg) on Manawagonish Island in the Bay of Fundy than at Mandarte Island (from approx. 100 ng/kg to <20ng/kg) on the B.C. coast.

Three ecotoxicological studies on the Bay's seabirds are reported. Boersma *et al.* (1986) compared the activity levels of the MFO systems of 25-d embryos of herring gulls (*Larus argentatus*) between Great lakes sites and one "relatively uncontaminated colony in the Bay of Fundy". They showed greatest effects, a suppression of the aniline hydroxylation system (AnH), in Great Lakes colonies, attributing this to the higher levels of Mirex in the Lakes compared to coastal waters. In a second study, Moccia *et al.* (1986) conducted a quantitative assessment of thyroid histopathology of herring gulls from the Great Lakes and the Bay of Fundy. In comparison to the single colony from the Bay of Fundy (location not stated), the majority of gulls from the Great Lakes suffered from goiter (having much larger thyroids, with microfollicular and hyperplastic characteristics). Finally in a third study, it is clear that Bonaparte gulls (*Larus philadelphia*) in the southwestern Bay of Fundy contain mercury. Braune and Gaskin (1987) calculated a bioenergetics-based budget for mercury obtained in the diet; this budget predicted net total Hg loss during the period of the autumn molt. It was estimated that 68%(in females) and 59% (in males) of the mercury was eliminated via the feathers during the period of autumn molt. The source and composition of this mercury were not described. Collectively, these studies show the value of making biological effect measures on Bay of Fundy seabirds, and point to the need to expand such a program to enhance knowledge of the Bay's environmental quality.

> ***"these studies show the value of making biological effect measures on Bay of Fundy seabirds, and point to the need to expand such a program to enhance knowledge of the Bay's environmental quality"***

3.3.6. Marine mammals

(D.W. Johnston, P.G.Wells)

Studies have been conducted largely by the University of Guelph researcher, D.E. Gaskin, and his co-workers, for over 25 years. Early papers by Gaskin *et al.* (1971, 1972, 1973,) dealt with levels of mercury and organochlorines (pesticides and PCB's) in seals (*Phoca vitulina*) and porpoises (*Phocoena phocoena* L.) in the Bay of Fundy region. More recent reports include those by Gaskin *et al.* (1979, 1982, 1983), describing mercury and organochlorines in porpoise tissues, and Woodley *et al.* (1991), describing organochlorines in the blubber of North Atlantic right whales (*Eubalaena glacialis*). The summary of Thurston (1990) and synthesis of Thurston and Larsen (1994) are also useful. The studies are grouped and discussed below by species .

3.3.6.1 Contaminants in harbour porpoises

(D.W. Johnston)

3.3.6.1.1 Introduction

The harbour porpoise (*Phocoena phocoena* L.) is a small odontocete cetacean that inhabits the coastal waters of the Northern Hemisphere in a nearly circumpolar distribution. It frequents the lower half of the Bay, particularly in the Passamaquoddy region, where it feeds mainly on clupeoid and gadoid fishes. The coastal habitat and feeding ecology of these animals suggest that they may be accumulating significant amounts of heavy metals and organochlorines, which can have toxic effects in mammals at low levels (P. Beland, pers. comm.). This animal is currently listed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) as a "threatened species in the Bay of Fundy" (Gaskin 1992).

The harbour porpoise in the Bay was the subject of early studies on bioaccumulation of mercury (Gaskin *et al.* 1972, 1979), and organochlorines (Gaskin *et al.* 1971, 1976, 1982, 1983). Most recently, Johnston (1995) and Westgate (1995) have evaluated spatial and temporal trends on metals and OC's, respectively, in porpoise in the western North Atlantic. Their findings are summarized below.

3.3.6.1.2 Heavy metals

Copper (Cu), cadmium (Cd), zinc (Zn), and total mercury (Hg) concentrations were determined for liver, kidney and muscle tissues sampled from Fundy harbour porpoises in 1989 (Johnston 1995). Copper and Zn levels in Bay of Fundy porpoises were similar to values previously published for conspecifics from other locations (Falconer *et al.* 1983) and to other cetaceans in Canadian waters (Wagemann *et al.* 1990). Mean Cd concentrations in porpoises from the Bay of Fundy were somewhat higher than levels reported for porpoises in British waters (Law *et al.* 1992). Mean concentrations (mg/Kg) of Hg in Fundy porpoises were similar to those reported for porpoises in other locations (Teigen *et al.* 1993, Joiris *et al.* 1991) but were significantly lower then those previously recorded for porpoises from the Bay of Fundy (Gaskin *et al.* 1979). No other long-term monitoring studies of heavy metal concentrations in porpoises are known to exist, mainly because the only historical data available for comparison are restricted solely to Hg.

3.3.6.1.3 Organochlorines

Over 90 individual organochlorine contaminants were quantified in blubber samples obtained from Fundy harbour porpoises during 1989 to 1991 (Westgate 1995). PCB's were the most prominent organic contaminants in porpoises from this region, but concentrations were much lower than those previously reported for Fundy porpoises (Gaskin *et al.* 1983). Similar trends were found for DDT's, with average levels being approximately two orders of magnitude lower then those previously reported (Gaskin *et al.* 1973).

3.3.6.1.4 Summary

The significance of contaminant levels in porpoises is extremely difficult to determine. However, in hundreds of detailed necropsies of porpoises, none of the pathologies associated with contaminants in marine mammals, as observed by P. Beland and others, have been found.

The above results indicate that the levels of some contaminants in porpoises from the Bay of Fundy are decreasing, and likely reflect similar changes in the Fundy ecosystem. Periodic monitoring of these contaminants is still essential, and will provide a consistent baseline for further comparisons both locally and globally. Periodic monitoring will also permit determination of the rates of such changes in environmental contamination, an important and logical extension to simple monitoring.

The data on organochlorine contaminants are more complete than those available for heavy metals and steps should be taken to rectify this problem. "Bay of Fundy harbour porpoises contain levels of DDT and PCB's greater than the St. Lawrence Beluga, which has been called the most contaminated animal on earth" (Thurston and Larsen 1994). Surely the wide range of contaminants in these and other mammals is reason for urgent concern.

3.3.6.2 Contaminants in seals

Only one study has been reported, measuring OC's (DDT, dieldrin, PCB's) and mercury in various tissues of the harbour seal, *Phoca vitulina*, from Deer Island and Grand Manan Island at the mouth of the Bay in 1971 (Gaskin *et al.* 1973). Tissues (blubber, muscle, liver and cerebrum) were sampled. Blubber consistently had higher concentrations of OC's (*e.g.* 7-63 mg/L PCB's). Values for all substances were similar to those found for harbour porpoise, and the same magnitude as in the southern Gulf of Maine, except for mercury being higher in Bay seals. The significance of such contaminants to the seal's overall health is little understood.

3.3.6.3 Contaminants in whales

In the only reported study to date (Woodley *et al.* 1991), PCB's, total DDT (DDT+DDE+DDD), dieldrin, heptachlor epoxide, chlordanes, and hexachlorobenzene (HCB) were found in blubber of the North Atlantic right whale (*Eubalaena glacialis*) in the Bay of Fundy, using a remote biopsy technique. PCB's were most prevalent (up to 1.9 μg/g wet weight residues), followed by total DDT (trace to 0.47 μg/g); however, a large number of OC's were found. Levels in females suggested OC residue transfers during lactation. Levels of PCB's and DDT found were below those known to cause reproductive disorders. However, little is known about possible joint effects of low levels of such contaminants on the health of individuals.

> ***"the levels of some contaminants in porpoises from the Bay of Fundy are decreasing, and likely reflect similar changes in the Fundy ecosystem".***

3.3.7 Ecological significance of contaminant burdens in biota (P.G. Wells)

There are data on the sources, fates and effects on specific toxic substances in the Bay of Fundy, as a result of 25 years of research, regulatory action on industries, and monitoring programs. Though incomplete in many ways, what is known and reported permits the construction of a simple conceptual model of one or more contaminants as they move through the food chain (Figure 3.1).

The most exhaustive data reported in the primary literature are for PCB's, mostly measured during the 1980's (Table 3.1). The PCB data were assembled, distilled, and organized into a trophic dynamics model, following from Noble and Burns (1990) and G.C.H.Harding (pers. comm.). The model shows concentrations measured in various environmental compartments from water and sediments through to higher trophic levels (Figure 3.2). Data from the southern Gulf of St. Lawrence for seawater, phytoplankton and zooplankton were used (courtesy of G.C.H.Harding) in the absence of Fundy data, but with the confidence that open water and plankton PCB levels are probably comparible between the two water bodies.

PCB's clearly biomagnify from lower compartments of the ecosystem to seabirds and mammals in the Bay of Fundy (Figure 3.2). This is a classic food chain bioaccumulation picture (also see Hargrave *et al.* 1992, among others) and believed to be the first time it has been shown for the Bay of Fundy ecosystem. Its features are typical. Levels in intermediate species (*e.g.* mussels and fish) are largely in ppb's, while in seabirds, porpoise and whales, levels are in low ppm's. Three order of magnitude differences between compartments are shown. Levels in the Bay are generally lower

Table 3.1 Data on PCB's in the Bay of Fundy marine ecosystem.
(Compiled by P.G. Wells, January 1996)

Organisms	Concentrations	Location	Reference
Clams	N.D. (n=87)	Annapolis Basin	*Prouse et al. 1988*
Mussels	2.6-20.8 ng/g d.w. (n=92)	5 sites	*Crawford et al.1994*
Amphipods	N.D. (n=86)	Minas/Shepody	*Napolitano and Ackman 1989*
Herring (gonad)	5.9-44.9 ng/g w.w.	Grand Manan	*Rosenthal et al. 1986*
Sports fish	N.D.	St. John Estuary	*Prouse & Uthe 1994*
Striped bass (g)	0.02-8.5μg/g w.w.	Annapolis River	*Ray et al. 1984*
Striped bass (m)	tr.-0.09μg/g w.w.	Annapolis River	*Ray et al. 1984*
Seabird eggs (Cormorant)	3.56 mg/kg w.w. (n=84)	Manawag Island	*Norstrom 1988*
Seabird eggs (Petrel)	3.44 mg/kg w.w. (n=84)	Kent Island	*Norstrom 1988*
Seabird eggs (Atl. Puffin)	3.20 mg/kg w.w. (n=84)	Machias Seal Island	*Norstrom 1988*
Hbr. porpoise blubber (m)	17.28 μg/g w.w.	Fundy/Maine	*Westgate 1995*
Hbr. porpoise blubber (f)	11.38 μg/g w.w.	Fundy/Maine	*Westgate 1995*
Hbr. porpoise blubber (m)	64.9-89.7 ppm	Fundy approaches	*Gaskin et al. 1983*
Hbr. porpoise blubber (f)	22.5-55.6 ppm	Fundy approaches	*Gaskin et al. 1983*
Hbr. seal blubber	7.10-63 μg/g w.w. (n=71)	Quoddy region	*Gaskin et al. 1973*
Right whale blubber	0.1-0.4 μg/g w.w. (n=88)	Quoddy region	*Woodley et al.1991*
Right whale blubber	0.1-1.9 μg/g w.w. (n=89)	Quoddy region	*Woodley et al. 1991*

* Total PCB's: total of all congeners measured in tissues

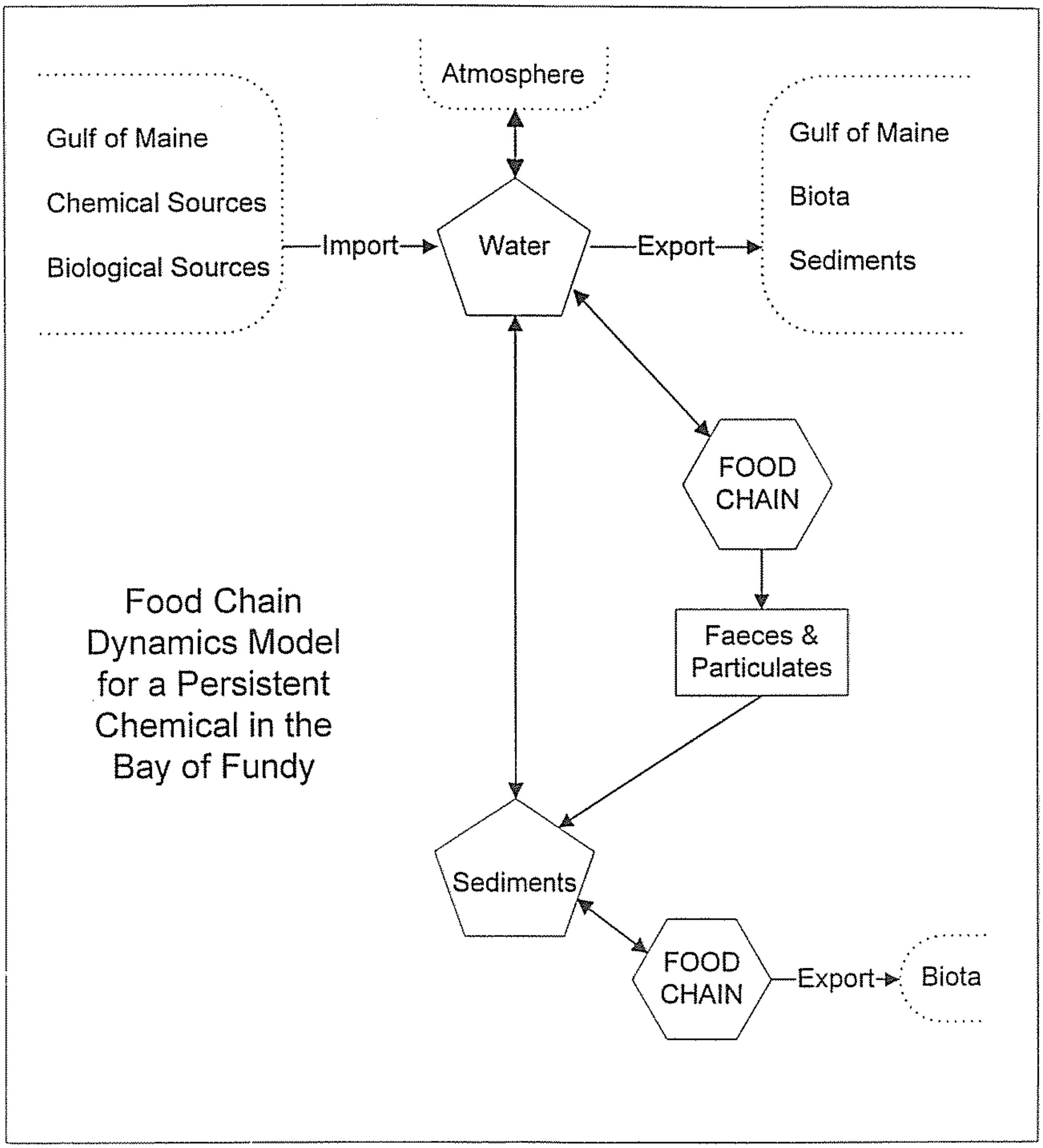
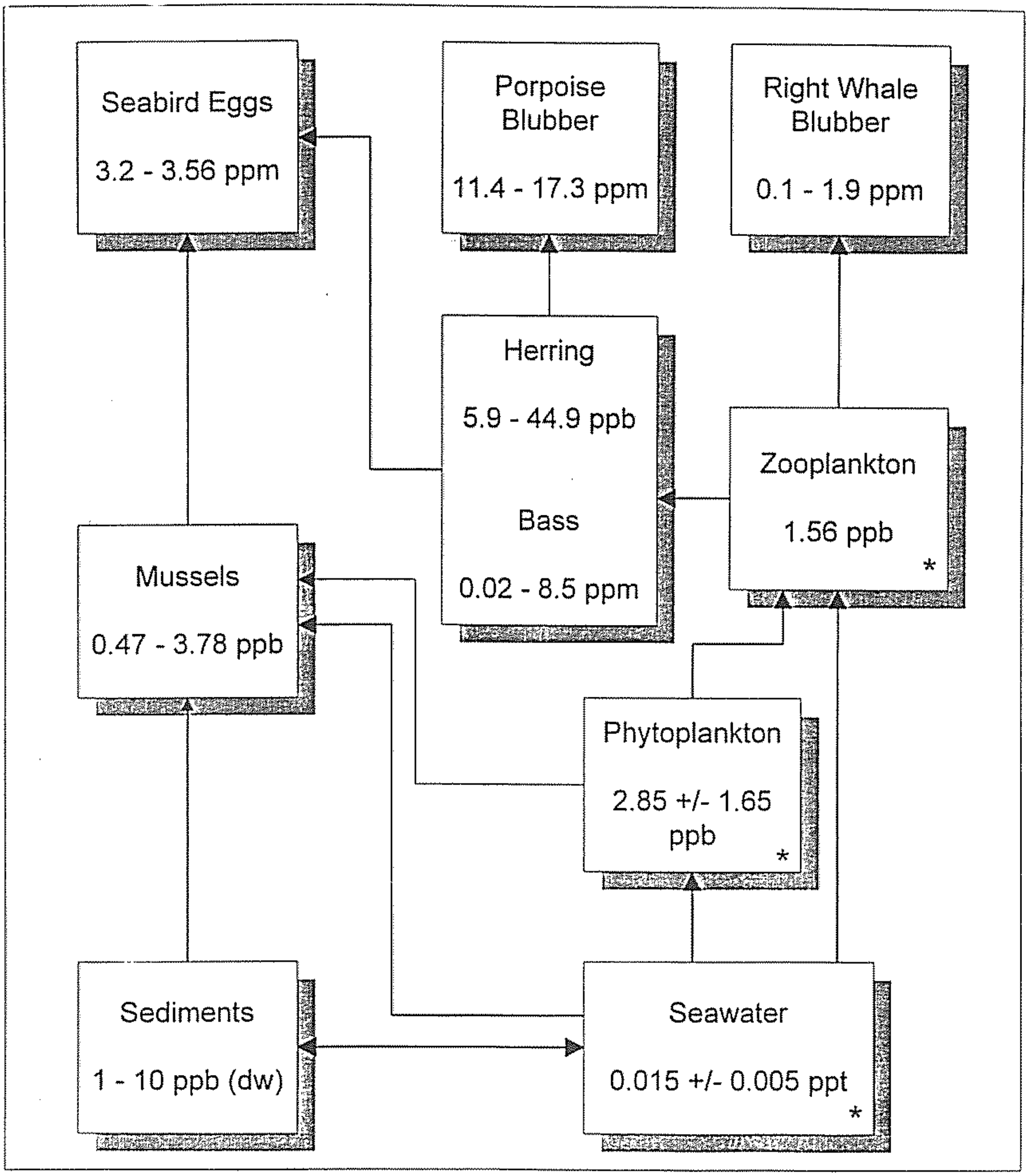
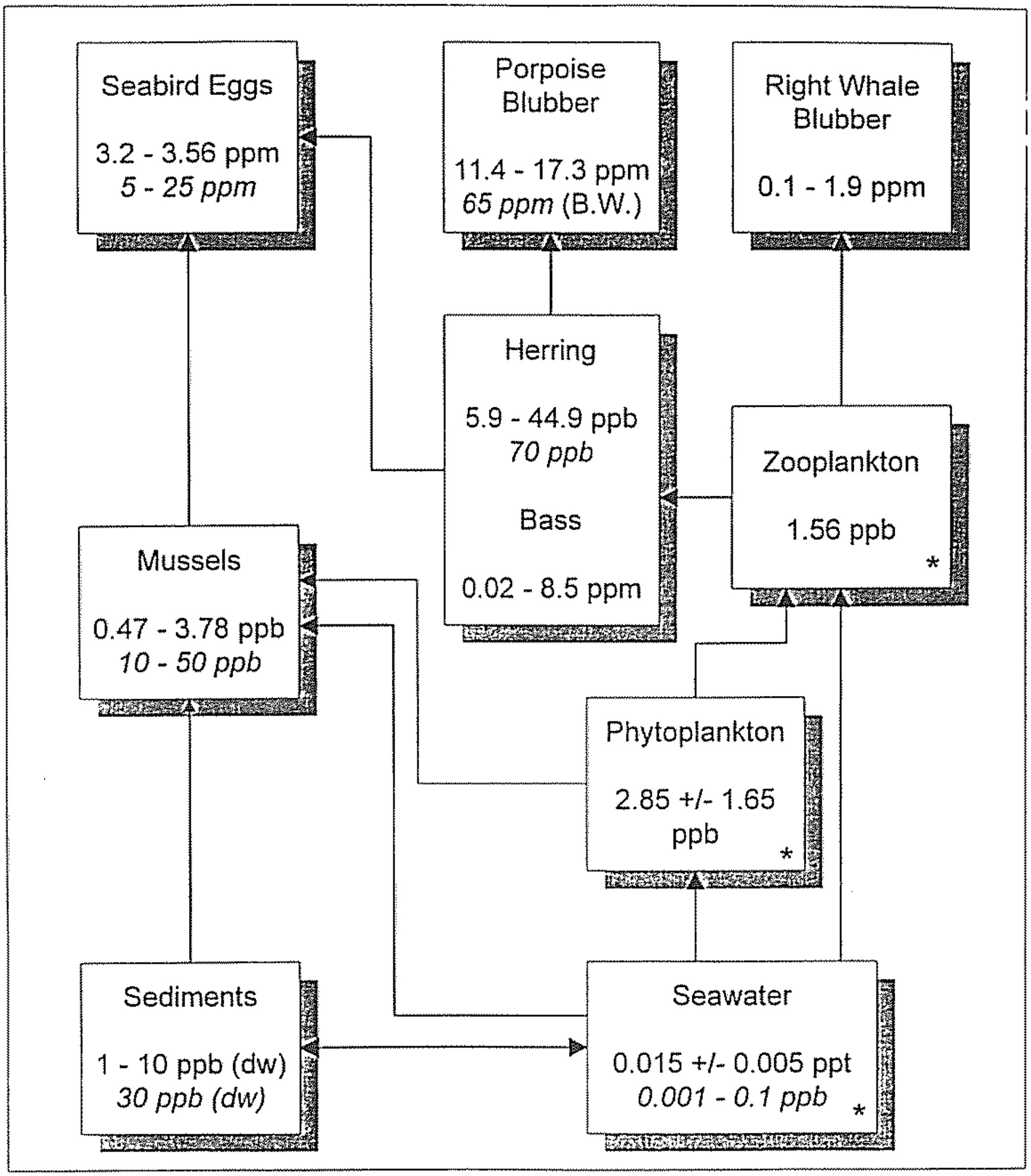


Figure 3.1 Food chain dynamics model for a persistent chemical in the Bay of Fundy.



* S. Gulf of St. Lawrence data (G.C.H. Harding, pers. comm.)

Figure 3.2 PCB's in the Bay of Fundy present in water and sediments and accumulating in marine organisms to higher concentrations.



* S. Gulf of St. Lawrence data (G.C.H. Harding, pers. comm. 1996)
Italicized data from St. Lawrence Estuary (Noble & Burns, 1990)

Figure 3.3 PCB's present in water and sediments and accumulating in marine organisms to higher concentrations in the Bay of Fundy compared with the St. Lawrence Estuary.

"Further refinement of the PCB food chain dynamics model, and building complementary comparative models for DDT and mercury, on which considerable data exist, would be a very worthwhile research project for the Bay"

than in the St. Lawrence Estuary (Figure 3.3), possible reflecting the lower exposure to constituents of industrial discharges and wastes in the less industrialized Bay of Fundy and its watershed, and lower inputs from air-borne routes (though this remains an area begging more study).

This initial and rather simple food chain PCB dynamics model for the Bay of Fundy should be enhanced with additional data for specific compartments (sediments, seawater, benthic microalgae, phytoplankton, zooplankton), which requires new research, and data for specific groups or species (*e.g.* copepods, horse mussels, tomcod, eagles), which may exist from current programs of research (St. Andrews; Gulf of Maine Program; Biology and Chemistry Departments, Woods Hole Oceanographic Institute). The model should also be cognizant of the distinction between non-migratory species (*e.g.* mussels) and migratory species (*e.g.* many fish, birds and whales), which may influence the body burdens of PCB's obtained and the consequent interpretation of the food-chain bioaccumulation (*i.e.* the PCB's are not necessarily solely originating within the Bay of Fundy ecosystem and watershed; they may come from the greater Gulf of Maine watershed and beyond).

Further refinement of the PCB food chain dynamics model, and building complementary comparative models for DDT and mercury, on which considerable data exist, would be a very worthwhile research project for the Bay. It would be one way of demonstrating some of the broader ecological consequences of persistent, bioaccumulative and toxic chemicals being present in coastal waters in the Gulf of Maine and Bay of Fundy, and one way of demonstrating one of the whole ecosystem responses to effective regulations and other controls, as well as to natural degradation and loss. Certainly the current levels of chemicals in an endangered species such as the North Atlantic right whale are a major cause for concern for this species overall health and survival, considering the known consequences of such contamination in belugas from the St. Lawrence Estuary (Wells and Rolston 1991, P. Beland, pers. comm.).

3.3.8 Conclusions and recommendations

The environmental quality of the Bay of Fundy has been compromised due to wide-spread chemical contamination of waters, sediments and biota, and relatively little understanding or monitoring of the biotic and ecosystem response to such contamination. Although nutrients and metals generally appear to present little threat, beyond localized sites, the wide-spread distribution of low levels of persistent organics may present risks to target biota. A comprehensive fate and effects model for specific substances in the Bay could be constructed as part of a process for determining the ecological significance of such contamination, and identifying management, industrial and social actions required to reduce such insults.

"The environmental quality of the Bay of Fundy has been compromised due to wide-spread chemical contamination of waters, sediments and biota, and relatively little understanding or monitoring of the biotic and ecosystem response to such contamination"

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CHAPTER FOUR

THE BIOLOGICAL ENVIRONMENT OF THE BAY OF FUNDY

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4.1. Introduction (M. Brylinsky)

The biological environment of the Bay of Fundy has been studied for almost 100 years, and is well described in a large literature, and numerous syntheses (*e.g.* Bay of Fundy Project 1993, Gordon and Dadswell 1984, Plant 1985, Thomas 1983, Thurston 1990, among others).

The Bay of Fundy is in many ways unique with respect to its biological environment. Biological processes within the Bay are dominated by physical processes, of which tidal mixing is most prominent. The levels of pelagic primary production are controlled largely by light availability, which is in turn controlled by vertical stratification and turbidity, both of which are a function of tidally induced mixing. The distribution and production of subtidal and intertidal benthic systems is strongly influenced by sediment characteristics, particularly stability, which is controlled largely by hydrodynamic forces. Intertidal salt marsh and macroalgal production, and its export to pelagic and benthic systems, is also largely influenced by tidal energy. There is also evidence that the migratory paths and distribution of fish within the Bay are controlled in part by tidal circulation patterns.

> *"Biological processes within the Bay are dominated by physical processes of which tidal mixing is most prominent."*

The following discussion of the biological environment of the Bay attempts to summarize what is known about the processes that determine the levels of biomass, production and distribution of organisms within the Bay. The emphasis here is largely on processes. Information on the biological resources of the Bay is presented in Chapter Five.

4.2 Primary production (M. Brylinsky)

4.2.1 Introduction

The major primary producers and the level of production contributed by each producer for the different regions of the Bay of Fundy system have been summarized by Prouse *et al.* (1984) as shown in Table 4.1. Because of the diversity of habitats within the Bay, there is a corresponding diversity of primary producers. In the outer regions of the Bay, phytoplankton contributes more than 90 percent of total primary production. Fucoids are most abundant in the inner Bay where they may contribute up to 10 percent of total production. Within the upper Bay, phytoplankton may still account for as much as 25 percent of production, but because of high turbidity levels within the water column, salt marsh and benthic algae become more important, contributing as much as 30 and 40 percent, respectively, of total production in some of the larger bays.

4.2.2 Phytoplankton

The phytoplankton community consists mainly of diatoms of which more than 100 species belonging to 35 genera have been documented. There are also about 12 species of dinoflagellates common to areas in the outer Bay. The phytoplankton populations appears to exhibit seasonal variations typical of temperate coastal regions. Chlorophyll *a* levels in the outer Bay typically range between 0.5-3 µg/L, with the lower values occurring during the winter and the higher values during the summer. Within the upper Bay, chlorophyll *a* levels are generally < 1.5 µg/L and show less seasonal variation. There is little indication of the spring and fall blooms typical of stratified systems, and the seasonal variation in biomass tends

Table 4.1 Distribution of primary production in the Bay of Fundy *(From Prouse et al. 1984)*

Tonnes C/yr x 10^3

Region	Phytoplankton	Seaweeds	Benthic Algae	Salt Marsh	Total
Upper Bay	**23.4** *(56.3%)*	-	**12.7** *(30.6%)*	**5.4** *(13.0%)*	**41.5** *(3.7%)*
Inner Bay	**125.7** *(89.8%)*	**13.5** *(9.6%)*	**0.4** *(0.3%)*	**0.4** *(0.3%)*	**140.0** *(12.5%)*
Outer Bay	**927.8** *(98.5%)*	**13.5** *(1.4%)*	**0.4** *(0.04%)*	**0.4** *(0.04%)*	**942.1** *(83.8%)*
Total	**1076.9** *(95.8%)*	**27.0** *(2.4%)*	**13.5** *(1.2%)*	**6.2** *(0.6%)*	**1123.6**

to follow the seasonal variation in day length. Annual phytoplankton production in the outer Bay is ca. 150 g C/m^2/yr. Within the inner Bay, the Minas Basin and the larger upper Bays, phytoplankton production is at least an order of magnitude lower.

Emerson *et al.* (1986) obtained measurements of the size fractions of phytoplankton at a station located within the southwestern mouth of the outer Bay. They found that between June and September over 87 percent of the algal cells were < 20 µm in diameter. There has been only one investigation (Brylinsky and Daborn 1987), carried out within the southern bight of the Minas Basin, of the potential importance of picoplankton production within the Bay. This study showed that < 10 percent of total phytoplankton production occurred in the ultra- and nannoplankton size classes.

The major factor thought to limit phytoplankton in the upper portions of the Bay is light availability. The absence of water column stratification, combined with high levels of inorganic turbidity, result in a high ratio of mixing depth to euphotic zone depth. There is little indication that nutrients are limiting in these regions (Keizer *et al.* 1984).

4.2.3 Benthic microalgae

Benthic microalgae account for about 15 percent of the total primary production of the Bay. They occur in all intertidal sediments but are most extensive in the upper regions of the Bay where the extensive tidal range results in large areas of intertidal mud and sand flats. Benthic diatoms are the major primary producers in these areas. Average annual chlorophyll *a* levels range between 10-215 mg Chl *a*/m^2 in the upper intertidal and between 10-180 mg Chl *a*/m^2 in the lower intertidal. There is a distinct seasonal variation in chlorophyll a levels with a peak in September and a minimum in February/March. Estimates of annual production are on the order of 50 mg C/m^2.

Benthic algal biomass and production are thought to be controlled mainly by light availability and grazing. Because of the high water column turbidity, photosynthesis occurs only when the flats are exposed. Maximum daily photosynthetic rates occur during the summer when day length is longest and during periods when solar noon is coincident with the time of low tide. Being a high quality food source, benthic algae are subject to considerable grazing pressure by a variety of invertebrates. In particular, intense grazing pressure by *Corophium volutator* depresses biomass during certain periods and this probably limits production at times. A third factor that may also limit production is nutrient availability. Although nutrient levels within the water column are relatively high, intense photosynthesis within the microlayer of the surface sediments may exhaust nutrients for short periods of time. Little is known of the importance of re-suspension in controlling the biomass of benthic microalgae.

4.2.4 Seaweeds

Fucoid seaweeds are found along the rocky shorelines of the outer and inner Bay and as small isolated patches in some areas of the upper Bay. The seaweed community is dominated by a few species. Rockweeds, particularly *Ascophyllum nodosum*, dominate most of the littoral zone. The lower littoral and sublittoral contain mainly kelps, of which *Laminaria digitata* and *L. longicruris* are the most prominent. Biomass values measured along the New Brunswick coast of the outer Bay range between 100-2500 g dry weight/m^2. Along the Nova Scotia coast biomass values are somewhat lower because of the relative paucity of suitable substrate. Total annual production is on the order of 850 gm C/m^2.

There is considerable uncertainty as to the fate of seaweed production. Direct grazing by sea urchins occurs in most areas and this can seriously deplete seaweed biomass when urchin populations become very large. Loss of live seaweeds by natural leaf sloughing or storm events probably results in considerable export to the pelagic and intertidal systems. In an intensive study of the fate of seaweeds in Passamaquoddy Bay, N.B., Bradford (1989) estimated that 37 percent of the standing stock of intertidal seaweeds, representing > 80 percent of total annual production, was exported from the intertidal during the summer months. Within the pelagic system floating seaweed patches may play an important role as a feeding area for seabirds, marine animals and fish. Much of this material is likely broken down as part of the detrital system, which could involve the microbial food loop, where it either becomes degraded by microorganisms or enters higher trophic levels ('link or sink phenomena'). Within the intertidal system the seaweed detritus forms beach wrack, which is degraded by an invertebrate and microbial community that appears to be specifically adapted to this habitat. It has been suggested that, in both the pelagic and intertidal systems, a portion of the seaweed detritus becomes solubilized and enters the food chain of microorganisms as dissolved organic materials. It has also been suggested that some of these humus-type dissolved organics can act as growth stimulators of phytoplankton.

Seaweeds are not only important as an energy source but, because of their large size and structural characteristics, are also important in providing habitat for various species of marine organisms. The current controversy regarding the harvesting of seaweeds has resulted in a number of reports that review the numerous roles played by seaweed communities (see Section 5.2.4).

4.2.5 Salt marsh

The largest tracts of salt marsh occur in the upper Bay, particularly the Cumberland Basin and the Southern Bight of the Minas Basin. Gordon and Cranford (1994) estimated that nearly 80 percent of Bay of Fundy salt marshes have been lost as a result of extensive dyking, much of which was carried out by the original Acadian settlers.

> ***"nearly 80 percent of Bay of Fundy salt marshes have been lost as a result of extensive dyking, much of which was carried out by the original Acadian settlers."***

Fundy marshes are often categorized as either high marsh or low marsh. High marsh occurs above the mean high water level and usually occupies a narrow vertical zone about one meter wide. The dominant plant is *Spartina patens*. Low marsh is that portion of the marsh located between mean high water and about two meters below mean high water. It is composed almost exclusively of *Spartina alterniflora*. Within the upper reaches of the Bay of Fundy, the relative areas of high and low marsh are about 55 and 47 percent, respectively (Cranford *et al.* 1989). Since only high marsh has been dyked, the original area of high marsh was probably much greater.

There is some evidence that Fundy marshes may differ from more southern marshes in the major species of macrophytes present. Connor (1995), in a study of an outer Bay salt marsh located at Dipper Harbour, New Brunswick, reported the forb *Plantago maritima* to be an important plant in the transition zone between low and high marsh, accounting for as much as 26 percent of the total surface area of the marsh.

Salt marsh productivity studies within the Bay have reported annual above-ground net production of both high and low marsh to be on the order of about 200-300 g C/m^2. High marsh is slightly less productive than low marsh. The productivity of Fundy marshes is considerably less than that of more southern marshes but is consistent with the limitation in more northern areas imposed by the shorter growing season. In the one study in which *P. maritima* production was estimated (Connor 1995), this amounted to about half that of *S. patens* or *S. alterniflora*. This study was also the only one to have measured the amount of below-ground net production of the major macrophytes, which was estimated to be more than twice that of above-ground production.

The fate of salt marsh production is not well understood. It appears that in the Fundy marshes, which are characterized by relatively high tidal energy and exposed marshes, most of the low marsh production is exported offshore as opposed to being degraded within the tidal channels of the marsh. High marsh export is much less, on the order of 25-40 percent (Connor 1995, Gordon *et al.* 1985). Schwinghamer *et al.* (1983) showed that water column and intertidal sediments of the Cumberland Basin contain considerable amounts of salt marsh detritus. Cranford *et al.* (1987) estimated that 0.3-2.7 percent of suspended particulate organic carbon and 0.2-0.9 percent of intertidal sediment organic carbon in the Cumberland Basin originates from *Spartina* and that this represents about 10-24 percent of the total net production of low marsh *Spartina* in the Basin.

The most intensive study of the production and export of salt marsh macrophytes was carried out by Connor (1995) for the Little Dipper Harbour marsh. He estimated that 40, 60 and 100 percent of the net above-ground production of *S. patens*, *S. alterniflora* and *P. maritima*, respectively, was exported from the salt marsh, and that roughly 20 percent of the total production was exported in the form of dissolved organic material.

"The fate of salt marsh production is not well understood"

4.3 Zooplankton (G.R. Daborn)

4.3.1 Zooplankton surveys

The work of the Fundy Environmental Studies Committee stimulated considerable interest in the zooplankton populations of the Bay of Fundy during the early 1980's, and this resulted in several publications over the next few years. Many of these studies were opportunistic, taking advantage of the systematic surveys for larval herring (*Clupea harengus*) conducted by Fisheries and Oceans personnel at St. Andrews Biological Station. The surveys were seasonal, occurring in March and November from 1969, and also in mid-summer from 1980. The number of stations varied between 116 and 169, and extended from the eastern regions of the Gulf of Maine to Chignecto and Minas Basins (Stobo and Iles 1973, Corey 1990). Stations in Minas Basin were only infrequently visited because of time and weather limitations. The survey consisted of oblique tows of 60 cm diam. bongo samplers fitted with 0.5 mm mesh nets; consequently only the largest species of zooplankton were routinely captured. The microzooplankton (generally those less than 1 mm in length) are almost entirely missed in such samples. Only a few studies have been designed adequately for microzooplankton in the outer regions of the Bay of Fundy (Emerson and Roff 1987, Middlebrook *et al.* 1987, Gilron and Lynn 1989).

"Only a few studies have been designed adequately for microzooplankton in the outer regions of the Bay of Fundy"

General distribution patterns of plankton in the outer part of the Bay derived from the early larval herring surveys were summarised in Daborn (1984). Zooplankton from the later surveys were examined by Corey and her associates at the University of Guelph. The objectives of the analyses were to determine species composition (Locke and Corey 1986, Corey and Milne 1987), distribution patterns of major species (Milne and Corey 1986, Corey 1988, Locke and Corey 1989, Corey 1990), or aspects of the general biology (Corey 1987, 1988).

Although the general distribution patterns derived from these surveys are probably reasonable for the outer Bay, the large tidal excursions characteristic of the inner Bay and basins was not generally recognized in the analyses. Depending on the stage of the tide, the geographic locations of stations may not accurately represent the water masses being sampled (Daborn, unpubl. data).

In the inner part of the Bay of Fundy, there has been little zooplankton work since 1984 except for a number of studies of the Cornwallis Estuary and the southern bight of Minas Basin (Brown 1983, Crawford 1984, Daborn 1986, Crawford and Daborn 1986, Redden 1986, Roberts 1987, Redden and Daborn 1991, Mantiri 1993, DeMerchant 1995). Emphasis in these studies has been on tidal and seasonal changes in species composition, and the role of zooplankton in the diets of resident and migratory fish.

4.3.2 Zooplankton of the Bay of Fundy

The plankton of the outer part of the Bay is influenced by species that drift into the region from centers of concentration elsewhere, principally the southwest Nova Scotia region of the Gulf of Maine. Using recurrent group analysis on the ichthyoplankton survey samples, Corey and Milne (1987) identified a core group of six species for the outer Bay of Fundy region : the chaetognaths *Sagitta elegans* and *S. tasmanica*, the euphausiid *Meganyctiphanes norvegica*, and the copepods *Calanus finmarchicus*, *Metridia lucens* and *Eucheta norvegica*. Three of these, *S. elegans*, *C. finmarchicus* and *M. lucens*, were common also in southwest Nova Scotia, and were probably imported into the Bay by tidal currents. Other common Gulf species that occasionally drifted in were *Pleurobrachia pileus*, *Pseudocalanus minutus*, and *Calanus hyperboreus*. The ctenophores, *P. pileus* and *Beroe cucumis*, are primarily Gulf species, but appear in the Bay either continuously (*Pleurobrachia*) or seasonally (*Beroe*), although the decline in body size of animals captured in the upper regions suggests that planktonic food is limiting (Milne and Corey 1986).

> ***"The core [zooplankton] species of the Bay are all boreal species that have breeding populations either in the Bay or the Gulf of Maine,"***

The core species of the Bay are all boreal species that have breeding populations either in the Bay or the Gulf of Maine, but *C. hyperboreus* and *Metridia longa* might be indicators of deep Scotian slope waters penetrating into the Bay (Corey and Milne 1987).

Because of the important upwelling regions at the mouth of the Bay, principally between Grand Manan and Brier Islands, near-surface zooplankton populations in these areas include relatively large concentrations of normally mid-water species such as *Meganyctiphanes norvegica*. Large swarms of this species, estimated at $<41{,}000/m^3$ (Nicol 1986), appear to be important for the feeding of baleen whales, fish (Themelis 1987, Stone and Daborn 1987, Stone and Jessop 1994) and seabirds (Brown *et al.* 1979) that congregate in the outer part of the Bay. Kulka *et al.* (1982) found that greatest concentrations of *Meganyctiphanes* were found at depths >140m in the Bay.

The upwelling phenomenon has also been identified as a possible mechanism contributing to the diverse neuston populations encountered by surface plankton tows in the Bay (Locke and Corey 1989, Corey 1990, Daborn 1984). Of 24 species collected in neuston nets during the larval herring surveys, only one, the isopod *Idotea metallica*, was considered as truly neustonic (Locke and Corey 1989). The other numerically abundant species, including *I. baltica* and *I. phosphorea* (Isopoda) and the amphipods *Calliopius laeviusculus*, and *Parathemisto gaudichaudi*, were primarily associated with floating seaweed mats, and are therefore only facultative members of the neuston. Other accidental species are derived from both terrestrial and freshwater sources (Locke and Corey 1986), but all contribute to a substantial food source for pelagic organisms.

Because of the coarse nets used, other euneustonic species such as the endemic "blue feed" copepod, *Anomalocera patersoni*, were under-represented in these studies. As part of a survey for larval lobsters and crabs, however, Brylinsky and Daborn (in Daborn 1984) found that the neuston is well developed throughout the Bay, and smaller species represent an important feeding opportunity for fish larvae, particularly the lumpfish (*Cyclopterus lumpus*) and the fourbeard rockling (*Enchelyopus sp.*) (Daborn and Gregory 1983).

Studies carried out as part of the Bay of Fundy Environmental Studies Programme showed significant declines in pelagic chlorophyll concentrations in the inner part of the Bay where the water column is well mixed, coinciding with rather high abundances of suspension-feeding benthos. Daborn (1986) proposed that the shift from pelagic to benthic production was related to tidal mixing, and hypothesized that competition between zooplankton and benthic suspension feeders would generally result in decline of the former wherever the benthos had access to the whole water column. Further into the Bay, and especially in the upper basins, however, the increasingly strong turbulence begins to restrict suspension feeders, which are intolerant of high suspended sediment loads. As a result, zooplankton populations once again become prominent, and the benthos is dominated by deposit feeders and infauna. In the extremely scoured inner estuaries, the benthos is almost entirely eliminated, whereas zooplankton populations (without much phytoplankton) are often abundant.

> ***"Studies on feeding of larval fish in the southern bight have usually indicated that Eurytemora is a principal prey of most species using the region as a nursery, and continues to be important for planktivorous species .... for much of their life"***

4.3.3 Zooplankton of Minas Basin

Much of the research on zooplankton in the upper Bay has been carried out in the southern bight of Minas Basin, especially in the Cornwallis Estuary. Most of the dominant species are very small and pass through the coarse nets commonly used for ichthyoplankton surveys, giving rise to the original opinions (now known to be incorrect) that plankton populations in the upper Bay are non-existent (Huntsman 1952, Jermolajev 1958). In fact, zooplankton populations in the most turbid regions are often extremely abundant, and play a major role in nutrition of estuarine fish (Redden 1986, Redden and Daborn 1991, Roberts 1987), although many normally planktivorous species switch to feeding on benthos where this represents a better food source (Stone 1986, Stone and Daborn 1987, Roberts 1987, Mantiri 1993, Nasution 1992).

Brylinsky (unpubl. data) used principal components analysis on samples taken in Chignecto Bay, Cumberland Basin and Minas Basin during the FESC cruises of 1978-79 to identify zooplankton associations prevalent in the innermost part of the Bay of Fundy system. The most persistent and numerically abundant species is the copepod *Eurytemora herdmani*, which is endemic to eastern Canada, and is found throughout the inner portions of the Bay (Daborn 1984). Brown (1984) found densities of *Eurytemora* < 128,000/m^3 in the Cornwallis Estuary in December, and estimated its annual production at > 1g/m^3. In summer months, *Eurytemora* is apparently restricted to the deeper, cooler waters of the southern bight, its dominance in the Estuary being taken by *Acartia tonsa* and *Pseudodiaptomus coronatus*. Crawford and Daborn (1986) investigated seasonal changes in the body size and fecundity of *Eurytemora*, concluding that slow growth during cold winter months leads to large body size of spring females, and an explosive population increase as the waters warm up. The slow growth also results in extensive development of epizootic ciliates on *Eurytemora*, although this does not appear to impede their swimming ability (Daborn, unpubl. data). Studies on feeding of larval fish in the southern bight have usually indicated that *Eurytemora* is a principal prey of most species using the region as a nursery, and continues to be important for planktivorous species such as the Atlantic silverside, herring and alosids for much of their life (see references above). Redden (1986) confirmed earlier observations by Gilmurray (1980) and Imrie and Daborn (1981) that egg-bearing females of

Eurytemora are over-represented in the diets of pelagic feeding fish; it was subsequently shown that *Eurytemora* eggs are resistant to digestion (Redden and Daborn 1991).

4.4. Benthos (M. Brylinsky)

4.4.1 Subtidal

The distribution of benthic community types appears to be determined largely by the nature of the substrates found in the Bay. On hard bottoms the subtidal benthos consists of a crustose coralline algal community at shallower (<40 m) depths, and a *Terebratulina*-dominated community at deeper depths (Logan *et al.* 1984). On soft bottoms the subtidal benthic community is dominated by the horse mussel *Modiolus modiolus*. Wildish and Peer (1983) suggested that the strength of tidal currents determines the distribution of community types and benthic production within the Bay through their effect on sediment stability, larval settlement and feeding. Areas with low current speeds and net deposition of organic matter are dominated by suspension feeders and areas of high current velocities, having no net deposition of organic matter and little erosion, are dominated by suspension feeders. In areas where currents are not so strong as to scour the seabed, there is a strong logarithmic relationship between benthic production and the turbulent supply of seston (Wildish and Kristmanson 1979). They also suggested that deposit feeders, which consist generally of soft-bodied forms, are more likely to be eaten than the generally hard-shelled suspension feeders. As a result, much of the organic matter ingested by suspension feeders may be less available to demersal predators, but more available to pelagic predators through the production of spawn having a larval dispersion stage.

Production estimates, based on biomass measurements and empirically derived P:B ratios, have been made for over 300 soft-sediment stations in the Bay and maps of production of benthic suspension feeders have been prepared (Wildish and Peer 1983, Wildish *et al.* 1986). There do not appear to be any studies on production of hard bottom communities and there is a noticeable lack of information on microbenthos and meiobenthos (bacteria, protozoans, nematodes, *etc.*) for subtidal communities.

Logan *et al.* (1984) carried out a survey of sublittoral epibenthos on hard substrates off Deer Island and reported a distinct depth zonation. The shallow zone to 5 m below MLW consists of a crustose coralline algae community with little macroalgae or bryozoa. Sea urchins were present, and it was suggested that this may explain the observed paucity of macrophytes. The mid-depth to 10 m below MLW consisted of bryozoans, anemones, sponges and brachiopods, and had a much higher species richness than the shallow zone. The deep water zone had the greatest species richness and included sponges.

Logan (1988) also carried out a similar survey in the Head Harbor Passage where a hard substrate exists at a depths of 30-100 m due to the high current velocities in the Passage. The epibenthic community at depths >30 m lacked coralline algae and consisted mainly of tubellarian hydroids and horse mussels and was termed the *Tubularia-Tealia felina-Modiolus modiolus* community.

Wildish and Lobsiger (1987) carried out a study in the southwest Bay of Fundy to determine the potential of three-dimensional underwater photography for characterizing benthic communities. Their results indicated that although many of the infauna known to be present from conventional sampling techniques could not be easily identified from the photographs, the density of some epibenthic organisms, especially the more delicate tube-living sabellid polychaetes, may be seriously underestimated using conventional sampling techniques.

4.4.2 Benthic-pelagic coupling

A number of investigators have produced evidence to show that the coupling between pelagic and benthic communities is controlled largely by the degree of water column stratification within the Bay; the idea being that a stratified water column would increase the proportion of primary production grazed by pelagic organisms leaving less to be deposited to the benthic community. Daborn

(1986) analyzed the distribution of subtidal benthic production described by Wildish and Peer (1983) within the outer Bay and suggested that it's variation could be explained partly by the gradient of stratification that exists between the lower and upper parts of the outer Bay. Emerson *et al.* (1986) analyzed the trophic links from May and October at a weakly stratified station located at a depth of 100 m in the southwestern mouth of the Bay. Based on data collected from sediment traps deployed at the base of the euphotic zone they estimated that, on average, 30% of the chlorophyll *a* biomass sinks out of the euphotic zone as algal cells and the remainder as zooplankton fecal pellets. The amount of material deposited was estimated to be much more than that required to support production of the underlying, mainly deposit feeding, benthic community. They suggested that the unutilized organic carbon may be buried within the sediments or transported to other areas within the Bay.

> ***"The intertidal zone of the Bay of Fundy is most extensive in the upper reaches comprising an area of about 30,000 hectares. About two-thirds of this area is contained within the Minas Basin and Cobequid Bay."***

4.4.3 Intertidal benthos

The intertidal zone of the Bay of Fundy is most extensive in the upper reaches comprising an area of about 30,000 hectares. About two-thirds of this area is contained within the Minas Basin and Cobequid Bay. The intertidal is considered to be a relatively harsh environment as a result of high current velocities, high turbidity, warm summer temperature and winter ice scour. As a result, the intertidal benthic community has a low species diversity, composed mainly of a few dominant species, mostly bivalves, deposit feeding crustaceans and burrowing polychaetes. Aside from the mud snail (*Ilyanassa obsoleta*), epibenthic macrofauna are conspicuously absent. McCurdy (1979) surveyed the intertidal fauna at a site in the western portion of the Minas Basin and reported 71 species of macroinvertebrates, of which three (*Corophium volutator*, *Heteromasis filiformis* and *Chaetozone setosa*) made up 76% of the total numbers. In other areas, *Macoma balthica* and *Mya arenaria* may reach high densities.

Although storms (Yeo and Risk 1979) and ice scour (Gordon and Desplanque 1983, Wilson 1989) can periodically affect intertidal macrofauna densities, many of the organisms present within the intertidal seem to be able to recover relatively quickly, and some polychaetes seem not to be affected at all (Wilson 1991). Brylinsky *et al.* (1994) examined the effects of flounder trawls on the intertidal community of Minas Basin and found little evidence of long-term damage.

Peer (1984) reviewed production of macrofauna in the upper reaches of the Bay. Secondary production is dominated by the bivalve *Macoma balthica* and the amphipod *Corophium volutator*. Overall, *Corophium* is the most important secondary producer and exhibits a strong seasonal variation in abundance, which appears to be related to predation by either fish (May-June) or migratory shorebirds (August-September).

Despite the low species diversity, there is still considerable uncertainty as to the trophic relationships within the intertidal. Schwinghamer *et al.* (1983) attempted to determine feeding relationships based on stable carbon isotope ratios but, because of the similarities of ratios, were unable to determine the relative importance of the two major primary producers, benthic diatoms and *Spartina*. They did conclude, however, that phytoplankton and 'aged' detritus did not appear to be important organic sources for intertidal organisms.

The exact food source of *Corophium* is not well-known. Murdoch *et al.* (1986). carried out a study of the population dynamics and nutrition of a *Corophium* population in the Cumberland Basin and, based on gut content analyses and other techniques, were unable to determine the exact nature of the organic material consumed by *Corophium*. They were also unable to find any relationship between organic, protein or chlorophyll content of the sediments and *Corophium* densities. Hawkins

(1985), in a study also carried out in the Cumberland Basin, estimated that 27% of the net diatom production would sustain the *Corophium* production in the upper Bay.

Wilson (1991) carried out a series of experiments within the intertidal of the Minas Basin to determine the importance of predation on various components of the macrofauna. His results indicated that on mudflats where both *Corophium* and polychaetes were present, fish predation affected *Corophium* but not polychaete abundance. In areas where *Corophium* was absent, fish preyed on some polychaetes (*Tharyx acutus*) but not on others (*Heteromastus filiformis* and *Scoloplos fragilis*). Shorebirds were reported to have little effect on polychaete densities.

"Spartina detritus entrained within the intertidal sediments of the upper Bay is utilized rapidly by a number of intertidal organisms."

Measurements of sediment organic content in intertidal sediments of the upper Bay often indicate relatively low amounts of organic matter, usually < 1%. A number of studies have indicated that *Spartina* detritus entrained within the intertidal sediments of the upper Bay is utilized rapidly by a number of intertidal organisms. The mud snail (*Ilyanassa obsoleta*) is particularly abundant in some areas of the southern bight of the Minas Basin reaching densities of $100/m^2$. Cranford (1988) carried out a population study of the mud snail in this area and concluded that benthic microalgae biomass was insufficient to meet the energy requirements of the population. He suggested that *Spartina* detritus may be a major component of the mud snail's diet. He also reported that mud snails do not appear to be an important prey item.

Schwinghamer and Kepkay (1987) performed a series of laboratory experiments to determine the time and course of degradation of *Spartina* buried in sediments obtained from the intertidal of the upper Bay. They found that the fluxes of DOC and nutrients were enhanced in sediments containing *Spartina* detritus. Sediment bacterial biomass increased significantly when *Spartina* was added to the sediments, but meoifauna (mainly nematodes) showed little response over the incubation period (29 days). They also reported microalgae growth to be inhibited by the addition of *Spartina*.

Cammen and Walker (1986) carried out studies on the relationship between bacteria and microalgae in intertidal sediments at Peck's Cove in the Cumberland Basin. They found a strong relationship between bacteria and microalgal biomass (primarily pennate diatoms), which they attributed to the release of extracellular material by the microalgae. They did, however, point out that the relationship could be a result of both being subject to the same grazing pressures.

Despite numerous studies on the intertidal biology of the upper Bay, there have been no attempts to calculate a detailed carbon budget for this system. Schwinghamer *et al.* (1986) made an attempt to partition production and respiration among intertidal organisms for Peck's Cove, based on available data on average seasonal biomass and literature P:B values. They found good agreement between measured and estimated rates of production for the dominant macrofauna (*Corophium* and *Macoma*) and benthic microalgae, but poor agreement between estimated and measured total community respiration.

Schwinghamer (1983) used path analysis to identify causal factors determining benthic biomass, based on biomass spectra (Schwinghamer 1981), using data from both the intertidal and subtidal of the upper and lower Bay. His analysis suggested that macrofauna abundance is largely a function of exogenous predation and sediment disturbance, meiofauna were most abundant in fluid, fine-grained sediments where algal biomass was high, and that meiofauna and macrofauna may compete for food. His results also suggested that intertidal benthic algae are controlled by macrofaunal grazing and nutrient conditions within the sediments, and that bacteria were abundant where macrofauna were also abundant, both of which showed strong positive relationships to sediment particle size and sediment organic content. Path analysis has not been used much in this field, but Schwinghamer's work shows that it is a promising tool.

4.4.4 Perspective on benthic biological research:1983-95 (D. J. Wildish)

4.4.4.1 Introduction

During the 1970's, when a cartel of oil producers forced the world price of oil to unprecedented high levels, alternative sources of energy were actively sought. One such was the harnessing of tidal power in the Bay of Fundy by construction of dams and turbines driven by tidal flows to produce electrical power. At a meeting at Acadia University on November 4-5, 1976, organized to consider the possible environmental implications of tidal power, the major benthic question was considered to be how benthic production and its transfer to commercially important fish or invertebrate stocks would be affected by tidal power development (Wildish 1977). At a later workshop at l'Université de Moncton on November 8-10, 1982, a review of subtidal benthic research in the period 1976-82 was presented by Wildish (1984) and Peer (1984). A preliminary answer to the question of how benthic production would be affected by one specific tidal power project was presented in an interdisciplinary study by Wildish, Peer and Greenberg (1986).

> ***"Both fundamental and applied research are interdependent, with the latter requiring the former to help answer many questions of practical concern."***

It is the purpose of this presentation to highlight the work done in the period since 1983 to date, and to suggest those studies with highest priority for future work. Because this is a brief overview, the reader will not find a detailed list of references for this period.

4.4.4.2 What have benthic biologists been up to since 1983?

Since 1983 when the first benthic workshop was held in St. Andrews, there have been five subsequent meetings (Table 4.2), approximately at biennial intervals. The group who attends these meetings may be described as the invisible college of the benthos of the NE Atlantic. A significant number of the presentations made at them directly concern the Bay of Fundy, although by no means all of them.

By consideration of Table 4.2, it can be seen that two of the six topics are clearly applied (#'s 4 and 6), whereas the rest may be described as fundamental in nature. The distinction between these two may sometimes be difficult to make. Fundamental research applies to curiosity-driven questions, whereas applied research refers to those questions with an obvious and direct practical application in human society. Research scientists usually do not notice or make this distinction, al-

Table 4.2 Themes of biennial benthic workshops held at St. Andrews Biological Station.

Number	Dates	Theme
1	Dec. 8, 1983	Biology of the sediment-water interface
2	Oct. 29-30, 1985	Fluxes of particulate matter across benthic boundaries
3	Nov. 2-4, 1988	Advective transport and benthic productivity
4	Nov. 7-8, 1990	Mariculture impacts on coastal systems
5	Oct. 28-29, 1992	Hydrodynamics of the benthos
6	Oct. 26-27, 1994	Bivalve culture

though the ultimate goals of each may lead in very different directions. Both fundamental and applied research are interdependent, with the latter requiring the former to help answer many questions of practical concern.

Benthic biology is acknowledged (*e.g.* Wildish and Kristmanson, in preparation) to be a relatively young scientific discipline, dating from 1911 and remaining essentially an observational study until the early 1970's. Thus, during the period of review, the thrust of benthic research accomplished was hypothesis-driven laboratory or field experimental work, relating to themes 1, 2, 3 and 5 shown in Table 4.2. It is hardly surprising that very few predictive models of general utility are yet available for benthic biology.

4.4.4.3 Fundamental versus applied research

The goals of fundamental benthic biological research are to further any part of the understanding of a relatively narrow field, and are thus reductionist. By contrast, applied benthic research is holistic in nature because it seeks to understand the effects of human activities on not just the benthic, but the whole of the marine environment.

In considering marine environmental effects, it is necessary to consider all of the multiple uses (Table 4.3) to which the coastal zone may be put (Wildish 1983). For it is only if all multiple uses are considered simultaneously that simple models can provide a holistic management tool for coastal zones to optimize or choose between competing multiple uses (Strain *et al.* 1995).

Because of the poor state of development of fundamental benthic biology, very few methods are available for predictive use in applied research. This means that direct applied research in benthic biology is still not very effective. I believe that individual research scientists in the field of benthic biology should spend approximately one-half of their time on each endeavor. Representative questions are shown in Table 4.4.

> ***"it is only if all multiple uses are considered simultaneously that simple models can provide a holistic management tool for coastal zones to optimize or choose between competing multiple uses"***

Table 4.3 Human uses of the coastal zone ranked by need for high quality seawater.

Rank	Use
1	Aquaculture
2	Commercial fishing
3	Recreational fishing
4	General recreation *(e.g. whale watching, canoeing)*
5	Water abstraction - for processing, cooling
6	Electrical generation from tidal power dams
7	Municipal waste disposal
8	Industrial waste disposal
9	Seabed mineral or oil extraction
10	Commercial shipping

4.4.4.4 Future directions

From what is said above, it is clear that the choice of fundamental questions is a personal decision of an individual research scientist. The questions I have suggested in Table 4.4 may not be the high priority ones for another research scientist with different interests. I believe this to be a healthy and desirable state of affairs for benthic science.

For applied questions, the choice of those to address by research can be decided rationally in discussion with other coastal zone users and with coastal zone managers. An initial step (#5, Table 4.4) is to prioritize the potentially most significant human activities affecting sediments in the Bay of Fundy. Considering the spatial scale of the effects within the Bay, I believe that a large tidal power project, if implemented, would qualify as significant, as would benthic trawling or dredging.

I believe that the best scenario for marine coastal zone management is a proactive one. With such a paradigm, the resource manager is given some idea of any long-term plans to develop the Bay and thus has time, using simple ecosystem simulation models (#7, Table 4.4), to predict what may result

Table 4.4 Potential questions of importance relating to benthic biology in the Bay of Fundy.

Category	Question
Fundamental	1. How is pelagic-benthic coupling affected by flow?
	2. Do hydrodynamic-sediment interactions determine the settlement of deposit- versus suspension-feeding larvae exclusively?
	3. Do hydrodynamic-sediment interactions determine post-settlement mortality variability between deposit and suspension feeders?
	4. How does water movement inhibit suspension-feeder production?
Applied	5. What human activity causes the actual and potential most significant benthic effects in the Bay of Fundy?
	6. How would one design a satisfactory long-term benthic monitoring project to indicate estuarine changes over periods >10 yrears?
	7. How would one predict the results of resource management changes based on simple ecosystem simulation models?
	8. How do climatic changes affect the benthos?

in the Bay of Fundy. Such information is a powerful resource management tool, allowing him/her to optimize location and timing of the development.

It should be recalled that we still have no simple, efficient benthic monitoring method suitable for detecting benthic change (#6, Table 4.4) over long temporal periods, or how, and if, climatic changes caused by aerial pollution (#8, Table 4.4) influence the sediment and fauna that live there.

4.5 Fish (M.J. Dadswell)

The Bay of Fundy has always had a tremendous production of fishes, and much of the early European settlement in the region was largely in response to the marine productivity and the timber resources of the region. The marine productivity remains to the present day, and even if certain species have recently fluctuated in abundance, there remain large stocks of fish.

The productivity is due to two main phenomena. One, the Bay functions similar to a large, high salinity estuary with high levels of allochthonous nutrient input and two, its physiography and current structure make it a cul-de-sac for coastal migrating fishes, resulting in large numbers of individuals occurring within a small area.

The Bay of Fundy has two distinct fish communities or aggregations. The first is an estuarine group consisting of small-bodied species which remain in the Bay year round. This group has a large component of anadromous species and includes fishes such as smelt, tomcod, stickleback, silversides and flatfishes. Many of these species occur in immense numbers but have relatively low biomass because of their small size. They dominate the inner, low salinity regions such as Cumberland Basin and Cobequid Bay. The second group consists of large-bodied species which mostly occur as summer migrants to the Bay, although the juveniles of some such as herring and pollock are found year-round. This group includes anadromous species such as American shad, Atlantic sturgeon, river herrings (alewife, etc.), Atlantic salmon and striped bass, as well as oceanic fishes such as cod, haddock, pollack, flatfish, herring and sharks (dogfish, porbeagle, *etc.*). These fishes make up the bulk of the commercial fish catch and support landings as high as 100,000

> ***"[the Bay's] physiography and current structure make it a cul-de-sac for coastal migrating fishes, resulting in large numbers of individuals occurring within a small area."***

MT for species such as herring. During spring, summer and fall, fish are distributed throughout the Bay with a dominance of anadromous fishes in the inner regions and oceanic species in the outer Bay. There is a mix of pelagic and benthic feeders in all regions of the Bay, and seasonal distributions are more a factor of the migratory behaviour than food availability.

The resident fishes do not appear to move great distances, rather they spend the winter in more saline regions of the Bay and move into less saline water in summer. Their distributions are regulated largely by spawning requirements and the availability of their preferred foods. The community is about equally divided between pelagic feeders (smelts, silversides) and benthic feeders (tomcod, flatfish).

"During spring, summer and fall, fish are distributed throughout the Bay with a dominance of anadromous fishes in the inner regions and oceanic species in the outer Bay."

The summer migrants move over immense oceanic distances, many spending part of their life cycles as far away as the south USA coast (shad, sturgeon, striped bass, dogfish), offshore on the Scotian Shelf (cod, haddock, halibut, herring) or as far north as Greenland (salmon). Again the fish community is about equally divided between pelagic feeders (herring, shad, salmon, pollack, sharks) and benthic feeders (cod, haddock, flatfishes). Some of these fishes migrate to the Bay of Fundy primarily for reproduction (anadromous species) but the greater portion are probably in the Bay in response to food availability (cod, haddock, shad). Herring aggregate in the Bay from May to October and use it as a major feeding and reproductive area. It might be more correct to say that herring migrate out of the Bay to overwinter, as most of their important life dynamics occur in the Bay (Wayne Stobo, pers. comm.).

Research and observations from the seasonal distribution of commercial catches indicate the summer migrant group to a greater or lesser degree follow a similar migration path. The great bulk of the fish arrive in the Bay of Fundy on its southeastern shore (Nova Scotia) in spring, move inward in the Bay during summer and leave in the fall along the New Brunswick shore. This migration pathway seems to be well established for shad, cod, haddock and sharks, but further work needs to be done to determine if it is a generalized behaviour. Some tagging studies also indicate cod, haddock and pollock movement into and out of the Bay on the Nova Scotian side by populations tagged on the Scotian Shelf area; and movement more related to the Gulf of Maine by individuals tagged on the New Brunswick side (Wayne Stobo, pers. comm.). When leaving the Bay, one group of fishes migrates south along the U.S. shore (Maine) and another group crosses the Bay past the Nova Scotia shore on their way to the Scotian Shelf. This latter group supports very large and persistent fisheries in the Brier Island - Yarmouth region. The migration pattern appears to be cued by the counter-clockwise residual current structure of the Bay and the fish appear to be able to navigate using currents and the coastal configuration. There may also be a secondary response to the possible production cycles in the Bay of Fundy itself. In spring the warmest and most saline water is off Nova Scotia, in summer production peaks in the inner regions probably supported by the breakdown of marsh grasses, and in fall the coastal regions of New Brunswick undergo production peaks probably in response to immense spring-summer outflow of the Saint John River, the second largest river on the east coast of North America after the Saint Lawrence. Productions peaks related to the annual inflow of the Saint Lawrence have been demonstrated for the Gulf of the Saint Lawrence. It may be fruitful to examine this relationship for annual inflows of the Saint John River to the Bay of Fundy.

"The migration pattern appears to be cued by the counter-clockwise residual current structure of the Bay and the fish appear to be able to navigate using currents and the coastal configuration"

4.6 Birds (P.W. Hicklin)

4.6.1 Introduction

The Bay of Fundy is well-known for its abundant and diverse bird life, especially its coastal and pelagic seabirds. The region has many year-round resident birds, as well as being a major migration corridor for millions of coastal shorebirds flying southwards from arctic breeding grounds (Hicklin 1987).

From January 1960 to January 1987, the Canadian Wildlife Service in the Atlantic Region (CWS-AR) conducted systematic aerial surveys along the coastlines of the three Maritime Provinces. The surveys were performed to determine species composition and abundances of waterfowl at different times of the year, and between years, particularly in spring and fall (unpublished information). Thirty-five surveys were conducted specifically along the coast of the Bay of Fundy in New Brunswick and Nova Scotia over the survey plots shown in Figures 4.1 and 4.2. Of these surveys, 14 were undertaken during the winter months (December, January, February), 10 in spring (March, April, May) and 11 in autumn (September, October, November).

> ***"The Bay of Fundy is .... a major migration corridor for millions of coastal shorebirds flying southwards from arctic breeding grounds."***

In 1976, the CWS-AR hired a contractor to conduct 10 aerial surveys in the upper Bay of Fundy (Chignecto Bay and Minas Basin) to document the numbers of migrant shorebirds present throughout the annual "fall" migration beginning in July (Hicklin 1976). Annual shorebird surveys conducted since then have been coordinated by personel at CWS-AR (see newsletter *Calidris* Nos. 1-3). More detailed field studies on sandpipers and plovers in Minas Basin have been undertaken by biology students of Acadia University since 1976. Overall, the data obtainable from CWS at present provides the most complete overview of waterfowl populations available for the Bay of Fundy.

4.6.2. Waterfowl

4.6.2.1 Seaducks

At least five species of waterfowl were commonly seen over the 27 years that aerial surveys were conducted over the Bay of Fundy: Common Goldeneye *Bucephala clangula*, Bufflehead *Bucephala albeola*, Oldsquaw *Clangula hyemalis*, Common Eider *Somateria mollissima* and Scoter *Melanitta* spp. (three species combined: Black Scoter *M. nigra*, Surf Scoter *M. perspicillata* and White-winged Scoter *M. fusca*).

The maritime distributions and abundances of eiders, scoters and oldsquaws in the spring, fall and winter months are shown in Figures 4.3 - 4.11. The most abundant species in the Bay of Fundy was the Common Eider in spring, the only species of seaduck which breeds in the maritime provinces. The next most common were the three species of scoters (combined) which were numerous in the Bay during the spring and fall migrations. Because little was known about the status of the three species of scoters at the time of these surveys, they were not considered priority species for conservation; they were simply grouped under the heading "scoters" when encountered.

The results of the CWS-AR aerial surveys clearly show that the Passamaquoddy Bay area (including the island of Grand Manan and The Wolves archipelago) in the western portion of the mouth of Fundy was the most important staging area for these seaducks during spring and fall in the Bay of Fundy (see figures 4.3 - 4.11). The small islands between Deer Island and Black's Harbour in Passamaquoddy Bay (i.e. the Wolves and Grand Manan Island) collectively support a breeding population of approximately 2,500 pairs of Common Eider (Erskine and Smith 1986).

King eiders are only rarely seen in the Bay of Fundy during the winter months and spring and fall migrations. For example in winter, King eiders have been recorded in Maces Bay in January

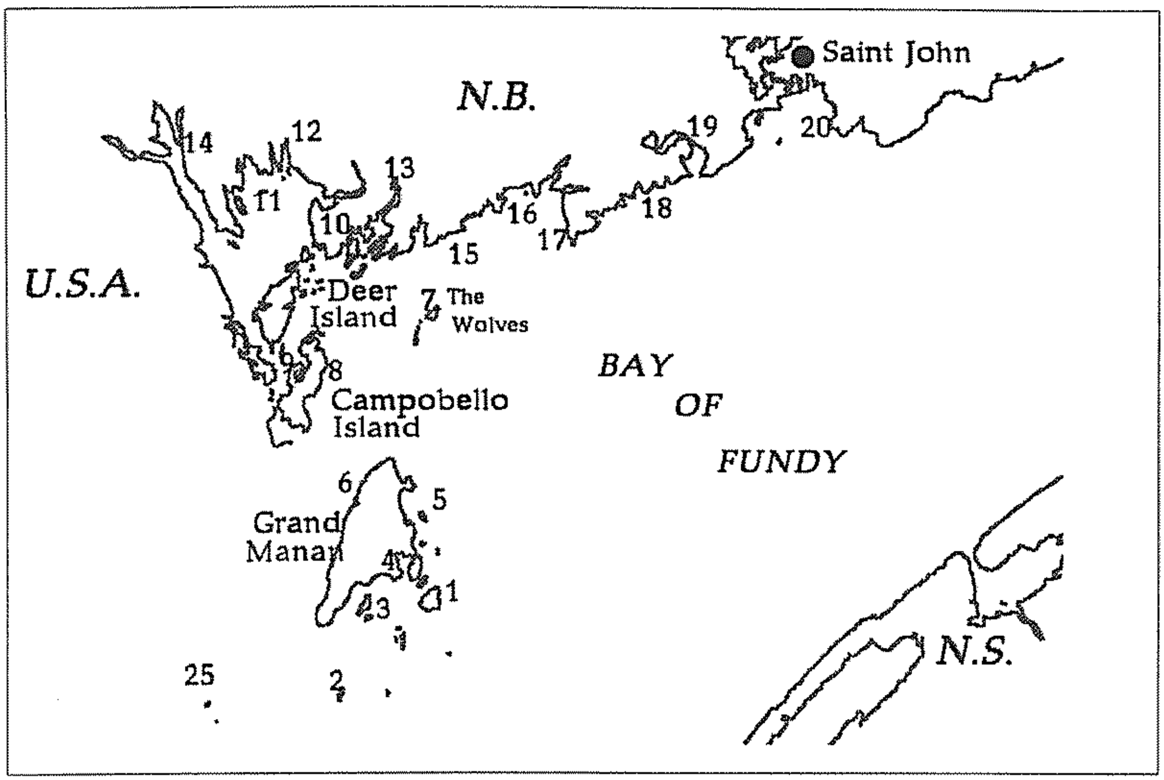

Figure 4.1 Coastal survey blocks: Grand Manan to Saint John, N.B. Numbers indicate general position of survey blocks through the study area.

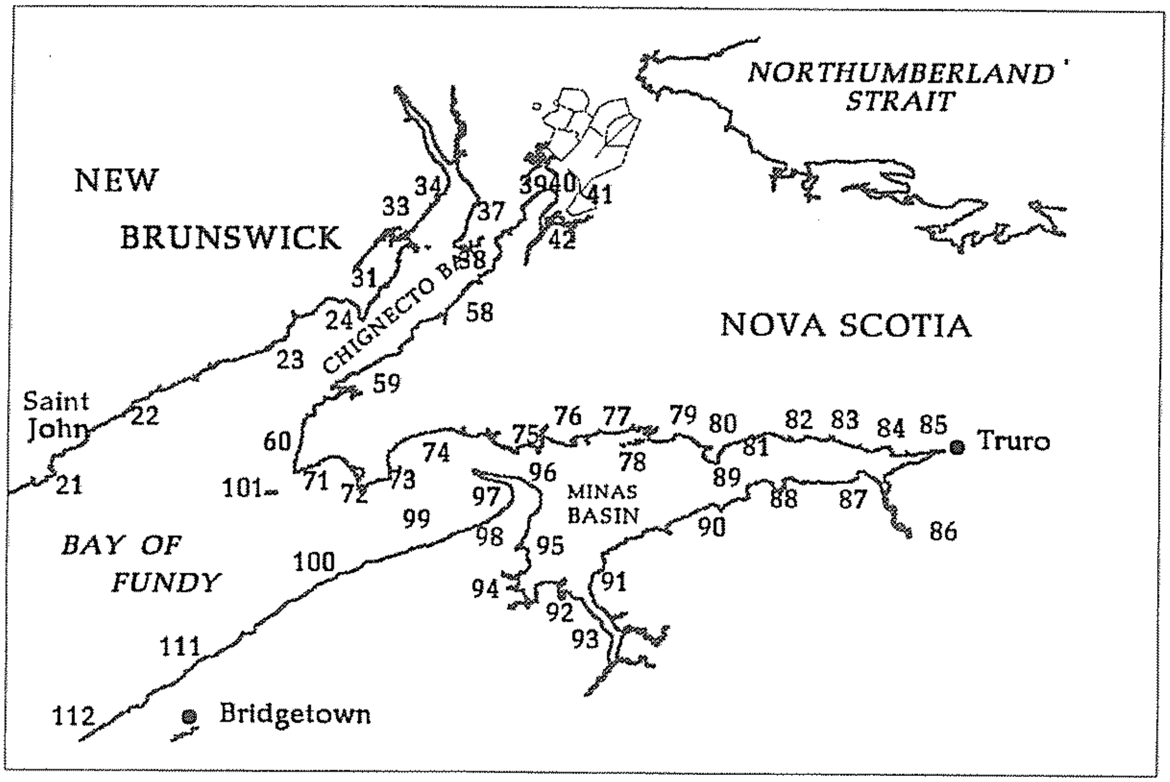

Figure 4.2 Coastal survey blocks: Saint John, N.B. to Bridgetown, N.S. Numbers indicate general position of survey blocks through the study area.

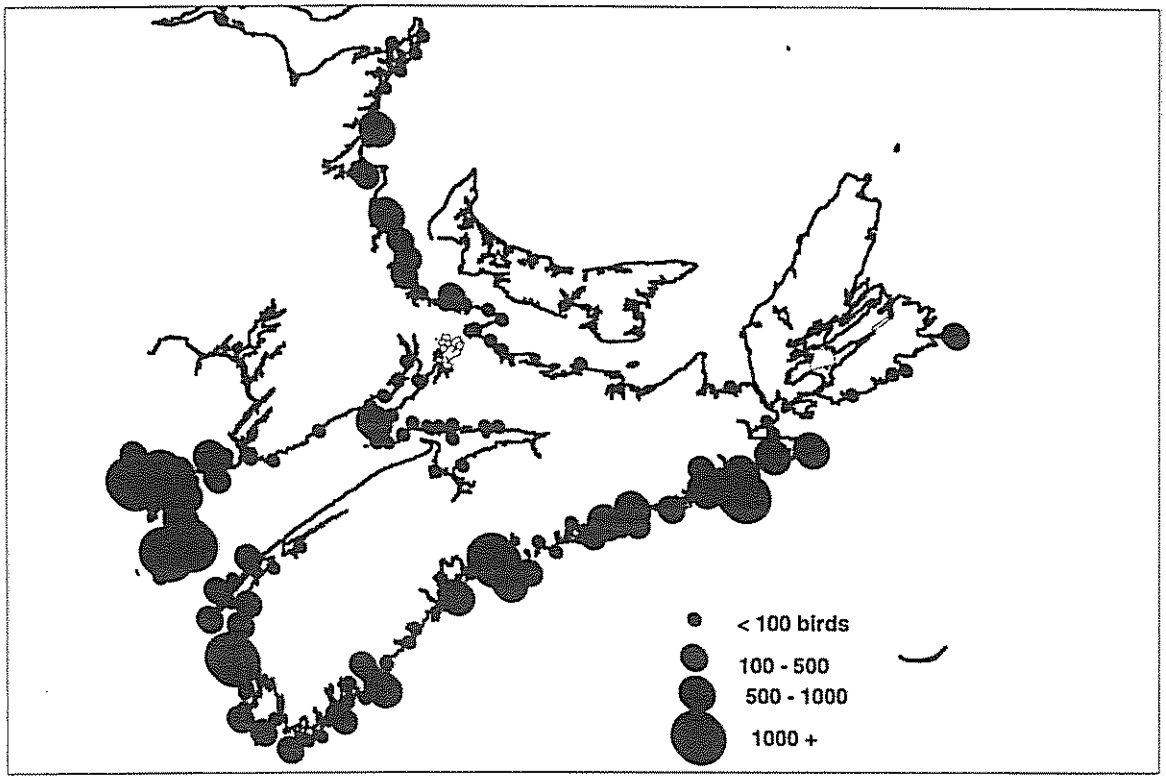

Figure 4.3 Maximum number of Common Eider per survey block in spring (March, April, May) based upon CWS aerial surveys conducted between 1960 and 1987.

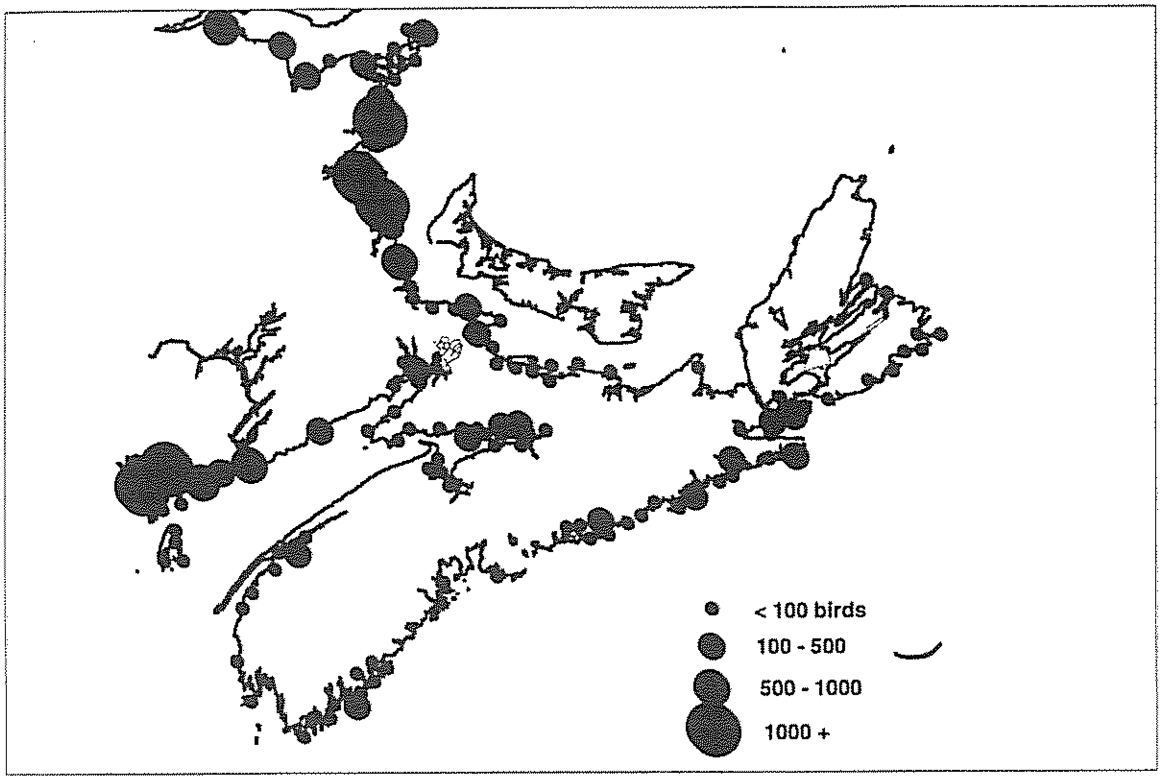

Figure 4.4 Maximum number of Scoter spp. (3 species combined) per survey block in spring (March, April, May) based upon CWS aerial surveys conducted between 1960 and 1987.

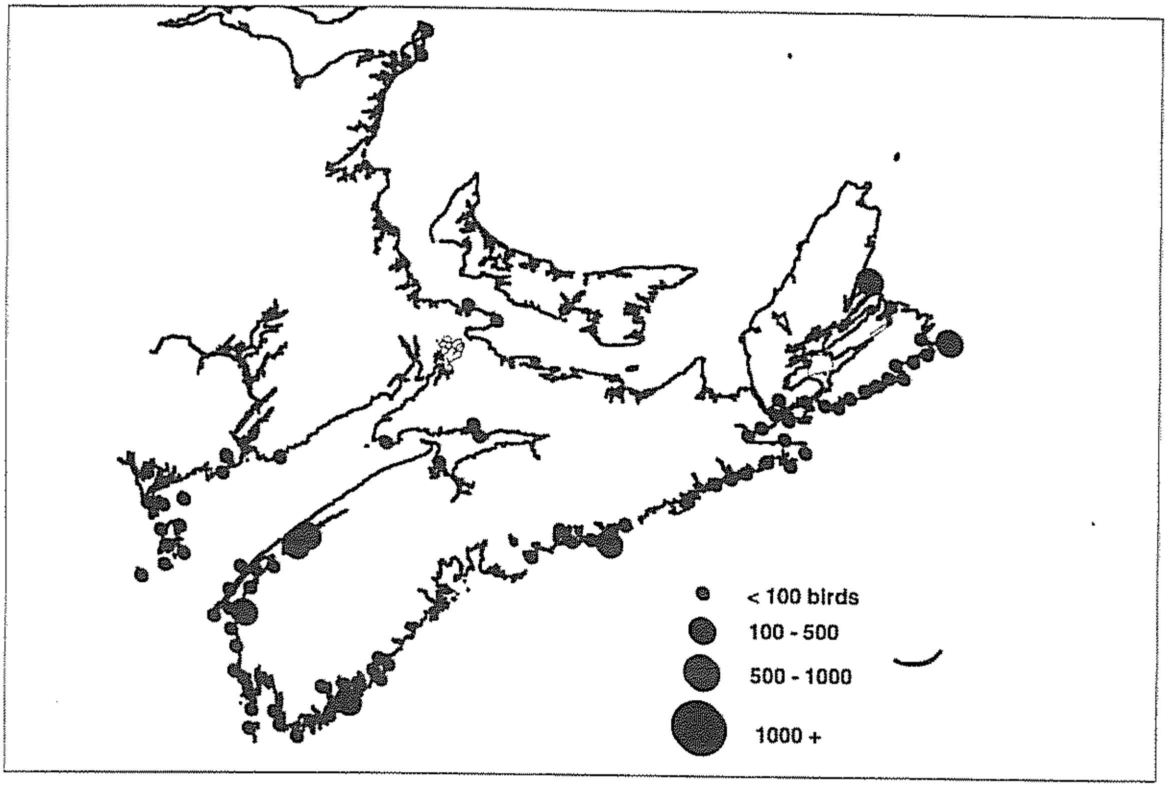

Figure 4.5 Maximum number of Oldsquaw per survey block in spring (March, April, May) based upon CWS aerial surveys conducted between 1960 and 1987.

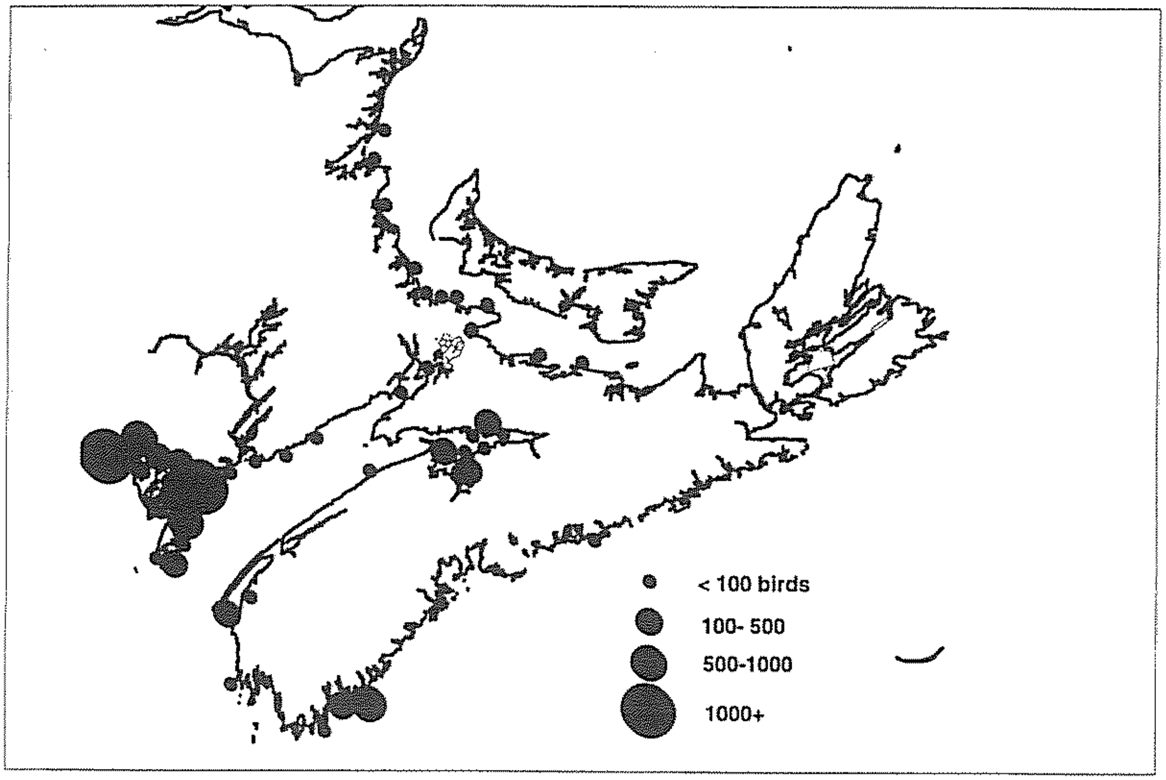

Figure 4.6 Maximum number of Common Eider per survey block in fall (September, October, November) based upon CWS aerial surveys conducted between 1960 and 1987.

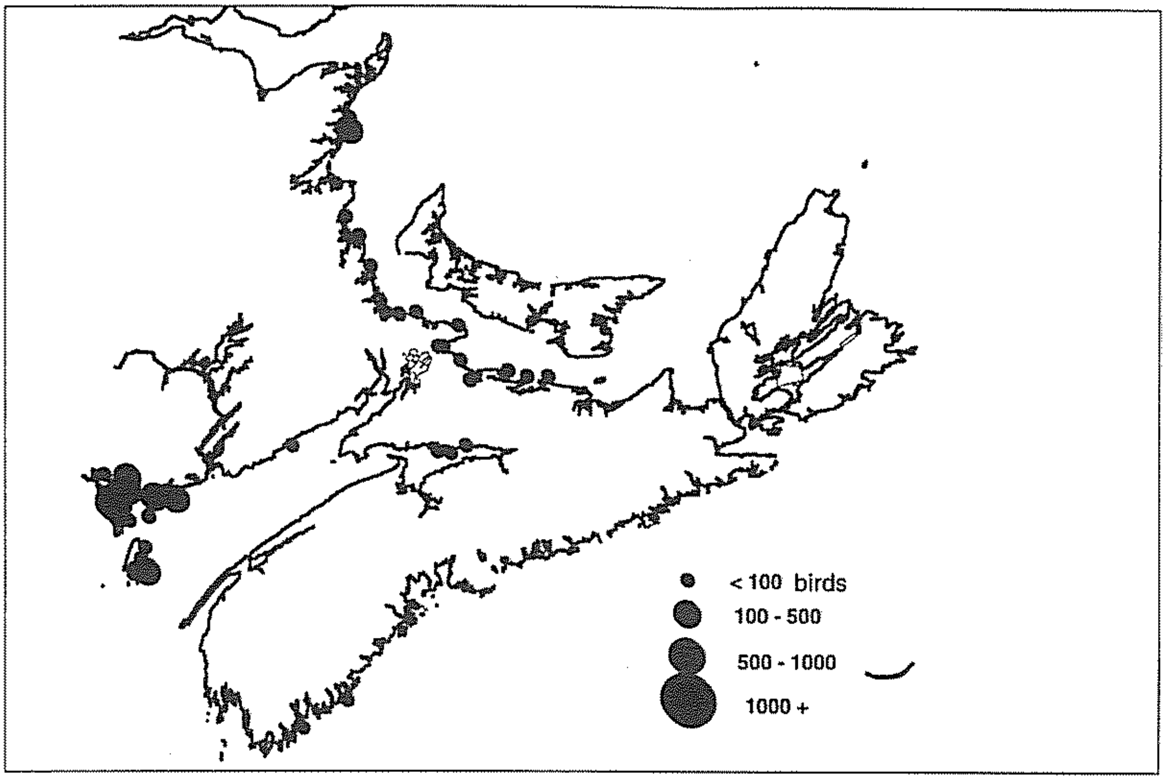

Figure 4.7 Scoter spp. (3 species combined) distribution in fall (September, October, November) based upon CWS aerial surveys conducted between 1960 and 1987.

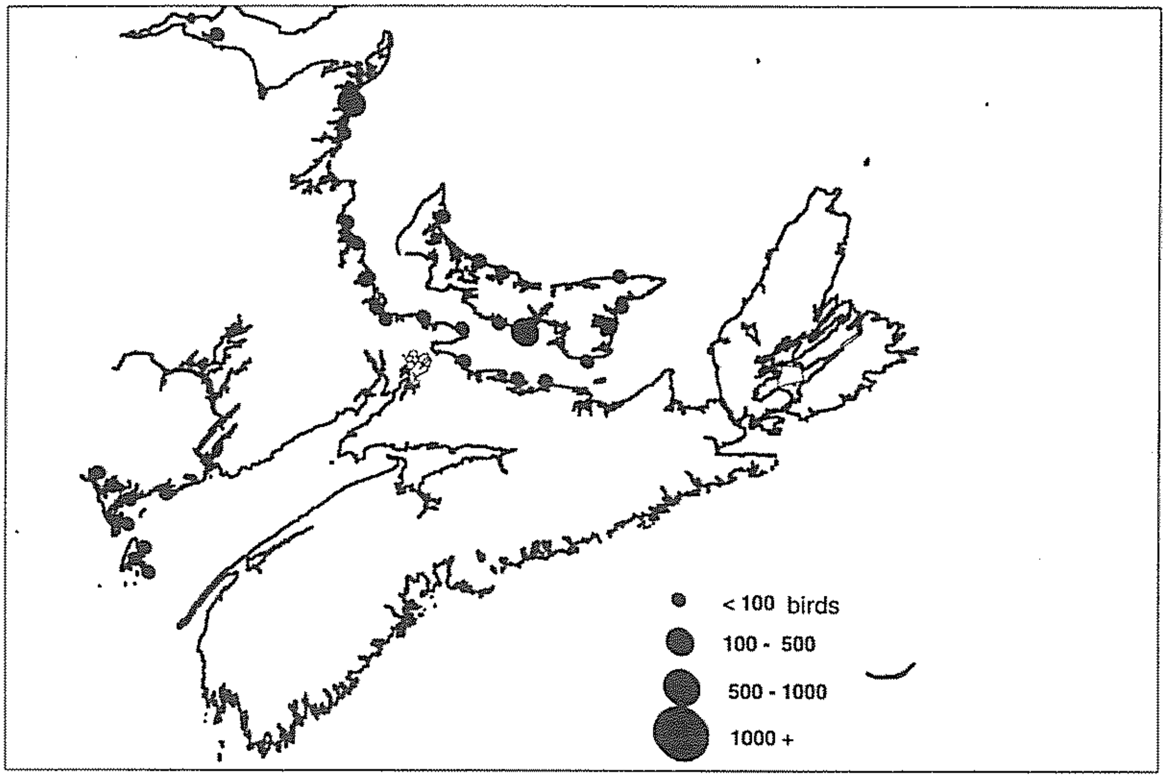

Figure 4.8 Oldsquaw distribution in fall (September, October, November) based upon CWS aerial surveys conducted between 1960 and 1987.

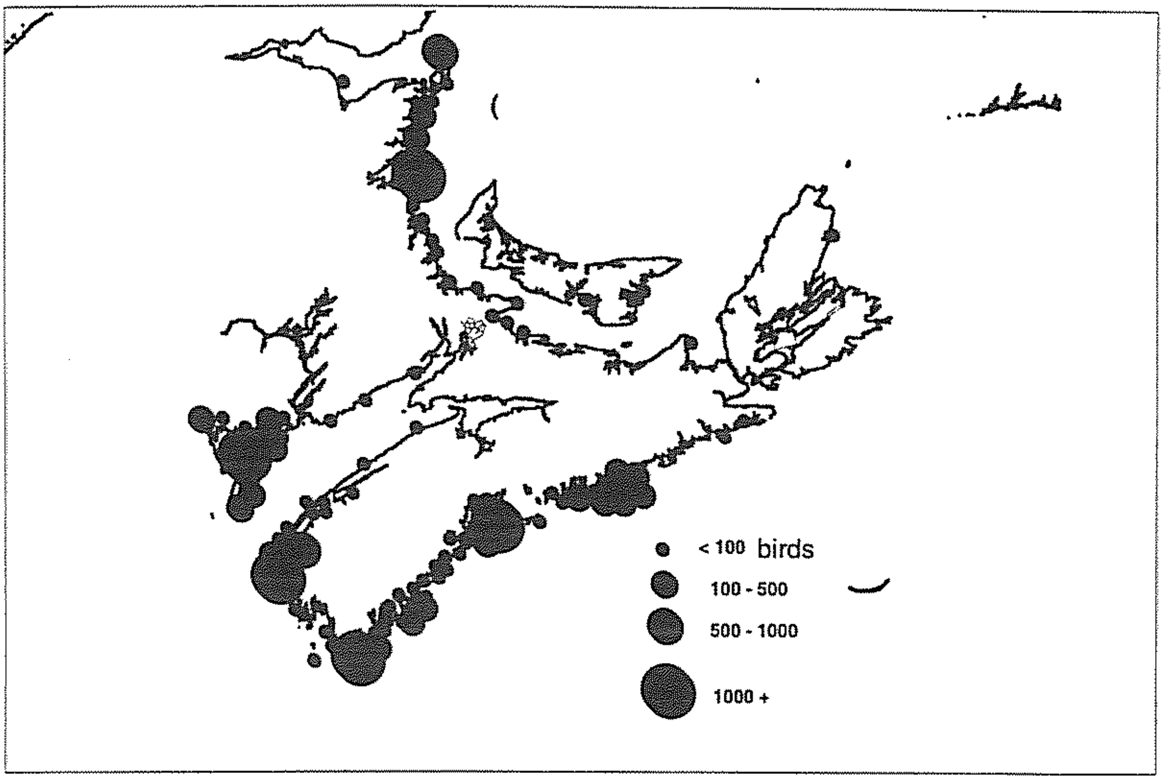

Figure 4.9 Common Eider distribution in winterl (December, January, February) based upon CWS aerial surveys conducted between 1960 and 1987.

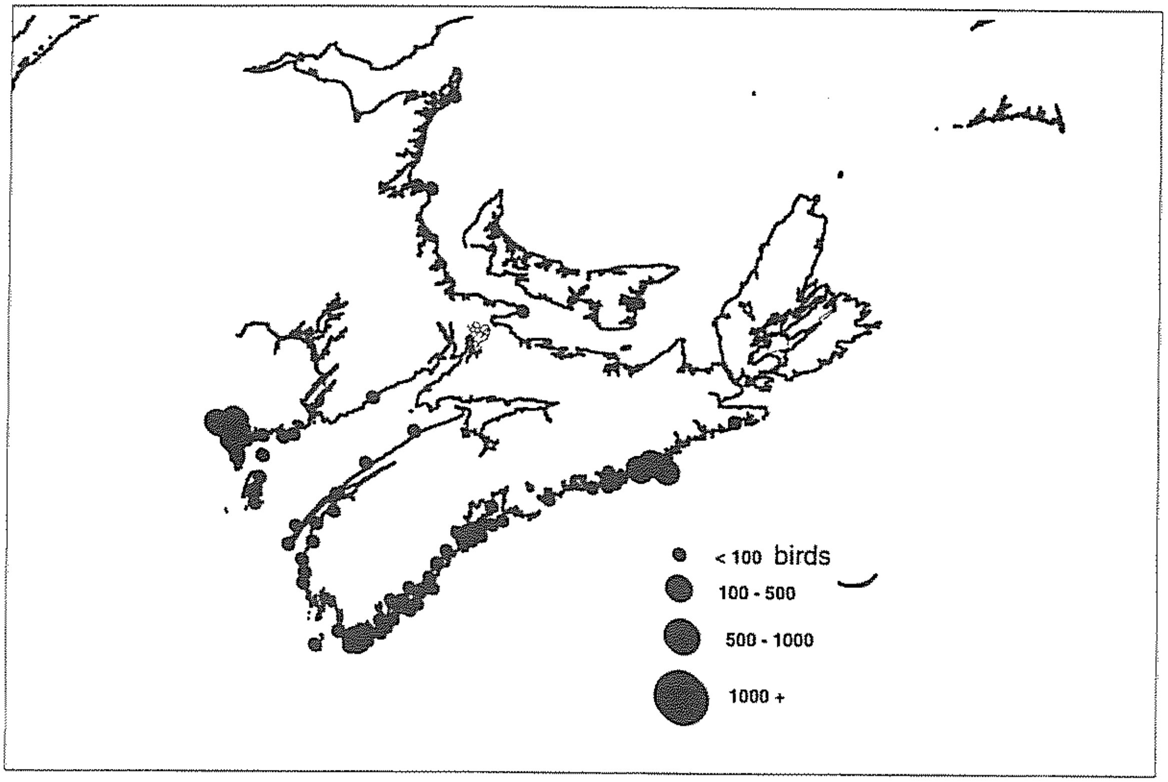

Figure 4.10 Scoter spp. (3 species combined) distribution in winter (December, January, February) based upon CWS aerial surveys conducted between 1960 and 1987.

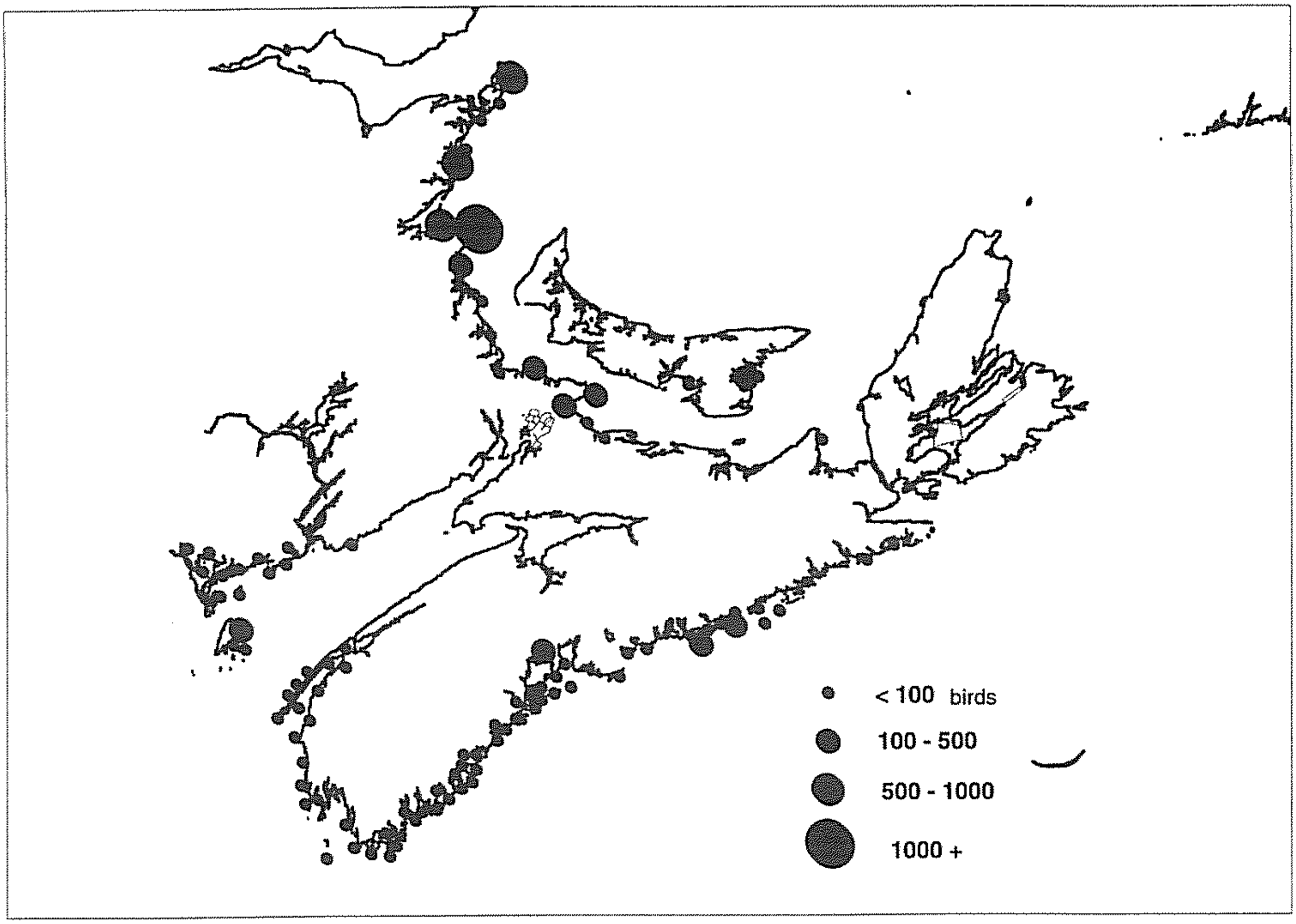

Figure 4.11 Oldsquaw distribution in winter (December, January, February) based on CWS surveys conducted between 1960 and 1987.

(20 birds in 1972) and during spring migration in the same location in March (two birds in 1966), in Cape Enrage in April (three birds in 1971) and Point Lepreau in May (a female in 1896) (Squires 1976). There is no data available to indicate the population numbers of the three species of scoters which overwinter in the bay or stage during spring and fall migrations. With regards to Surf Scoters, Squires (1976) reported that "small flocks remain in the Bay of Fundy in winter concentrated mostly from Point Lepreau to Grand Manan" and Chamberland (1882 cited in Squires 1976) stated that "a few non-breeding young birds remained at Maces Bay all summer."

"The Bay of Fundy is an especially important staging and overwintering area for the Black Duck."

The same is true for Black Scoters; Squires (1976) reported the presence of Black Scoters in December near Saint John (six birds in 1969), Saint Andrews (103 birds in 1963) and Point Lepreau (37 birds in 1969). King Eiders and Scoters were not reported for that portion of the Bay which lies in the province of Nova Scotia (Tufts 1986).

Those birds wintering on the Atlantic coast would migrate over Atlantic Canada in spring and fall to reach overwintering areas which stretch along the east coast from southern Newfoundland to Georgia; however, 70% of the overwintering population of all three species of scoters winters in the area from Long Island Sound to Chesapeake Bay (Bellrose 1976). How many of the eastern wintering population of Black, White-winged and Surf Scoters actually stop in the Bay of Fundy during migration is unknown.

Aerial surveys of wintering scoters undertaken between 14 December 1992 and 3 March 1993 in Chesapeake Bay, Massachussetts, resulted in wintering population estimates for that region of 120,000 Surf Scoters, 28,000 Black Scoters and 17,000 White-winged Scoters for a total scoter population of 165,000 birds (Forsell 1995). J. Bull (cited in Bellrose 1976) estimated 75,000 White-winged Scoters wintering off Long Island and Griscom and Snyder (cited in Bellrose 1976) estimated the wintering populations of White-winged Scoters off Cape Cod and Nantucket at 100,000 - 400,000 birds in 1964 and 1953, respectively. Bellrose (1976) estimated that up to 5,500 scoters wintered between Cape Cod and Newfoundland. These estimates amount to a total population ranging around 340,000 - 645,500 wintering scoters. A proportion of this population would make up the numbers of birds which stage in Passamaquoddy Bay in spring and fall, the size of which is uncertain.

4.6.2.2 Geese and dabbling ducks

In 1972, and in collaboration with CWS-AR, the Nova Scotia Department of Lands and Forests conducted aerial surveys for ducks and geese in the vicinity of Grand Manan. Large numbers of Brant Geese *(Branta bernicla)* were found in numbers varying from 79 birds on 16-17 January to 1,775 on 30 March (Hughson 1972). Total numbers of waterfowl seen in the Passamaquoddy Bay area from Lorneville, N.B. to the estuarine portion of the St. Croix river on those surveys amounted to 5,241 birds on 21 March, 1972, whereas 3,541 were counted around Grand Manan on the same day, albeit later in the day. Brant Geese, Black Ducks *Anas rubripes* and Common Eiders comprised 40% of total numbers (Hughson 1972).

From aerial surveys conducted over Shepody Bay and Cumberland Basin in spring 1966 through to 1971, Canada Geese (*Branta canadensis*) were found to be more common in that portion of the Bay of Fundy (see Hughson 1972); average numbers amounted to 2,400 birds in March (average number per day in that month) and 2,800 in April (Hughson 1972). However, since 1975, the numbers of Canada Geese in both portions of the upper Bay of Fundy have declined to about 1,500 birds because large numbers are believed to now use habitats in Prince Edward Island in March and April.

The Bay of Fundy is an especially important staging and overwintering area for the Black Duck.

Fall and winter populations are concentrated in the Passamaquoddy Bay/Grand Manan region and large numbers concentrate in Cumberland Basin and the Southern Bight of Minas Basin in the upper Bay of Fundy. Over the 27 years of CWS aerial surveys, the maximum numbers of this species per block ranged between 200 and 2,810 birds (mean = 509, s.d. = 386, N = 83 surveys) for the blocks shown in Table 4.5. The lowest numbers of Black Ducks seen per survey by season were in spring (March, April & May; mean ± s.d.= 462 ± 293; n= 21) and almost identical mean numbers were observed in fall (September, October & November; 532 ± 474; n= 32) and winter (December, January & February; 506 ± 351; n= 31). Overall, regardless of season, the largest numbers of Black Ducks were recorded in the southern bight of Minas Basin, between blocks 92 and 95, inclusive.

Table 4.5 Survey blocks and dates where 200 or more Black Ducks *Anas rubripes* were seen in the Bay of Fundy during aerial surveys between 1960-1987, inclusive.

Block No.	No. ducks seen	Date
1	463	17/10/73
3	304	13/03/86
4	427	13/03/86
5	555	27/11/85
8	480	17/10/73
9	306	01/03/77
10	436	11/02/77
10	895	15/12/72
14	906	21/02/75
16	378	18/02/72
17	970	14/01/74
19	591	18/02/72
20	318	26/04/72
22	432	26/04/72
24	319	26/04/72
31	390	14/01/74
33	250	19/11/71
34	224	17/04/74
36	386	09/04/69
36	672	19/11/70
41	514	19/11/70
43	300	16/09/70
45	200	16/09/70
46	300	27/09/66
50	200	16/09/66
51	452	18/09/69

4.6.3 Shorebirds

4.6.3.1 Abundance and distribution of Semi palmated Sandpipers in the upper Bay

In 1976, the Canadian Wildlife Service hired a contractor to conduct a series of ten aerial surveys of shorebirds along the entire coastline of the upper Bay of Fundy (Hicklin 1976). The ten surveys spanned the entire interval of southward migration. The study was undertaken in response to public requests for an evaluation of the potential impacts of Fundy tidal power developments in the Bay of Fundy. Roosting areas known to be important for shorebirds (see Elliot 1977) were also surveyed during the Maritimes Shorebird Surveys between 1977 - 1994 (Morrison 1979, Morrison and Campbell 1980, 1981, 1982, 1983, Hicklin 1993, 1994, 1995). The results of these surveys were analysed to provide population trends (Morrison *et al.* 1994). All the surveys described above are summarized below.

<u>1976 surveys</u> - Ten aerial surveys were undertaken between 19 July and 12 September, 1976, to monitor the numbers and species composition of migrant shorebirds in the Bay of Fundy during southward migration (Hicklin 1976). A peak number of 566,000 'peeps' (primarily Semipalmated Sandpipers *Calidris pusilla*) was recorded on 29 July; peak numbers of Short-billed Dowitchers *Limnodromus griseus* (3,300) were also recorded on that date. Black-bellied Plover *Pluvialis squatarola* numbers peaked on 20 August when their population was estimated to be 5,000 birds. Overall, on 29 July, the numbers of migrant shore-

birds were slightly higher in Minas Basin where a total of 300,000 'peeps' was recorded whereas 266,000 birds was the total for Chignecto Bay.

<u>1976-1993 surveys</u> - The population of migrant shorebirds utilizing the upper Bay of Fundy over the entire southward migration in 1976 was estimated to range between 800,000 and 1,400,000 birds (Hicklin 1987). A re-evaluation of population numbers in 1993 resulted in a revised estimate of 1,122,000 to 1,200,000 birds (Mawhinney *et al.* 1993). This revised estimate was based partly on an improved methodology (Mawhinney *et al.* 1993) but may also reflect real increases in bird numbers.

Another significant change in shorebird populations in the Bay of Fundy between 1976 and 1993 is a clear shift in the distribution of the birds. In Minas Basin in 1975, R.D. Elliot estimated peak numbers of roosting 'peeps' at Evangeline Beach at 20,000 birds; "this pattern of occurance was similar to that found by J.F. Kearney (unpublished data) in 1971, 1973 and 1974" (see Elliot 1977, p. 66). In 1976, 44,860 'peeps' were observed at Evangeline Beach (Hicklin 1976) and by 1991, the number of 'peeps' roosting at Evangeline Beach had increased to 131,200 birds (Mawhinney *et al.* 1993). Furthermore, intertidal areas which were unused by shorebirds in 1976 near Windsor, Nova Scotia, supported roosting and feeding shorebirds estimated at 108,000 birds in 1994 (J. S. Boates, pers. comm.).

> ***"Another significant change in shorebird populations in the Bay of Fundy between 1976 and 1993 is a clear shift in the distribution of the birds."***

In the early 1970's in Chignecto Bay, Mary's Point always had the largest numbers of roosting birds reaching peak numbers of 100,000 birds or more, annually. Between 1976-1988, peak numbers at Johnson's Mills/Dorchester Cape never exceeded 60,000 (P. Hicklin, unpublished information). Since 1988, the numbers of 'peeps' at Mary's Point have remained at around 100,000 birds whereas those at Dorchester Cape have increased markedly (*e.g.* about 300,000 birds on 4 August 1992). During simultaneous counts at the three main roosting areas on 2 August that same year, the numbers of shorebirds at Mary's Point were 150,000 birds while at Johnson's Mills/Dorchester Cape, observers recorded 175,000 and 86,000 were seen at Evangeline Beach (*Calidris* No.1) for a total number of 411,000 at the three major roost sites. But in 1994, the peak number at Mary's Point was 75,000 birds.

In summary, fewer shorebirds now appear to roost at Mary's Point, while numbers substantially increased at Johnson's Mills and Dorchester Cape in Chignecto Bay as well as at Evangeline Beach and Windsor in Minas Basin.

4.6.3.2 Diets and foraging ecology of sand pipers and plovers

4.6.3.2.1 Diet

The first papers on the diets of migrant shorebirds in the Bay of Fundy were published in 1979 (Hicklin and Smith 1979, Boates and Smith 1979). Later, Boates (1980) conducted field studies on the foraging ecology of the Semipalmated Sandpiper *Calidris pusilla* and Hicklin (1981) related the distribution of foraging sandpipers on the mudflats of the Bay of Fundy to the abundance of intertidal invertebrates, particularly the amphipod *Corophium volutator* (Hicklin 1981).

These early studies documented the importance of the amphipod *C. volutator* as a major food source to migrant shorebirds in the Bay of Fundy, especially sandpipers (Family Scolopacidae). Plovers (Family Charadridae) such as the Semipalmated Plover *Charadrius semipalmatus* also foraged on *Corophium* (28.4% dry weight of stomach contents) along with polychaetes (20.9%), gastropods (7.6%) and pelecypods (4.0%) (Peach 1981). The diet of the larger Black-bellied Plover *Pluvialis squatarola* also consisted of *Corophium*, although this species only made up 4.0% of the dry weight of the stomach contents (Hicklin and Smith 1979); its main prey was the large polychaete *Glycera dibranchiata* which comprised 49.6% of the identifiable biomass in the gut (Dubois-

Laviolette 1985).

4.6.3.2.2 Foraging ecology

Mawhinney-Gilliland (1992) studied the foraging ecology and body condition of Semipalmated Sandpipers on three mudflats in Minas Basin. Semipalmated Sandpipers which foraged in areas where *Corophium volutator* occurred in the highest densities deposited more fat, and did so at a faster rate, than those sandpipers which foraged on mudflats where *Corophium* occurred in lower densities (Mawhinney-Gilliland 1992). In 1992 and 1993, Shepherd (1993) examined the effects of baitworm harvesting on Black-bellied Plover and Semipalmated Sandpiper and their preferred prey *Glycera dibranchiata* and *Corophium volutator*, respectively. On mudflats where bloodworms were harvested, there occurred significant reductions in the densities of *Glycera* and *Corophium* (20% and 39%, respectively) and in the plovers' and sandpipers' prey capture success (66% and 60%, respectively).

"studies documented the importance of the amphipod C. volutator as a major food source to migrant shorebirds in the Bay of Fundy"

Prior to any baitworm harvesting activities, Dubois-Laviolette (1985) studied the capture rates and sizes of *Glycera* taken by Black-bellied Plovers and showed that this species deposited fat at the rate of 5.1 g/day by feeding on this prey species prior to completing the last leg of its southward migration. Shepherd's (1993) findings suggest that the Black-bellied Plovers' rate of fat deposition may be lower since the commercial harvest of bloodworms began in Minas Basin in 1985. Unfortunately, no field research has been done on Black-bellied Plovers in Minas Basin since the initiation of bloodworm harvesting.

4.6.3.2.3 Sediment types and *C. volutator*

Hicklin (1981) described the different sediment types of the mudflats in his study on the abundance and distribution of foraging shorebirds and infaunal invertebrates in the southern bight of Minas Basin. He classified each flat on the basis of the relative proportions of particle sizes (sands, silt and clay) which made up the sediments. The relative abundances of the different invertebrate groups (*Corophium*, polychaetes, bivalves and gastropods) were then compared to sediment types. This study concluded that *Corophium* was most abundant in well-drained sandy substrates, whereas the polychaete *Heteromastus filiformis* was common in various substrate types. The polychaete *Spiophanes bombyx* was restricted to areas of fine sands and the large errant polychaetes (*Nephtys caeca*, *Glycera dibranchiata*, *Nereis virens*) occured in muddy (silt and clay) substrates.

Black-bellied Plovers foraged in highest numbers where large, errant polychaetes were most abundant, whereas, Short-billed Dowitchers and Semipalmated Sandpipers were most common where *Corophium* was also most abundant (Hicklin and Smith 1984). The population dynamics of *Corophium volutator* and its importance to sandpipers in the Bay of Fundy is described in Peer *et al.* (1986).

4.6.3.2.4 Impacts of bait harvesting and barrage construction on sediments, invertebrates and shorebirds

The harvest of the polychaete *Glycera dibranchiata* in Minas Basin has caused a reduction in the species' abundance in that part of the bay and the disturbance by harvesters reduced the birds' rate of food intake (Shepherd 1993). Moreover, since about 1970 in the upper Bay, causeways and barrages have been built across tidal rivers. At present, of the 22 tidal rivers in the Bay of Fundy, only two remain fully tidal.

Between 1977 and 1979, Hicklin *et al.* (1980), Boates (1980), Hicklin (1981) and Hicklin and Smith (1984) described the abundances and distri-

"The harvest of the polychaete Glycera dibranchiata in Minas Basin has caused a reduction in the species' abundance in that part of the bay and the disturbance by harvesters reduced the birds' rate of food intake"

butions of intertidal invertebrates and sediment types on ten mudflats in Minas Basin and Chignecto Bay. The main purpose of these field studies was to better understand the population dynamics of the amphipod *Corophium volutator*, the main prey of the Semipalmated Sandpiper in the Bay of Fundy.

The lowest densities of *Corophium* in those years occurred at the Elysian Fields where the mean density for a sampling transect covering fourteen sampling stations was 21.4 ± 54.5 *Corophium*/m^2 on 29 May 1978 and the maximum mean density for a transect reached 10,177± 2,246/m^2 at Starrs Point on 22 July, 1977 (Hicklin *et al.* 1980). The Grande Anse mudflat at Johnson's Mills, New Brunswick, contained a mean density of 6,908 ± 2,436 *Corophium*/m^2 on 19 September 1978 and the maximum density along that transect on that date was 9,900/m^2 at station 2. In July, 1978 (when the birds were present), the highest density along that transect at Grande Anse was also 9,900/m^2 but at station 7 (Hicklin *et al.* 1980).

In July 1993, P. W. Hicklin (unpublished information) sampled the same transect at Johnson's Mills and found not a single *Corophium*. He also found the texture of the mudflat to be very "soupy" (*i.e.* the water content appeared to be significantly higher than in 1978). The most likely explanation for this occurrance was that a change in sediment type and/or deposition processes had taken place due to the construction of barrages across the tidal rivers in Chignecto Bay, notably the Petitcodiac and Tantramar Rivers. In 1994, in order to determine if these changes noted at Grande Anse also occurred in other areas of the Bay of Fundy, the same transects sampled by Hicklin sixteen years earlier in 1978 were re-sampled in 1994 to determine invertebrate abundances, sediment types and water content (Shepherd *et al.* 1995).

> ***"the extensive seaweed beds from Point Lepreau to St. Andrews are used as brood rearing areas for the young [eider ducks]"***

4.6.3.2.5 Changes in sediments and invertebrates between 1977 and 1993.

The most significant changes in the intertidal mudflats of the Bay of Fundy between 1977 and 1993 were:

i) a significant increase in water content of the sediments in four major mudflats in Chignecto Bay (Mary's Point, Grande Anse, Peck's Cove and Minudie) and one mudflat in Minas Basin (Starrs Point) ($p=0.001$: Wilcoxon signed ranks test)

ii) significant reductions in the densities of the burrowing amphipod Corophium volutator at the Grande Anse and Peck's Cove mudflats in Chignecto Bay ($p<0.05$) but significant increases at the Avonport mudflat, Kingsport and the Starrs Point Flat in Minas Basin ($p<0.05$)

iii) polychaete densities also increased significantly at Evangeline Beach and the Starrs Point sandbar in Minas Basin ($p<0.05$) (Shepherd et al. 1995).

Changes in water content would have the greatest impact on sediment stability and the abundances and the species composition of the intertidal infauna. Reasons for such changes in water content are unknown, but are most likely due to shoreline and seabed erosion (Shepherd *et al.* 1995).

4.6.3.3 Phalaropes in the Bay of Fundy

(Charles D. Duncan*)

4.6.3.3.1 Red-necked Phalarope

Since the end of the 19th century, it was known that Red-necked Phalaropes *Phalaropus lobatus* staged in large numbers in the Quoddy region in Eastport and Lubec on the coast of Maine and Deer Island and Campobello Island in New Brunswick during the southward migration from mid-July to mid-September (Knight 1987; Palmer 1949; Squires 1976). Mercier and Gaskin (1985) conducted a major study on this species during the autumn passage. They identified *Calanus fin-*

**Charles Duncan (Institute for Field Ornithology, University of Maine at Machias) could not attend the workshop but prepared the summary presented here.*

marchicus as the birds' major prey and demonstrated that the phalaropes moved as the tide changed and thus stayed in in areas of high copepod densities. In 1982, their estimate of the total number of Red-necked Phalaropes passing through the area was 1 million birds which agreed well with birdwatcher's informal guesses at that time which ranged from hundreds of thousands to a high of 2 million (Finch 1977, Vickery 1978, Forster 1984). It has been suggested (R.G.B. Brown *in* Duncan, 1996) that this may represent the entire breeding population of this species in eastern Canada, Greenland and perhaps Iceland.

"a major decline in the numbers of [Phalaropes] staging in the Quoddy region began in 1986 and by 1990, the species was essentially absent."

Starting in 1986, a major decline in the numbers of birds staging in the Quoddy region began in 1986 and by 1990, the species was essentially absent. Plankton tows which had been performed in the 1970's and repeated in 1990, showed greatly-reduced levels of copepods (Brown 1991). This lack of plankton is likely the proximate cause of the decline in phalarope numbers.

Concern that the absence of staging Red-necked Phalaropes in the Quoddy region reflected a potential crash of the species' entire population was ameliorated by the fact that, at least on one occasion after the collapse in Quoddy, very large numbers were seen on northbound passage off Nova Scotia (Duncan 1996). An alternative staging area has not yet been confidently identified, however. Suggestions that Brier Island, Nova Scotia (where Red-necked Phalaropes have traditionally occurred in smaller numbers than in the Quoddy region (Tufts 1986)) is being visited in some years by greatly-increased numbers of phalaropes need much more careful attention. The wintering grounds used by Red-necked Phalaropes is unknown (Cramp 1983, Duncan 1996).

"lack of plankton is likely the proximate cause of the decline in phalarope numbers"

4.6.3.3.2 Red Phalarope

Up to 1986, large flocks of Red Phalaropes *Phalaropus fulicarius* were seen regularly during autumn migration near Brier Island from mid-July to late September. Red-necked Phalaropes were always present as well, although in lesser numbers. Red Phalaropes are quite rare in the Quoddy region on the western side of the Bay where Red-necked Phalaropes were once found in large numbers (see above). Since around 1986, the mixed-species phalarope flocks at Brier Island sometimes failed to materialize, much like the collapse of Red-necked Phalarope concentrations across the Bay in New Brunswick (Brown 1991; Duncan 1996). By the 1990's, large flocks of phalaropes were again seen at Brier Island, but more irregularly than in past years. Although the exact species composition of these recent gatherings has not been investigated, there seem to be far more Red-necked Phalaropes among them than previously recorded (Brown 1991, C. Haycock pers. comm.).

Brown (1980) demonstrated that Red Phalaropes at Brier Island in autumn were most likely to be seen at upwelling "streaks" where plankton is brought to the surface. In 1990, repeats of the plankton tows made in the 1970's showed little change in the zooplankton community (Brown 1991) and thus failed to explain the differences in the numbers and species composition of the phalaropes across time. The Red Phalaropes seen in Fundy most likely overwinter among the large flocks recorded off Senegal (Cramp 1983).

4.6.4 Seaducks

4.6.4.1 Eider ducks

There are about 6800 pairs of Common Eiders (*Somateria mollissima dresseri*) breeding on islands on the New Brunswick side of the Bay of Fundy: Deer Island/Campobello Island (2,800), The Wolves archipelago (1,300) and Grand Manan (2,700). On the Nova Scotia side of the Bay, there are only about 100 pairs breeding: Five Islands (10), the Brothers Islands (9), Spencers Island (50), and Ile Haute in Minas Basin (Erskine and Smith 1986).

Once the eggs have hatched, the extensive seaweed beds from Point Lepreau to St. Andrews are used as brood rearing areas for the young (K. Mawhinney, unpublished data). Indian Point in St. Andrews and Grand Manan, New Brunswick are important overwintering areas for Common Eiders in the maritime provinces (see above and Erskine and Smith 1986). The primary food source of adult Common Eiders is the blue mussel (*Mytilus edulis*) and occasionally small rock crabs (P.W. Hicklin, unpublished).

4.6.4.2 Impacts of rockweed harvesting

Since the 1980's, commercial harvesting of rockweed on a large scale has occurred along the Nova Scotia shores of the Bay. Recently, the harvest has also begun expanding in southwestern New Brunswick. As newly-hatched eider ducklings depend extensively on invertebrates found in coastal seaweed beds, there is considerable potential for negative impacts on eider populations due to loss of these feeding grounds to ducklings prior to fledging. Research is needed to properly assess the magnitude and significance of such impacts.

4.6.5 The seabirds of Machias Seal Island

Machias Seal Island, located 20 km southwest of Grand Manan, is the most important nesting area for seabirds in the Scotian Shelf-Bay of Fundy-Gulf of Maine region (Nettleship 1973, 1977, 1980). The Government of Canada constructed and has operated a lighthouse on the island since 1832, and the Ministry of Transport has been responsible for the island since May 1912. In order to give special protection to the seabirds of Machias Seal Island, the island was declared a Federal Migratory Bird Sanctuary under the Migratory Birds Convention Act in 1944.

> ***"Machias Seal Island, 20 km southwest of the island of Grand Manan, is the most important nesting area for seabirds in the Scotian Shelf-Bay of Fundy-Gulf of Maine region"***

Approximately 900 pairs of Atlantic Puffins *Fratercula actica* nest on Machias Seal Island, along with 100 breeding pairs of Razorbills *Alca torda* and small numbers (5-20 individuals) of non-breeding Common Murres *Uria aalge*. Two Murre eggs were found on 14 July and 1 August 1994, but both failed to hatch. The Puffins and Razorbills nest among the boulders just above the overwash zone, and about 60 pairs of Leach's Storm Petrels *Oceanodroma leucorhoa* also nest in the short grasses of the island. The vegetated portion of the island is also used by about 2,000 pairs of nesting Arctic Terns *Sterna paradisaea* and 100 pairs of Common Terns *Sterna hirundo*. This is the largest colony of Arctic Terns in eastern North America (Nettleship 1980, Newell 1985).

4.7 Marine Mammals

4.7.1 Seals and seal issues (W.T. Stobo)

4.7.1.1 Background

The grey seal *Halichoerus grypus* is the most commonly seen seal between the Gulf of St. Lawrence and Cape Cod. Grey seal abundance has been increasing on the east coast of Canada and in the Gulf of Maine since the early 1960's, when the first reliable documentation of numbers was recorded (Mansfield and Beck 1977). The overall abundance in the early 1990's was estimated to be approx. 140,000 individuals (Zwanenburg and Bowen 1990). Historically, in eastern Canada, breeding colonies of grey seals have not been located in the Bay of Fundy. However, immature animals now can be seen throughout eastern Canada and the U.S., including the Bay of Fundy, during all months of the year. Mature adults and pups occupy the same areas from mid-February to December (Stobo *et al.* 1990).

Grey seals pup and breed between December and January, and their traditional pupping and breeding grounds have been located in the Southern

> ***"surveys of overall seal abundance in the Bay of Fundy, conducted in the mid-1980s to early 1990s, suggest an increase in abundance of harbor seals has occurred; an increase in abundance of grey seals was not as evident"***

Gulf of St. Lawrence and the eastern portion of the Scotian Shelf. In the Gulf of St. Lawrence they primarily use land fast ice for these activities, while on the Scotian Shelf they use several small islands off Cape Breton Island as well as Sable Island (Mansfield and Beck 1977, Boness and James 1979). About 90% of the pupping occurs on the Gulf ice and on Sable Island in roughly equal proportions. The grey seal population has been increasing at a rate of 6-12% annually since the early 1960's (Stobo and Zwanenburg 1990, Zwanenburg and Bowen 1990). Associated with this increase has been the development of a few small breeding colonies on additional islands off Cape Breton and one off Cape Cod. Although not documented, it is possible that other new breeding colonies have, or will, develop as the overall abundance of grey seals continues to increase.

"Seals have long been accused of damaging fishing gear and commercial fish catches"

The harbor seal *Phoca vitulina* is the other commonly seen seal in the Gulf of St. Lawrence to Cape Cod area (Boulva and McLaren 1979). Again it can be seen at all times of the year. Unlike the grey seal, however, the harbor seal does not congregate in a few large groups for pupping and breeding. Pups are produced in May-June in numerous small isolated breeding groups spread along the coast. The Sable Island population was arguably the largest single breeding group with a pup production in 1989 of over 600 pups (Stobo, unpubl.). The overall abundance in eastern Canada is not known. Breeding groups have been recorded in the Bay of Fundy (Kovacs *et al.* 1990) but no long-term studies have been conducted to determine permanency of such breeding areas nor abundance trends within these areas. It is quite probable that the summer increases in numbers seen in the Bay of Fundy are due to a northeast movement of harbor seals from the Gulf of Maine. Summer surveys of overall seal abundance in the Bay of Fundy, conducted in the mid-1980's to early 1990's, suggest an increase in abundance of harbor seals has occurred; an increase in abundance of grey seals was not as evident (Stobo and Fowler 1994). The work also documented both the haulout areas and the numbers of seals seen at these haulout sites for each year of the survey.

Within the Bay of Fundy, the mixture of grey and harbor seals varies with distance into the Bay and between New Brunswick and Nova Scotia. Harbor seals have predominated sightings in the upper reaches of the Bay and on the New Brunswick side. Few grey seals have been seen between Saint John and Passamaquoddy Bay. But on the islands and ledges south and southwest of Grand Manan, the proportion of grey seals has approached 50%. On the Nova Scotia side of the Bay, relatively few seals are seen east of Annapolis Basin. From Digby to Cape Seal Island, the numbers gradually increase, with the proportion of grey seals sighted being greater than harbor seals.

4.7.1.2 Seal issues

Seals have long been accused of damaging fishing gear and commercial fish catches (Anon. 1986). Although harbor seals are usually blamed, it is extremely difficult for most people to distinguish between a yearling grey seal and an adult harbor seal. Since the grey seal population has been increasing exponentially on the east coast, identifying which species is primarily responsible has not been established satisfactorily in the outer reaches of the Bay of Fundy.

The alleged interactions include damaging lobster traps, or merely opening them, in order to take lobster. Whether this is actually due to the seals predating on lobster or merely trying to obtain access to the bait bags is not well documented, but the end result is either a trap left unlatched or damaged, so that it no longer fishes successfully. Seals are also known to 'tend' gillnets, a process whereby they remove fish caught in the nets, usually damaging the nets and leaving part of the fish carcass as evidence of their actions. Occasionally seals become entangled in the nets and drown.

Of greater impact is the interaction between seals and herring weirs or aquaculture sites. In the case of herring weirs, the seals usually enter the weir through the weir mouth, and in the process of catching fish, drive some, or all, of the contained herring out of the weir. Only rarely do seals become entangled in, or damage, the weir mesh. At aquaculture sites, the seals usually enter over top of the float line and create considerable damage to the contained fish while catching prey. As well, damage frequently occurs to the cage mesh allowing large numbers of the cultured fish to escape. Another problem occurs when the seals try to catch fish through the mesh resulting in both fish and mesh damage.

As a result of these interactions, fishermen have employed a variety of techniques to discourage seals from approaching nets. This includes using acoustic devices on gear, developing gear resistant to seal attack, and killing the seals. Currently in the Bay of Fundy, aquaculture operators are allowed to kill nuisance seals by Departmental permit with the proviso that they maintain documentation on the numbers taken and collect certain morphometric information. There have been no data collected on the completeness of the reporting function. Furthermore, many fishermen are believed to carry rifles or shotguns in their boats and routinely shoot at seals near their nets, although no documentation exists to quantify this. Attempts to develop resistant gear have not been very successful. The extreme tidal flows (which will collapse the mesh bag of a cage, and forces the use of floating structures) and high primary productivity in the vicinity of such sites due to the nutrient inflow (requiring regular removal and cleaning of gear in many areas) make it difficult to universally use structures which are rigid (*e.g.* steel mesh) or heavy enough to withstand a seal attack. Site specific solutions are required, and these can become prohibitively expensive. Acoustic devices have had some success, but many problems exist pertaining to their use. One is that studies have not proved that permanent damage does not occur to the auditory system of the seals. Other studies have shown that seal quickly acclimate to the sound and in some cases the acoustic device becomes similar to a "dinner bell". In addition, there are concerns that the decibel levels used may adversely affect the hearing or movements of other marine mammals or fish in the area such as herring (on which adjacent weir sites depend).

> ***"The potential for animal rights groups to boycott fish products in response to lethal deterrents is a major concern for both government and industry"***

The negative public reaction to some industry responses to seal interactions, and the tourism value of seals in the Bay of Fundy, are also important issues. The potential for animal rights groups to boycott fish products in response to the use of lethal deterrents is a major concern for both government and industry. In southwest New Brunswick and southwest Nova Scotia, an increase in the number of sight-seeing ventures directed towards seals and cetaceans has occurred. A negative image associated with killing seals could impact the degree of development of the tourism industry. In addition, there is also potentially high tourism value in having seals frequent inshore areas.

4.7.1.3 Information needs

To evaluate the impact of seals on fisheries and their role in a changing environment, more information on specific questions is needed. The abundance and distribution of seals in the Bay has not been well established. Although several comprehensive surveys have been conducted, abundance estimates from these data are not reliable quantitatively since sources of error have not been investigated. Information is needed on seasonal utilization of the Bay and the error associated with timing of surveys around low tide, and more detailed information is needed on the degree of mixing of grey and harbor seals. The stock relationships between harbor seals seen in the Bay of Fundy and the Scotian Shelf versus Gulf of Maine are not known, but are crucial to understanding abundance trends and factors which will influence those trends. Effort is required to establish if, and where, pupping areas exist within the Bay and the magnitude of these areas. The extent of interactions with the fishing industry need to be quantified by documentation of status of the commercial activities and the impact of seals on these operations. Research is needed on the suitability of existing deterrent methods and on the development of novel devices.

4.7.2 North Atlantic Right Whales

(M.W. Brown and S.D. Kraus)

4.7.2.1 Introduction

The North Atlantic right whale (*Eubalaena glacialis*) is the most endangered large whale in the world, with no more than an estimated 350 remaining (NMFS 1991). Hunted to near extinction by 1850, right whales have been protected from commercial whaling for over 50 years, yet this population is estimated to be increasing at only 2.5% per annum (Knowlton *et al.* 1994). This is in contrast to other populations of right whales in the eastern and western South Atlantic that are increasing at 6.8% and 7.2% per annum (Best 1990, Payne *et al.* 1990).

"There are no other known locations in the western North Atlantic where such consistently large aggregations of right whales have been observed between July and early November."

The slow recovery of the North Atlantic right whale has been attributed to a number of factors, including injury and mortality from collisions with ships or entanglement in fishing gear, as well as to inbreeding depression and the loss of critical habitat areas (Kraus *et al.* 1988, Schaeff 1993). While little can be done about the last two factors, the effects of human activities on right whales are potentially manageable. An analysis of the causes of known right whale mortality from 1980 to 1990 shows that human activities along the east coast of both Canada and United States have accounted for 32% of all known right whale deaths since 1970; 20% due to collisions with vessels and 12% from entanglement in fishing gear (Kraus 1990). In Canadian waters, there have been at least two entanglement and two ship collision mortalities within the last 8 years.

The right whale is known to occur seasonally in five geographically distinct areas in the western North Atlantic, two of which are located in the waters of Atlantic Canada (Winn *et al.* 1986). Sighting data collected since 1968 show that Grand Manan Basin, in the lower Bay of Fundy (Kraus *et al.* 1982), and Roseway Basin, between Browns and Baccaro Banks on the southern Scotian Shelf (Stone *et al.* 1988), are both critical areas for right whales in the summer and fall. The Bay of Fundy functions, in part, as a right whale nursery where most of the cows bring their suckling calves. A high percentage of juveniles, as well as some adults, are also observed in this area, which represents an important summer and fall feeding ground for this species. The southern Scotian Shelf functions as a summer and fall feeding ground for a high percentage of juveniles and adults; however only five cow/calf pairs have been seen. Each year large numbers of courtship groups have been observed, ranging in size from 2-30 animals. Over 50% of the catalogued animals have been recorded in one or both of these areas annually since 1980 (Brown 1994). There are no other known locations in the western North Atlantic where such consistently large aggregations of right whales have been observed between July and early November. In fact, these two areas represent the only known locations in the world where right whales can be observed in the summer and fall.

Over the last three years, we have documented a distribution shift of right whales from the Browns-Baccaro Banks area into the Bay of Fundy. Since 1993, about 50% of the known individually identified right whales have been photographed in the Bay of Fundy, more than double the number seen annually in that one area since 1980. We would like to compare our distributional data on right whales with data on zooplankton surveys, water temperatures and currents.

"The Bay of Fundy functions, in part, as a right whale nursery where most of the cows bring their suckling calves."

4.7.2.2 Designation of conservation areas

The Canadian government through the Department of Fisheries and Oceans designated two conservation areas for right whales in the waters of Atlantic Canada in 1993. The boundaries of the right whale conservation areas were derived from sighting data collected during annual photographic surveys conducted in the Bay of Fundy and on the southern Scotian Shelf from 1980 to 1993 (Kraus and Brown 1992, Brown *et al.* 1995). These surveys were designed to systematically inventory and identify individual right whales. In the initial stages, the area boundaries were determined by drawing a box around the majority (95%) of the right whale sightings. The remaining sightings, scattered outside of the boundaries, did not have the same consistency between seasons. As more information is collected, the boundaries of these areas may need to be modified in response to seasonal shifts in right whale distribution. At the present time, the boundaries of the areas are as follows:

> ***"The designation of a conservation area for right whales in the Bay of Fundy is an inadequate measure to reduce the potential for collisions between ships and whales."***

Grand Manan Basin, lower Bay of Fundy

Northeast	44°45' x 66°18'
Southeast	44°30' x 66°18'
Northwest	44°45' x 66°35'
Southwest	44°30' x 66°35'

Roseway Basin, southern Scotian Shelf

Northeast	43°05' x 65°03'
Southeast	42°45' x 65°03'
Northwest	43°05' x 65°40'
Southwest	42°45' x 65°40'

Seasonal announcements made over Coast Guard Radio during routine Mariner's Advisories to alert shipping traffic to the presence of right whales began in June 1993, and are repeated annually during the summer and fall. Accompanying guidelines request ships to avoid areas with right whales if possible, and if not, to reduce speed and post a lookout. The Canadian Hydrographic Service has published guidelines for vessels in the Notices to Mariners and Pilotage publications and will show the boundaries of the areas on the next issue of nautical charts. A pamphlet explaining the location of the conservation areas, a physical description of what right whales look like from the bridge of a ship, and guidelines for vessel movement in or near the right whale areas has also been published (DFO 1994). This information was to be provided to ship captains leaving the harbours of Halifax, Nova Scotia and Saint John, New Brunswick as well as to all fishing boat owners and shipping companies in the Maritimes and Quebec.

4.7.2.3 Concerns

The designation of a conservation area for right whales in the Bay of Fundy is an inadequate measure to reduce the potential for collisions between ships and whales. There is no legislation in place, at either the provincial or federal level, so compliance with the existing guidelines is strictly voluntary and there is no enforcement. In conversations with Fundy Vessel Traffic, Canadian Coast Guard, Saint John, New Brunswick, we learned that many ships heading for Eastport and ports along the St. Croix river in Maine leave the shipping lanes and cut across the conservation area. We also learned that no pamphlets had been distributed by vessel pilots from that port. The guidelines, if followed, would only be effective during daylight hours in good weather.

In 1993, 1994 and 1995, the numbers of right whales identified in the Bay of Fundy were more than double the numbers seen annually from 1980 to 1992. This is a result of a distribution shift of right whales from the Browns-Baccaro Banks area of Roseway Basin into the Bay of Fundy. In our surveys of the Browns-Baccaro Banks area in 1993 and 1994, we did not see any right whales or sei whales (*Balaenoptera borealis*), a baleen whale species commonly seen in association with right whales. In 1995, 17 right whales were seen.

In previous years, 1980 to 1992, right whales typically arrived in the Bay of Fundy in late July and departed by mid-October. From 1993 to 1995, right whales starting arriving in June and the last sighting occurred in mid-to late December (Laurie Murison, pers. comm.). The shift in distribution and the increased length of seasonal residency in the Bay of Fundy is coupled with a decrease in the mean annual calving rate of right whales from 11.5 calves per year from 1980 to 1992 (Knowlton *et al.* 1994), to 6 calves per year from 1993 to 1995.

4.7.2.4 New initiatives

In September of 1995, we met with Fundy Vessel Traffic Control in Saint John, New Brunswick to investigate the possibility of reporting the locations of right whale concentrations to their office so that they could pass this information on to vessels transitting the Bay of Fundy. They agreed to do so, but this is only effective during our research season (August and September) and during daylight hours on good weather days.

We are investigating the possibility of using acoustics as an alternative monitoring method to determine if there is a correlation between the numbers of sounds made by right whales and the numbers of right whales present, thus providing data on distribution, seasonality and relative abundance.

4.7.2.5 History of the right whale research project in the Bay

The New England Aquarium began research on right whales in the Bay of Fundy in 1980 and has conducted annual surveys in August, September and early October each year. In addition to sightings and photographic identifications of right whales, we also curate an extensive sightings database on all whales, dolphins, porpoises, sharks and tuna seen between 1980 and 1995.

> ***"many ships heading for Eastport and ports along the St. Croix river in Maine leave the shipping lanes and cut across the conservation area"***

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CHAPTER FIVE

MARINE RESOURCES OF THE BAY OF FUNDY

J.A. Percy

5.1 Introduction

The marine resources of the Bay of Fundy have long been the economic mainstay of its coastal communities. These resources have been inventoried on a number of occasions (MacKay *et al.* 1978, Hanson 1982), and the fisheries and ecology of the more important species were reviewed as part of the assessment of impacts of proposed tidal power developments (Dadswell *et al.* 1984, Gordon and Dadswell 1984, Plant 1985). These reviews revealed that the richest and most diverse fisheries are found at the Bay's western end where it opens into the Gulf of Maine. Nevertheless, the macrotidal embayments of the middle and upper Bay are also productive and are occupied in summer by at least 54 species of fish, of which 24 are commercially fished, either in the Bay of Fundy or elsewhere along the Atlantic seaboard (Dadswell and Rulifson 1994). In the Bay as a whole, crustaceans and shellfish, chiefly lobsters, scallops and clams, constitute the most valuable fisheries.

Recent precipitous declines in several traditional fisheries have stimulated a growing interest in the harvest of many species virtually ignored thus far, and have also catalyzed the growth of aquaculture operations in a number of coastal areas. In a few instances, notably salmon and mussels, aquacultural production has already supplanted the commercial wild harvest in terms of value, and there is speculation that many other traditionally fished species may soon be farmed on a large scale. In many areas, the recreational fishery has for a long time been important to the local economy, and for some species, most notably salmon, it has outstripped the commercial fishery in terms of economic value. However, most recreational fisheries have also been in serious decline for many decades as a consequence of overexploitation and habitat deterioration and loss. Strenuous efforts are now being made to reverse these declines by enhancing habitats and restocking populations in many rivers and estuaries, as well as by encouraging the expansion of the sport fishery to encompass other marine species (ASE and CFC Consultants 1993).

A wide range of other human activities, coupled with various poorly known, long-term "natural" environmental fluctuations, also influence marine and diadromous populations and their habitats throughout the Bay of Fundy. Some of the more worrisome of these stresses that influence not just the Bay, but the entire Scotia-Fundy region, have been reviewed recently by Harding (1992a). Several other stresses that are largely localized within the Bay and that further exacerbate the wider regional impacts are discussed more fully below.

This chapter focuses primarily on the major marine resource species, emphasizing recent trends in populations, significant environmental or developmental issues affecting commercial stocks and recent research results. It also briefly reviews recent developments in the rapidly expanding aquaculture industry in the Bay. Table 5.1 provides an overview of the principal harvested species of plants and animals within the Bay. Their actual or potential roles in the commercial (com) and recreational (rec) fisheries and the likelihood of them being farmed on a significant scale (aqua) is indicated as follows. A closed circle (●) indicates that a significant fishery (or aquaculture operation) of the designated type exists at present. An open circle (○) indicates that a significant fishery existed at one time, and could possibly be restored if stocks were able to rebuild, or that there is a potential for developing a fishery for species little harvested in the past, or that the species is being seriously considered as a suitable candidate for

Table 5.1 Marine resource species of the Bay of Fundy and their status *[see text for a description of table headings and symbols]*

			Fishery			Stock	
Group	**Common name**	**Scientific name**	**Com.**	**Rec.**	**Aqua.**	**Stat.**	**Know.**
PELAGIC	Atlantic herring	*Clupea harengus*	●			++++	+++
	Bluefin tuna	*Thunnus thynnus*					
	Swordfish	*Xiphias gladius*					
	Mackerel	*Scomber scombrus*	●			+++	++
DEMERSAL	Atlantic cod	*Gadus morhua*	●	○	○	++	+++
	Haddock	*Melanogrammus aeglefinus*	●	○	○	++	+++
	Pollock	*pollachius virens*	●			+++	++
	Winter flounder	*Pseudopleuronectes americanus*	●			++	++
	Spiny dogfish	*Squalus acanthius*	○	○			+
	Lumpfish	*Cyclopterus lumpus*	○			+++	+
ANACATS	Shad	*Alosa sapidissima*	○	●		++	++
	Atlantic salmon	*salmo salar*	○	●	●	+	+++
	Striped bass	*Morone saxatilis*	○	●	○	++	+++
	Alewife	*Alosa pseudoharengus*	○	●		++	++
	Blueback herring	*Alosa aestivalis*	○	○		++	++
	Atlantic sturgeon	*Acipenser oxyrhyncus*		○		+	+
	American eel	*Anguilla rostrata*	●		○	++++	++
	Smelt	*Osmerus mordax*		●		+++	++
CRUSTACEANS	Lobster	*Homarus americanus*	●		○	++++	+++
MOLLUSCS	Sea scallop	*Placopecten magellanicus*	●		●	++++	+++
	Soft-shell clam	*Mya arenaria*	●	●		+++	+++
	Blue mussel	*Mytilus edulis*	○		●	++++	++
	Periwinkle	*Littorina spp.*	●			++++	+
ECHINODERMS	Green sea urchin	*Strongylocentrotus droebachiensis*	●		○	++++	+
	sea cucumber	*Cucumaria frondosa*	○			++++	+
POLYCHAETES	Bloodworm	*Glycera dibranchiata*	●			+++	+
	Sandworm	*Arenicola spp.*	●			+++	+
	Clamworm	*Nereis virens*	●			+++	+
SEAWEEDS	Dulse	*Palmeria palmata*	●			+++	++
	Irish moss	*Chondrus crispus*	●		○	+++	++
	Knotted wrack	*Ascophyllum nodosum*	●			+++	+

large scale aquaculture. The general status (stat) of the stock is indicated as follows: ++++ stock healthy; +++ stock reduced below optimum levels; ++ stock depleted to a significant degree; + stock severely depleted. Similarly, plus signs are used to somewhat subjectively indicate our level of knowledge about the biology and ecology of the species in the Bay, with + indicating little or no information available, ++ indicating that some research has been carried out and +++ indicating that the species has been the focus of considerable research or monitoring.

5.2 Status Of marine resources

5.2.1 Pelagic fish

The high primary productivity in the outer Bay goes largely to support secondary production within the water column, and thus contributes to the prolific pelagic fisheries in the region (Emerson *et al.* 1986). The most important of these fisheries are for Atlantic herring and mackerel. There is also a very small harvest of pelagic sharks. Although swordfish and tuna sustain important fisheries in nearby waters off southwestern Nova Scotia, they are not fished to any significant extent in the Bay of Fundy itself (Julie Porter, pers. comm). Swordfish seldom, if ever, enter the Bay, while only the occasional tuna is trapped in herring weirs near Grand Manan. There is little reliable information about the abundance of either species within the Bay, but they are generally assumed to be scarce.

Atlantic herring: The herring fishery has been important in the Bay of Fundy for many generations and it is part of one of the world's largest herring fisheries. The early literature pertaining to the fishery and the general ecology of herring have been comprehensively reviewed by Leim (1956) and Iles (1979). Within the Fundy region there are spatially distinct, seasonally varying, discrete patterns of distribution of different life history stages related to adult overwintering, summer feeding and spawning and larval distributions (Sinclair and Iles 1985). Several distinct populations, spawning at different times and places, occur in the region (DFO 1994b). One group, spawning in spring in the upper Bay, has been the subject of a number of recent studies (Bradford and Iles 1992, 1993). A summer spawning group also occurs in Scots Bay. Larger numbers usually spawn in the fall at the mouth of the Bay off Yarmouth. There is another discrete fall spawning population to the west of Grand Manan Island (Chenoweth *et al.* 1989). These annual spawning migrations sustain a lucrative roe fishery in the summer and fall, with the processing wastes largely being used in aquaculture feed in recent years. The large aggregations of juvenile herring that migrate into the lower Bay in spring, form the mainstay of the valuable New Brunswick sardine fishery (Ahrens 1990). Hydrographic and behavioural factors are important in influencing the retention of larvae in the vicinity of spawning areas, as well as in the subsequent dispersal of juveniles, and have been intensively studied in various parts of the Bay (Stephenson and Power 1988, 1989a, Chenoweth *et al.* 1989, Stephenson 1993, Bradford and Iles 1993). Knowledge about stock structure and movement of adults is largely based on tagging studies carried out in the 1970's (Stobo 1982, 1983) and more recently on computer simulations used to predict local movements of juveniles (Jovellanos and Gaskin 1983). However, recent puzzling population and distribution changes suggest that further tagging studies are required for continued effective management (Gary Melvin, pers. comm). A tagging program was launched on Georges Bank in 1993 and there are currently plans to expand the program into the Bay of Fundy itself (Gary Melvin, pers. comm.).

The Gulf of Maine/Bay of Fundy herring stocks have been assessed annually for at least 25 years, by extensive larval surveys that monitor spawning intensity as well as by sampling of commercial landings (Iles *et al.* 1985, Stephenson *et al.* 1986, 1989a,b, 1990a,b, Stephenson and Power 1989a,b,c, Hunt 1987, Power and Stephenson 1990). Increasingly, sophisticated hydroacoustic techniques are being used to assess herring stocks more directly (Buerkle 1989, 1990). The high resolution equipment now available can count individual fish, and the chief limitations on assessment effectiveness now appear to be the statistical design of adequate sampling programs for a patchily distributed and highly mobile stock, and regular, timely access to suitably equipped survey vessels (Gary Melvin, pers. comm). Recently, the commercial herring fleet itself has also become more directly involved in stock surveys and biological and oceanographic data collection.

These annual stock surveys provide a credible overview of the fluctuations in herring populations in the Bay of Fundy region over the last few decades. Landings peaked in the late 1960's and early 1970's before declining sharply (DFO 1994b), probably because of overfishing and poor recruitment under adverse environmental conditions (Ahrens 1990). During the early '90's stocks largely recovered, with indications of much higher spawning levels than during the preceding two decades (DFO 1994b). However, larval surveys in the fall of 1994 revealed that spawning stock biomass was once again severely depressed. This resulted in a major reduction in the TAC (total allowable catch) for the 1995 fishing season (Gary Melvin, pers. comm). Interestingly, in 1994 fish processing plants in the region also reported that the fat content of the herring landed was the lowest ever observed. The causes of this anomaly are not readily apparent, although zooplankton data routinely collected in conjunction with the larval surveys may provide some information about the possible role of food availability. The fat levels appeared to have returned to normal during 1995. However, there are indications that the migratory behaviour and distribution of the fish has altered in recent years and that they are not showing up in traditional areas (Gary Melvin, pers. comm.), possibly reflecting a population response to long-term hydrographic changes in the region.

> ***"the migratory behaviour and distribution of the [herring] has altered in recent years and that they are not showing up in traditional areas possibly reflecting a population response to long-term hydrographic changes in the region."***

Continued effective management of herring stocks requires a better understanding of the biological and environmental factors influencing recruitment variability, particularly during the juvenile stage (Stephenson 1993). More information is also needed about their complex predator/prey interactions with other species, particularly in light of the important role of herring as food of other valuable commercial fish. This trophic interaction has provided the rationale for recent growing demands by some fishermen for significant reductions in herring quotas as an important means of rebuilding decimated groundfish populations (Gary Melvin, pers. comm.).

Mackerel: Mackerel spawn in two principal areas on the eastern seaboard; just south of Cape Cod and in the southern Gulf of St. Lawrence (Sette 1950, MacKay 1967). Their extensive coastal migrations, to and from wintering grounds off Long Island, bring large numbers into Scotia-Fundy waters. However, the Canadian fishery, particularly in the Bay of Fundy, has always been relatively small (Stobo and Hunt 1974, Stobo *et al.* 1982), largely because of low market demand and high harvesting costs (DFO 1994b). The present Canadian fishery takes only about 20% of the biomass that could be fished sustainably. The fishery has traditionally been an inshore one, using fish traps and gillnets and with most of the catch serving as lobster and fish bait. There are growing efforts to greatly expand the fishery by opening it to seiners, initially on an exploratory basis, and by promoting the marketing of the fish to the general public. Harvests have been stable for many years and indications are that the stocks continue to be healthy. However, any substantial expansion of the fishery, such as that contemplated, will have to monitored very carefully to ensure long-term sustainability.

Pelagic sharks: Several species of large sharks occur regularly in the Bay, although information about numbers, distribution and general ecology is sparse for most of them. Available evidence indicates that most species are very low in abundance (Peter Hurley, pers. comm.). Some are occasionally caught incidentally by other fisheries, particularly herring weirs. Most are principally warm tropical species nearing the northern limits of their range in the Gulf of Maine-Bay of Fundy region.

Species that have been sighted include white, blue, short-finned mako, smooth hammerhead, thresher and basking sharks. A basking shark was even reported in the Minas Basin off Wolfville in the late 1980's. A notable exception is the mackerel shark or porbeagle, a cold temperate species which is the most common pelagic shark in the region, and the only one present in sufficient numbers to sustain a small (10 MT annually) directed, seasonal fishery, centered in the Grand Manan area (M. Dadswell, pers. comm.). The current population numbers and seasonality of occurrence of this species don't appear to allow much scope for further expansion of this fishery.

5.2.2 Demersal fish

Groundfish stocks in the Scotia-Fundy region are assessed annually by random stratified surveys with standardized bottom trawl gear. These surveys provide information about the abundance, distribution and general biology of the finfish and invertebrate species collected, as well as their relationship to oceanographic factors (Page *et al.* 1994). In addition, commercial landings are routinely monitored and various samples are taken to provide additional information about the status of the stocks. The information available usually encompasses the whole SW Nova Scotia region (NAFO Division 4VWX), although occasionally a breakdown is provided for Browns Bank/Bay of Fundy (Division 4X). These surveys provide a wealth of information about community structure, stock status, geographic distribution and seasonal movements of many demersal species (Scott 1971, Simon and Comeau 1994).

> ***"groundfish stocks were relatively stable through the 1970-1984 period, although there were indications that some stocks were being overexploited. During the ensuing decade, groundfish stocks .... experienced an unprecedented collapse."***

Matrix analysis of trawl survey data collected between 1970 and 1984 revealed three categories of association within the region: a shallow water group dominated by winter flounder, long-horn sculpin and sea raven; a mid-depth group with a dominant cod, haddock, thorny skate assemblage and a deeper water grouping of species with no strong recurring assemblages (Scott 1987, 1989). The Bay of Fundy was distinctive in having a significant association of shallow-water species and a low representation of deeper water species. The data revealed that in the Bay the distributions of the various species are strongly aligned with the physical environment, and tend to be consistent through time (Mahon *et al.* 1984). Analysis of the distribution of the abundant species in different seasons revealed a general withdrawal from the Bay and coastal shelf by spring, presumably in response to changing water temperatures (Scott 1988). A similar progressive seaward displacement of demersal assemblages in winter, and a reversal in summer, was also observed in studies in the lower Bay of Fundy area (MacDonald *et al.* 1985). For the most part, groundfish stocks were relatively stable through the 1970-1984 period, although there were indications that some stocks were being overexploited (Campana and Simon 1984). During the ensuing decade, groundfish stocks throughout the Scotia-Fundy region, and much of the northwest Atlantic, experienced an unprecedented collapse. Although overfishing has been widely recognized as an important contributory factor in the collapse, it is also generally conceded that a variety of environmental factors probably also played significant roles (Frank *et al.* 1994). It is not yet clear whether subsequent stringent conservation measures have allowed most stocks to rebuild to any significant degree, although there have been encouraging signs for some species.

Atlantic cod: Cod stocks in NAFO Division 4X are assessed annually, using information from trawl surveys and from the commercial fishery (Campana and Hamel 1992, Hanke 1993, Gavaris 1993, Chang 1994). It is generally agreed that there are a number of distinct stocks within this management region, including a separate one in the western half of the Bay of Fundy (Hunt and Neilson 1993). Although ichthyoplankton sampling indicates spawning in the western Bay, tagging studies reveal considerable exchange between the populations of the east and west sides of the

Bay. The 1970-84 surveys indicated that cod abundance in the waters of SW Nova Scotia was relatively stable throughout this period, although a longer-term trend of gradual population increase in the Bay appeared to have leveled off (Campana and Simon 1984). It was recognized at the time that the cod stocks were probably being overexploited, particularly in the Bay of Fundy. In recent years there has been a precipitous decline in cod populations to alarmingly low levels, raising concerns about the ability of these stocks to recover. This collapse has resulted in the imposition of a virtually total ban on fishing of this, and several other groundfish species, and stimulated intensive efforts to determine the cause of the collapse, to enhance population recovery and to improve management of the stocks in the future. As part of the research effort, cod broodstock have been raised at the Biological Station in St. Andrews in order to evaluate the effects of factors such as age, reproductive history and condition of spawners on fecundity, egg quality, fertilization success and survival (Trippel and Neilson 1992, Chang, 1994). In addition, food resource allocation and diet overlap among several demersal species, including cod and winter flounder, in relation to benthic community structure and sediment composition have been studied, particularly in the Passamaquoddy region (MacDonald and Green 1986). Other studies have examined the feeding behaviour of cod at low temperatures (Waiwood *et al.* 1991). Much of the current research is oriented towards east coast cod stocks in general rather than those of the Bay of Fundy specifically.

Halibut: The research and monitoring of this species being carried out by scientists at St. Andrews is largely focused on the populations of Georges Bank and is primarily stock management oriented (Neilson and Bowering 1989). Halibut are not common in the Bay of Fundy; those found in the lower reaches of the Bay are associated with populations on the outer Scotian Shelf (Stobo *et al.* 1988). Recently, however, attention has been directed to the feasibility of raising halibut in captivity, stimulating further research on its reproduction (Neilson *et al.* 1993) and other aspects of its general biology and ecology (Waiwood 1992). Some of this work is discussed more fully in the aquaculture section below.

Haddock: A substantial fishery for haddock has long been prosecuted in the lower reaches of the Bay, particularly in the St. Mary's Bay area and off Digby (McCracken 1960, Halliday and McCracken 1970). The populations in SW Nova Scotia have been routinely monitored during the annual groundfish surveys (Chang 1994) and by sampling of the commercial fishery, with most of the emphasis being on Georges Bank stocks. The age composition of these populations are also periodically assessed by otolith analysis for stock assessment purposes. Over the past decade there has been a sharp decline in haddock abundance throughout the region to the lowest levels ever observed, paralleling the situation of the cod stocks. In recent years, scientists at the St. Andrews Biological Station have also been studying various aspects of haddock biology and culture in support of possible commercial aquaculture of the species (Chang 1994).

Pollock: Annual assessments for pollock are carried out in NAFO zone 4VWX which includes the Bay of Fundy, to provide information for the effective management of the stocks (Annand and Beanlands 1992, Trippel and Brown 1993). In addition, there has been a commercial fishery-based estimate of pollock abundance in the area (Hanke 1993). There used to be a fairly large fishery for pollock in the Minas Channel. There was a pronounced increase in fishing efforts for this species by Canadian fleets after 1977 (Chang 1994). Stocks of adult fish in this region have been depleted during the past few years although there was some indication of a promising year class recruitment in 1994/95 (Chang 1994). The importance of coastal rockweed habitats as nursery areas for pollock is discussed more fully below.

Winter flounder: Winter flounder stocks in the waters of SW Nova Scotia are also assessed annually for management purposes. After reaching a peak in 1990, landings declined sharply during the next few years, along with those of most other groundfish stocks. In the early 1990's a collaborative project, involving DFO, the University of NB and the fishing industry, was launched to gather basic biological and ecological information about the stock in this area. Up to 12 years ago there was a sufficiently large winter flounder population in the Minas Basin to support a sustainable small-scale local fishery (Graham Daborn, pers. comm.). At about that time, large draggers, having fished out flounder stocks in St. Mary's Bay moved up into Minas Basin to prosecute an intensive fishery. Unlike the smaller local vessels these draggers were able to fish continuously at all stages of the tide and used much larger, heavier gear that scoured larger areas of bottom. In consequence of this overharvesting there is now not much of a demersal fishery left in Minas Basin and winter flounder appear to be few in number.

Spiny dogfish: The migratory spiny dogfish occurs from Labrador to Florida and is abundant between Cape Hatteras and Nova Scotia. It migrates northward along the shelf in spring from southern, offshore wintering areas. Dogfish appear to have an annual migration through the Bay of Fundy similar to that of the shad (Dadswell *et al.* 1984, Dadswell and Rulifson 1994), appearing on the Nova Scotia side of the Bay in the spring, becoming very abundant in the upper Bay during June, July and August and moving out past the New Brunswick shore in the fall. The population of the North Atlantic is generally considered to be a single stock unit. This is the only shark species present in the Bay that is considered capable of sustaining an expanded directed fishery. The apparent abundance of large females in the upper Bay may be an artifact of previous sampling methods (M. Dadswell, pers. comm.). At times dogfish are so abundant in the Bay that groundfish fishermen have to remove their gear from the water to avoid damage (M. Dadswell, pers.comm.). It has long been considered a nuisance by-catch species by local fishermen, and thus is generally killed and dumped. However, foreign fleets have harvested dogfish commercially in the Scotia Fundy region for several decades. These landings increased dramatically in the early 1970's, largely reflecting an intensified fishing effort (DFO 1995). However, landings declined to very low levels by 1978 and remained low but stable throughout the 1980's, before increasing sharply in the early 1990's, coincident with the collapse of the groundfishery throughout the region. A small directed Canadian fishery, mostly employing fixed gear, has existed only since 1987. The information about dogfish populations is considerably better than that for other sharks, because dogfish are assessed regularly as part of the annual groundfish surveys in the Scotia Fundy Region (Peter Hurley, pers. comm.). Most of the available population data for the Atlantic seaboard is being used by the U.S. Bureau of Marine Fisheries to develop a regional stock assessment model. The data indicate that at present the dogfish biomass in the region is high and there are growing pressures for an expansion of this fishery, to compensate in part for the downturn in other fisheries. There is considerable speculation, but no firm evidence, that the current elevated dogfish populations are somehow linked to the drastic declines in most of the groundfish stocks in the region. The U.S. stock assessment figures indicate that the dogfish populations of the eastern seaboard may be close to being fully exploited. There are thus growing concerns about the possibility of overexploitation, particularly given that the animals are relatively long-lived, slow growing and have a very low reproductive capacity. In addition, a high proportion of larger females are taken in the U.S. fishery. There is also uncertainty about the impact on the population of the apparently high but thus far unquantified number of discards of dogfish collected during other fisheries. Until such time as substantially more information is available about the stock, DFO has adopted a conservative approach to further development of both the commercial and recreational fishery for sharks in the Scotia Fundy region. A graduate student at Acadia University recently began research on the dogfish population in the Bay of Fundy (M. Dadswell, pers. comm.) and further information about these

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stocks should be available in the near future.

5.2.3 Diadromous fish

In addition to the diverse array of marine fish species that frequent the Bay of Fundy, several anadromous and catadromous species may also be abundant in summer during their annual coastal migrations to and from the estuaries and rivers of the Bay and other regions of the Atlantic coast. The more important species comprising this large migratory assemblage include Alewife (*Alosa pseudoharengus*), Blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), Atlantic herring (*Clupea harengus*), Atlantic salmon (*Salmo salar)*, Striped bass (*Morone saxatilis*), Atlantic Sturgeon (*Acipenser oxyrhyncus*) (Dadswell and Rulifson 1994) as well as American eel (*Anguilla americanus*), Tomcod (*Microgadus tomcod*), and American (rainbow) smelt (*Osmerus mordax*).

> ***"DFO has adopted a conservative approach to further development of both the commercial and recreational fishery for sharks in the Scotia Fundy region."***

Alosids: (alewife, blueback herring, American shad): The Alosids received considerable attention during the 1980's when tidal power research was at its height, but little additional work has been done in recent years. The earlier research largely concentrated on the occurrence of populations in the upper Bay as well as on their migration and feeding, and did much to increase the knowledge about these species (Dadswell *et al.*, 1984, Stone and Daborn 1987, Rulifson 1994). Recent work has largely been confined to the Annapolis River and has primarily been concerned with the effects of fish passage through the turbines of the tidal power station (Stokesbury and Dadswell 1991, Gibson and Daborn 1993, 1995a, b, M. Dadswell, pers. comm.). Shad populations have declined greatly throughout the Fundy region since about 1990 (Brian Jessop, pers. comm. to G. Daborn) with both numbers and age structure dropping considerably. Such population changes in the Annapolis Estuary have often been attributed to size-selective turbine mortality at the tidal power plant (Gibson and Daborn 1995b). However, there appears to have been a similar decline in the abundance and mean size at age of shad populations in many rivers along the eastern seaboard (Flagg 1994). In some U.S. rivers there was a reduction in mean size of 5-10% between mid 1980's and mid 1990's. This indication that the decline is occurring throughout the shad's range suggest that a variety of factors are probably implicated. Changes in oceanographic conditions in nursery areas, altered predation or competition because of reduced fishing efforts on predators and competitors and depletion of other fish stocks have all been suggested. In order to manage alosid populations effectively a great deal more information is required about their annual migrations, particularly in relation to the roles of chance, hydrographic conditions, topography and residual currents in determining migration routes (Dadswell *et al.* 1987).

Atlantic salmon: The wild Atlantic salmon has, of late, fallen on hard times. Salmon landings declined drastically in 1969 and by 1972 the sport fishery had surpassed the commercial fishery in terms of catch. In recent years, adult escapements to all rivers in the Bay of Fundy sampled by DFO has been at an all time low (Cutting *et al.* 1994). Since 1990 all upper Bay of Fundy rivers have been closed to exploitation, including angling. It might have been expected that the lack of exploitation since 1990 in all the rivers, the curtailment of the Newfoundland and Greenland commercial fisheries and various enhancement projects and stocking programs would have caused the salmon populations to increase by now. But this has not been the case and further research is urgently needed to clarify the situation.

> ***"Shad populations have declined greatly throughout the Fundy region since about 1990.......... with both numbers and age structure dropping considerably"***

Striped bass: Striped bass have long been an important commercial and recreational species along the American eastern seaboard, but less so in the Atlantic provinces, where commercial fishery landings usually ranked at least 2 orders of magnitude lower. Since the 1930's annual landings in the Maritimes have been sporadic and erratic, usually totaling less than 50 metric tons. In the Bay of Fundy the fishery was concentrated in two principal areas, with the St. John River Estuary largely supporting a directed fishery and the inner Bay area chiefly involving a by-catch from the gill net and weir fishery for shad (Rulifson and Dadswell 1995). Both these landings declined sharply after 1970 and the fishery was finally closed in 1978. The phenomenon was not restricted to the Bay of Fundy, as U.S. landings also declined markedly after 1980, while the St. Lawrence River stock had essentially disappeared as early as 1966 (Rulifson and Dadswell 1995), seemingly largely a consequence of pollution (M. Dadswell, pers. comm.).

The biology and life history of the species in eastern Canada have been reviewed by Melvin (1991), while recent research has been summarized by Rulifson and Dadswell (1995). In addition, striped bass biology, the history of the fishery and its management in the Bay of Fundy as well as the research programs undertaken by DFO at the St. Andrews Biological Station have all been reviewed by Jessop (1991) and Peterson (1991). The feeding habits of the species in the upper Bay have also been studied by Rulifson and McKenna (1987). The bass undertake extensive coastal migrations before and after spawning in brackish or fresh water areas in spring. Rivers in the Fundy region thought to have significant spawning populations include the Saint John, Annapolis, Shubenacadie and Stewiacke rivers (Rulifson and Dadswell 1995). Only the population in the last river has been adequately studied (Jessop and Vithayasai 1979). In the Annapolis River the construction of a causeway in the early 1960's, resulted in serious degradation of bass spawning areas, while the subsequent installation of a tidal power plant in the early 1980's has caused high mortalities during migration. Since the mid 1970's there has been a decrease in population abundance as well as in the age and size structure, comprising a clear trend to increasing proportions of older/larger fish (Rulifson and Dadswell 1995).

In spite of the previous commercial fishery, and studies spanning at least 20 years, striped bass remain one of the more poorly known fishes occurring in the Bay of Fundy. Much research remains to be done, as their life history and movements in the Bay are complex and largely unresolved. The location and success of spawning is still an open question for most rivers with populations. Tagging, parasite, genetic and meristic studies indicate that the Fundy population mixes extensively with U.S. populations in most years, with the degree of mixing probably influenced by varying water temperature regimes in different areas. (Rulifson and Dadswell 1995). There is a need for more intensive tagging studies to properly characterize the different populations and their interactions (Rulifson and Dadswell 1995).

Atlantic sturgeon: Atlantic sturgeon occur throughout the Bay of Fundy, but are most common in the Minas Basin during summer and in the Saint John River. The Saint John is the only river which has documented spawning of this species, but captures of juveniles and the occurrence of dead ripe females below the Annapolis tidal dam indicate that there is probably a spawning population in the Annapolis River. The occurrence of large numbers of Atlantic sturgeon in the Minas Basin during summer begs further study. It is possible that these are fish from the entire east coast of North America participating in an annual northward migration during summer (M. Dadswell, pers. comm.). Fishermen in West Hants report that Sturgeon are no longer entering the Avon River, although 10-15 years ago they were quite abundant and large ones were commonly caught (Alison Evans, pers. comm.).

American eel: Eel populations in New Brunswick rivers appear to be generally healthy at present, and in some rivers they are the dominant fish biomass (Dick Peterson, pers. comm.). There is a fishery for adult eels as well as for elvers. These latter are mostly shipped to Europe or Asia for use in aquaculture. Prior to the establishment of the causeway and tidal power plant there was a small scale commercial eel fishery on the Annapolis River. This fishery virtually collapsed soon after. Efforts are now being made to restart the fishery, but there appears to be little recent information about the status of the eel populations in the river.

Tomcod: In addition to a small scale commercial catch in the NW Atlantic, the spawning aggregations of these small fish in many Fundy rivers have been the basis for a significant recreational ice fishery. A detailed study of the biology and ecology of tomcod carried out in Frostfish Creek on the Digdeguash estuary in Passamaquoddy Bay demonstrated how closely its early life history is adapted to the seasonal hydrodynamics of the streams where it spawns (Peterson *et al.* 1980). It is notable that contrary to the situation prevailing at the time of this study, recent examinations of the populations in the same area during the past three years have failed to find any evidence of spawning (Dick Peterson, pers. comm.). There is no evident explanation for this, although it may not be due to local conditions, as a similar phenomenon has been reported for smelt and tomcod in some New England rivers. It is not known if this change has occurred in other Fundy rivers or not. As this is not a priority species, little monitoring or research is taking place.

American smelt: The American smelt (*Osmerus mordax*) is one of most common anadromous fish along the eastern seaboard and is largely restricted to shallow inshore waters. Smelt are an important component of the ecosystem in the upper Bay (Dadswell *et al.* 1984). However, the commercial value of the fishery has declined significantly over past 25 years and there has been only a limited commercial fishery in the Bay since the mid 1960's (Caddy and Chandler 1976). Nevertheless, there exists a small but active recreational fishery for smelt in various parts of the region, focused primarily on the spawning runs into freshwater in spring. In the lower Bay large catches have come from the Saint John and Tusket rivers (Jessop 1993), while in the Minas Basin the Stewiacke, Shubenacadie and Gaspereau Rivers have traditionally had important spawning runs of smelt that were harvested by dip netting and angling (Caddy and Chandler 1976). Although catch statistics are poor, and spatial and temporal variability are high, indications are that most populations have declined markedly since the mid 1960's, although there was a short-lived increase in the catch in New Brunswick rivers in the late 1980's (Jessop 1993). DFO surveys have found that an increasing number of smelt with tumours are appearing in the Parrsboro area. Analysis has revealed the presence of a herpes-like virus that may be a causative agent, although research into this is ongoing (BIO 1995b).

5.2.4 Invertebrates and marine plants

In terms of landed value, marine invertebrates, primarily lobsters, scallops and soft-shell clams form the core of the Bay of Fundy fishing industry. In recent years, particularly following the collapse of the traditional groundfishery there have been increasing efforts to identify, and enhance commercial harvesting of a variety of so-called "underutilized species" (DFO 1990b, c), including crabs, mussels, periwinkles, sea urchins, sea cucumbers, polychaetes and rockweed. However, many of these initiatives have been hampered by a need to foster new markets and to develop more economical and effective harvesting methods (DFO 1994a).

Lobster: The lobster fishery is one of the most valuable in the Bay of Fundy region, being conducted most intensively in the outer Bay, off SW Nova Scotia in the Yarmouth-Digby area, and in SW New Brunswick. (Campbell 1989a, DFO 1994a). In these areas landings rose sharply during the 1980's, reaching the highest levels of the past 90 years (Williamson 1992). This increase has been attributed to a combination of more effective management policies and unusually favourable environmental conditions for lobster reproduction and growth in the region (DFO 1994a). The harvest appears to have remained relatively stable during the past decade (Chang 1994). Although the lobster fishery in the upper Bay accounts for less than 10% of that in the whole Bay, it is thought that Chignecto Bay may be an important spawning area for larval recruitment downstream in the Bay (Campbell 1984).

Because of its economic importance, lobsters have long been an important focus for research at DFO's St. Andrews Biological Station. Much of this effort has been devoted to discrimination and assessment of stocks (Campbell and Robinson 1983, Miller *et al.* 1987, Waddy and Aiken 1990b, Harding *et al.* 1993, Pezzack 1994), monitoring of egg production (Campbell and Pezzack 1986) and identifying key breeding areas (Campbell 1990, Lawton and Robichaud 1990, 1991, Campbell 1992) in order to develop effective management strategies with respect to size limits, quotas, harvest season and fishing effort (Lawton and Robichaud 1992a, Chang 1994). Other studies have investigated almost all aspects of the animal's biology and ecology (Lawton and Robichaud 1992b) in an effort to better understand their environmental requirements and the influence of natural and anthropogenic factors on fluctuations in lobster populations (Harding 1992b). These have included studies on growth (Campbell 1983, Robichaud and Campbell 1991), size at maturity (Waddy and Aiken 1990b), mortality, recruitment (Campbell 1985), adult and larval migration (Campbell and Stasko 1986, Campbell 1989b, Lawton and Robichaud 1993a,b), environmental control of reproduction (Campbell and Robinson 1983, Aiken and Waddy 1989, 1990, Waddy and Aiken 1989a,c, 1990a, 1991a, 1992a,b), factors affecting survival of post-larvae and juveniles and regulation of molting (Waddy and Aiken 1989b, 1991c, Waddy *et al.* 1990, Aiken and Waddy 1991). Recently, there has been particular concern expressed about the potential impacts of salmonid aquaculture on lobster populations, both in SW New Brunswick and in the Annapolis Basin, resulting in increased efforts to identify areas of potential conflict (Lawton 1992, 1993, Lawton *et al.* 1995). Studies have indicated that lobsters tend to avoid bottom areas heavily contaminated by fish farm wastes and there is concern that this may interfere with lobster migrations in some areas.

> ***"In terms of landed value, marine invertebrates, primarily lobsters, scallops and soft-shell clams form the core of the Bay of Fundy fishing industry."***

Scallop: The scallop fishery is another of the important fisheries in the Bay of Fundy. The history of the fishery and the biology of scallop stocks in the region have been reviewed in DFO (1986). The fishery is prosecuted offshore on various banks as well as inshore, particularly near Digby (Robert *et al.* 1984, Sinclair *et al.* 1985, Kenchington and Lundy 1993b, Kenchington *et al.* 1995). The history of the scallop fishery in the Annapolis Basin and the status of the stock have also recently been reviewed (Kenchington and Lundy 1994). A baseline survey of stocks in the Minas Basin, that were historically fished on a relatively small-scale, was also carried out in response to growing fishing pressures in the area (Chandler *et al.* 1989).

Scallop populations fluctuate markedly because of variable survival of young in response to changes in climate, food, predators and disease. The fishery reached a low point in the mid 1980's, but steadily increased from 835 tons in 1986 to over 4500 tons in 1989, largely as the result of particularly strong year classes in 1984 and 1985. Catches then declined and stabilized near pre-peak levels. This stabilization was largely attributed to improved management policies that attempted to set harvest levels in accordance with long-term mean population size rather than with periodic population peaks. Seasonal no-fishing areas have also been established in various parts of the Bay to better conserve breeding stock (DFO 1994a). However, over the past year harvestable stocks have again declined drastically and more stringent quotas are contemplated.

Scallop research has largely involved studies of population dynamics required for effective management of the stocks. This includes periodic assessments of abundance and size structure in different areas (Jamieson and Lundy 1979, Robert *et al.* 1985, 1987, 1988, 1989, 1990, CAFSAC 1991, Kenchington and Lundy 1991, 1992, 1994, Lundy and Kenchington 1992, Robinson *et al.* 1992a, Kenchington and Full 1994), spat settlement rates in relation to environmental factors (Robinson *et al.* 1991a) and monitoring of reproduction and gonadosomatic indices (Paon and Kenchington 1995). Setting a minimum size/meat weight level has also been an important consideration in stock management (Kenchington and Lundy 1993a, Roddick *et al.* 1994).

A number of studies have elucidated the annual reproductive cycle and the longer term fluctuations in reproductive success (Beninger 1987, Parsons *et al.* 1992a). Effort has also been devoted to understanding the horizontal and vertical distribution and movements of larvae in the water column. The larvae largely originate within the Bay rather than being imported, although there is evidence of transport with residual currents (Tremblay and Sinclair 1988). Larvae are distributed throughout the water column, except within 10 m or so of the bottom, with a slight tendency to concentrate near the thermocline (Tremblay and Sinclair 1986, 1988). There are also subtle differences between inshore and offshore populations in terms of their vertical distribution patterns and diel movements (Tremblay and Sinclair 1991). Diel vertical migrations are generally low in amplitude, bringing the population centre of mass slightly closer to the surface at night (Tremblay and Sinclair 1990). Patterns of settlement of spat in relation to hydrographic factors have been studied in the Passamaquoddy area (Robinson *et al.* 1991a, 1992c). Substrates covered by biofilm are preferred by settling spat, suggesting that artificial collectors are best conditioned before use (Parsons *et al.* 1993a). Once settled, 76% of juvenile scallops were mobile during a 4 month study, moving an average of 3.3 m (Parsons *et al.* 1992b). The filtering, feeding, growth and morphology of juveniles and adults in relation to water velocity, flow direction, food concentration and other factors have been studied on a number of occasions (Dadswell and Weihs 1990, Wildish and Saulnier 1992, Wildish *et al.* 1992a, Parsons *et al.* 1993b). An abnormally high mortality of scallops in the Cape Spencer area was initially attributed to starvation as a result of a very high recruitment in 1988 outstripping the available food supply. This led to pressures to open harvesting in order to salvage the remainder of the stock. A subsequent study yielded no evidence of starvation and concluded that the high mortality had in fact probably been a result of overfishing (Robinson *et al.* 1991b, 1992b). Recent studies of adductor muscle RNA/DNA ratios in relation to size, location and season reveal a small-scale patchiness possibly related to the feeding regime, suggesting that the ratio could serve as a useful indicator of nutritional stress in wild stocks (Kenchington 1994).

Soft-shell clam: The maritime soft shell-clam fishery is largely centered in the Bay of Fundy and is prosecuted in both the upper and lower Bay, particularly in SW New Brunswick and the Annapolis Basin areas, as well as along the north shore of the Minas Basin (Witherspoon 1983, 1984). A general overview of the changing clam fishery in the Maritimes is provided by Robinson (1993b). Landings reached a peak in 1986 of 4517 tonnes followed by a drastic decline to 1832 tonnes by 1990 (DFO 1994a). This decline has continued into the mid '90's. The Minas Basin fishery began in the early 1940's and peaked at about 916 tonnes in 1946 (Witherspoon 1984). Following this landings declined sharply and remained at low levels through the 1950's and 1960's. Harvesting increased during the 1970's and by 1982, 110 full time licensed fishermen were active. Harvests have since shrunk considerably.

The steady decline in clam landings over the past decade is largely attributable to the fact that more and more of the most productive coastal areas are being subjected to municipal and industrial pollution and thus are being seasonally or permanently closed to harvesting. Overall, populations of harvest-size clams appear to be relatively high, but most are inaccessible or unmarketable. If these pollution problems could be overcome clam landings would dramatically increase. A few depuration facilities have been established to clean clams from particularly valuable closed areas (DFO 1994a) and attempts have also been made to transfer clams from polluted areas to clean areas (relaying). A further consequence of the steady increase in extent of the areas closed to harvesting is that there has been a tendency to overexploit stocks in areas where harvesting is permitted.

In some areas of the Bay, winter storms and ice scour influence sediment stability and pose a continuing threat to clam populations (Witherspoon 1984). Tidal power developments and barrage construction also adversely affect clam populations, largely because of alterations in the nature and stability of the sediment and its rates of deposition downstream (Witherspoon 1984). Following the installation of the Annapolis tidal power generating station in 1980-83 soft-shell clam populations were essentially destroyed over large intertidal areas of the upper Annapolis basin during the mid to late 1980's. There was evidence of recruitment failure in the population beginning as early as 1982. Although there was considerable evidence that changes in surficial sediment texture ("thin watery sediment layer" covering the clay substrate) almost totally blocked larval settlement and/or survival it was believed that this impact had been further exacerbated by earlier heavy overfishing, as well as by increased predation on clams by nemertean worms (Rowell and Woo 1990, Rowell 1991). Recruitment recommenced in the effected areas during the early '90's at a time when surficial sediments appeared to have undergone some compaction and firming up (Rowell 1991). Although there are clear indications that clam populations in these areas are recovering, large areas of the Basin's mudflats are still closed to harvesting because of bacterial contamination.

"The steady decline in clam landings over the past decade is largely attributable to the fact that more and mor e of the most productive coastal areas are being subjected to municipal and industrial pollution"

Monitoring of clam populations, particularly their densities, size structure and distribution have been carried out at a number of locations, principally in southwestern New Brunswick (Angus *et al.* 1985b) and the Annapolis Basin (Angus *et al.* 1985a, Robinson 1993a, Rowell and Woo 1993). Other studies have looked at the incidental mortality attributable to traditional harvesting methods (Robinson and Rowell 1990), thermal stability of PSP toxins in clam tissues (Gill 1985) the development of conversion factors for comparing different catch statistics (Hawkins and Rowell 1984) and the presence of tumours in clams from various maritime sites (Morrison *et al.* 1993). DFO has also carried out a number of clam enhancement projects between 1989 and 1991 in efforts to restore habitat and populations in certain areas (DFO 1994a). Associated studies looked at the effects of siltation and other environmental factors on growth and survival as well as on natural spat settlement (Robinson *et al.* 1992c). The use of brush barriers to enhance clam settlement produced variable results in different areas. The feasibility of closing areas for periods to permit recovery was also investigated. A major drawback of such closures is that there is a tendency for these areas to be overharvested almost as soon as they are reopened. Reseeding of mudflats with juveniles shows considerable promise as an enhancement technique but needs more research. All of these potential ameliorative techniques raise concerns pertaining to the thorny issue of ownership of the resources, as they generally imply leasing, licensing or other forms of private control of areas of mudflats and consequent restrictions of access by diggers.

Crab: There has been a limited fishery for crab in the Bay of Fundy, but this has only been marginally viable largely because of problems in harvesting economically by current methods. Markets do exist for these crustaceans, and there is a potential for a small scale, sustainable fishery for Jonah crab, rock crab and red crab if suitable harvesting techniques can be implemented (DFO 1990b).

Blue mussel: Blue mussels are an important resource in many parts of the Maritimes, with virtually all that are marketed coming from cultured stock, particularly along the eastern shore of Nova Scotia (DFO 1994a). Extreme currents and high sediment loads in much of the Bay of Fundy limit the scope for aquaculture in many areas.

Periwinkle: Periwinkles have been sustainably harvested by hand in the intertidal zone of the Bay of Fundy for many years. The main harvest areas have been in the outer areas of the Bay, particularly Digby County in Nova Scotia and Charlotte County in New Brunswick. In recent years the pace of harvesting has accelerated dramatically with the introduction of mechanical suction harvesting techniques. Traditional hand-harvesting methods, which collect only larger animals, and leave untouched many inaccessible refugia, posed little threat to the long-term health of the populations. However, the large-scale suction dredge harvesting techniques that were actively promoted by DFO, have raised concerns about the likelihood of overexploitation (Kearney 1994). The dredges not only vacuum up most of the standing stock in an area, but they also harvest virtually all size classes of periwinkles as well as many other species of intertidal invertebrates. There is little if any sound information about the resource standing stock, the sustainable harvest levels, the impact of intensive harvesting on periwinkle populations, or about the broader ecological ramifications of removing such large numbers of periwinkles from extensive areas of shoreline. In an attempt to get a better understanding of the distribution and standing stocks, scientists from St. Andrews have recently undertaken surveys of periwinkle populations in the Deer Island area of New Brunswick (Chang 1994). A detailed study of the growth and production of periwinkles in the Bay carried out by Gardner and Thomas (1987) suggested that there is already high predation pressure and severe winter stress on the populations.

Sea urchin: The harvesting and marketing of the green sea urchin in the Bay of Fundy region has increased dramatically in the past several years, driven largely by the growing Japanese demand for roe and recognition of the high quality product available from these waters. Harvesting is largely carried out by hand by divers as well as by towed drags (DFO 1994a). The status of the fishery in the Bay has been reviewed by Robinson (1994). In SW New Brunswick, the harvest rose from virtually nothing in 1987 to almost 1000T in 1993 (Chang 1994). Although the fishery is mainly centered in the SW New Brunswick it is now expanding in SW Nova Scotia as well (DFO 1994a). There is concern that this rapid expansion is occurring in the absence of clear management policies based upon sound scientific information concerning the sustainable harvest capacity or about the potential ecosystem impacts of widespread harvesting. There are also concerns that current harvest licenses are not site specific and thus there is little incentive to harvest responsibly or participate in stock enhancement efforts. There are growing demands for a system of designated lease sites. Although some stock assessments are being carried out, the critical lack of information necessary to manage the resource effectively has prompted scientists at DFO St. Andrews to undertake studies on the growth, mortality, reproduction, population structure and general ecology of urchins (Chang 1994), as well as on the impacts of scallop drags on urchin populations.

Sea cucumber: The fishery for sea cucumbers has been relatively small and most were usually collected secondarily during the sea urchin harvest (DFO 1994a). However, there is growing interest in a larger directed fishery to supply the Asian market. In support of this, DFO has conducted experimental fisheries designed to assess stocks and evaluate markets (DFO 1992). Field and laboratory studies of the structure and dynamics of sea cucumber populations in the Passamaquoddy Bay area are also being undertaken.

Polychaetes: Several species of polychaetes are harvested on the mudflats surrounding the Bay of Fundy primarily to supply the lucrative baitworm market. With populations along the U.S. eastern seaboard greatly reduced by overexploitation, harvesting pressures are steadily rising on more northerly populations, including those of the upper reaches of the Bay. There is little reliable information about abundances in the area or about production rates and sustainable harvest levels, making it difficult to develop meaningful long-term management policies. There is also growing concern about the potential effects on the stability of intertidal mudflats of the continual disturbance of surficial sediments by large numbers of diggers working particular areas intensively and repetitively. Mud flats are dynamic, often ephemeral structures and we know little about the longer-term impacts of such ongoing human disturbance. The sensitivity and critical importance of these mudflats to the marine ecosystem of the upper Bay were explored in more detail in an earlier section of this report.

Rockweed: Four types of seaweeds have been commercially harvested from the Bay of Fundy, primarily along the rocky coasts of the outer and middle Bay: dulse *Palmeria palmata*; irish moss *Chondrus crispus*;, Fundy weed *Mastocarpus stellatus*; kelps *Laminaria digitata, L. longicruris*; and rockweeds *Ascophyllum nodosum, Fucus spp.*

Dulse has been collected for food use for generations in the Yarmouth area of Nova Scotia and around Grand Manan in New Brunswick. The main harvest of irish moss has been as a raw material to produce the food additive carrageenan. The hand rake harvest of irish moss reached a peak of 10000 t in 1975. Since then, competition from third world wild and aquaculture production has reduced demand and thus effort. Irish moss continues to be harvested in the 1990's, averaging 2200 t annually in SW Nova Scotia.

Rockweeds, which dominate the rocky intertidal zone of the Bay (Thomas 1994), has long been collected as an agricultural fertilizer and mulch. However, large scale commercial harvest of rockweed for fertilizer and alginate extraction only began in 1959 and has until recently largely been confined to Digby and Yarmouth Counties (Gordon 1994). Since 1986 5-10% of the landings have come from the southern shore of Nova Scotia (Glyn Sharp, pers. comm). Earlier hand cutting and raking by fishermen working part time was soon supplanted by large mechanical harvesters operated full time by the processors themselves to provide a continuous supply. A study of the effects of these older mechanical harvesters on the resource, and of the factors contributing to a sustainable yield, was carried out in this area (Sharp 1981). However, the introduction of new suction harvesting technology dramatically increased the harvest in SW Nova Scotia from about 5000 T in 1985 to 27,000 T in 1988 (Sharp and Tremblay 1989). These new harvesters removed 40-80% of the rockweed biomass (Rangeley 1994). Landings did not continue to rise, and this peak harvest continued for only two years. Landings have remained below 20,000 t annually since 1992 (Glyn Sharp, pers. comm). This decline in landings was not directly related to changes in abundance, but rather to reduced effort, since one of the two principal purchasing companies reduced and then ceased operations. Prior to 1994 there was a steady reduction in the percentage of the harvest being landed by mechanical harvesters, and since 1990 the majority of the harvest has been taken with hand harvest equipment (Sharp *et al.* 1994). There has not been any mechanical harvesting of rockweed in eastern Canada for the past two years (Glyn Sharp, pers. comm.).

The available information on distribution and biomass of rockweed in the Scotia-Fundy region has been summarized by Sharp and Tremblay (1989). They estimate that the standing crop is about 270,000 T, with the majority of the harvestable biomass of 47,000 T occurring in southwestern Nova Scotia and southern New Brunswick. In the former area the estimated annual sustainable yield had already been reached or exceeded and they warned of a possible decline in the resource. A recent small-scale study of the distribution and reproduction of rockweed in the Annapolis Basin also concluded that the plants had been overharvested and that in consequence the biomass was much lower than in other less intensely harvested areas and the reproductive capacity probably impaired (Ang and Sharp 1993). There are now increasing pressures to expand the harvest to other areas and the recent decision by the New Brunswick government to permit the harvest of 10,000 tons of rockweed in the southwestern Bay of Fundy has aroused great concern about the potential impacts of this on the marine ecosystem. This decision to allow a "pilot" scale harvest was based on recent estimates of rockweed biomass (Bradford 1989, Sharp and Semple 1992). A recent CAFSAC review acknowledged that there were knowledge gaps and recommended that harvesting proceed on a pilot scale for three years, with some restrictions on effort and landings and that impacts be concurrently monitored (Mann 1992). Under the present controlled harvesting regime, exploitation rates for the entire southern New Brunswick rockweed resource is about 7% per year, while exploitation within sectors being harvested is limited to 17% per year over a three year harvesting rotation (Glyn Sharp, pers. comm.). However, there are concerns that already management strategies are being developed with the aim of even further expanding rockweed harvesting in the region (Rangeley 1994).

The harvest is expanding in spite of the fact that there is limited information about sustainable harvest levels (Rangeley, 1991a). In fact, it has been argued that "the sustainable yield or harvest concept......... does not apply when the organism under consideration is a major source of primary production and when it provides the physical structure of an ecosystem." (Rangeley 1991b). Clearly, removal of much of the plant canopy changes the physical structure of the intertidal community, but at present there is little information about the short or long term consequences for the many species inhabiting this zone (Gordon 1994). There has been only one study in the region that examined the effects of removing rockweed on the abundance and feeding intensity of fish in the intertidal zone (Black and Miller 1991). This involved total removal of rockweed from a relatively small area of 400 m^2 and looking at the impacts on fish utilization of the area. Although the authors concluded that there were "no large adverse effects" on fish populations, these results have recently been challenged on the basis of inadequate sampling techniques that did not collect fish less than 100 mm as well as faulty statistical analysis (Rangeley 1994). The original authors have subsequently published a rebuttal of some of the statistical arguments (Black and Miller 1994), but agreed that their study did not assess the role of intertidal rockweed areas as a nursery for small fish.

> ***"the sustainable yield or harvest concept......... does not apply when the organism under consideration [rockweed] is a major source of primary production and when it provides the physical structure of an ecosystem."***

The impacts of harvesting on the population structure of the rockweed itself has been examined by Ang *et al.* (1993), while some of the broader habitat implications of the harvest have been reviewed by Mann (1992) and Rangeley (1991b). Early studies indicated that macrophytes as a group contribute only about 2% of the primary productivity of the Bay as a whole (Prouse *et al.* 1984), although there are indications that in some regions of the Bay this proportion can rise as high as 30-40% (see Chapter 4.2 of this report). Nevertheless, there is growing evidence that rockweed is an important component of coastal marine ecosystems and plays a significant role in production in nearshore waters as well as in the life cycles of many marine invertebrates, fish and birds. Rockweed debris decomposing on beaches is not only important for nutrient regeneration in coastal waters but is also a major nutrition source for intertidal invertebrates that are in turn important in the diets of many marine fish and birds. Black and eider ducks forage amongst the rockweed for invertebrates at critical times during their life histories; eider ducklings seeking amphipods and the older ducks seeking periwinkles (Rangeley 1991a). A variety of other ducks, including buffleheads, goldeneye, oldsquaw, whitewing, surf scoters and greater scaup also depend heavily on the intertidal zone for winter feeding. Under the existing management plan for rockweed harvesting some areas have, after consultation with the Canadian Wildlife Service and the New Brunswick Department of Natural Resources, been set aside for special management based on their utilization by waterfowl (Glyn Sharp, pers. comm.)

It has also been suggested that the complex colloidal organic compounds released during the decomposition of rockweed may play a role in the nutrition of adult scallops (Alber and Valiela 1995) and their larvae (Bradford 1989), although the proportion of macrophyte-derived material in the diets has not been adequately assessed. Furthermore, the peak release of particulate matter from *Ascophyllum nodosum* populations is from mid May to late June (Glyn Sharp, pers. comm.), while the majority of scallop spawning takes place in July and August. Offshore, large rafts of detached rockweed support an extensive community of organisms (Rangeley 1994). Particulate plant material transported offshore also represents a significant contribution to subtidal benthic productivity (Lenonton *et al.* 1982).

Most importantly, the macroalgae of the intertidal zone appears to be a particularly important nursery area for many species of juvenile fishes providing both forage and refuge from predators (Rangeley 1994, Rangeley and Kramer 1995). At least 22 species of fish, including commercial ones such as pollock, herring and flounder, are known to be associated with rockweed during key parts of their life cycle. There is ample evidence, in particular, that rockweed provides summer nursery habitats for young of the year pollock (Rangeley 1994). Compounding the potentially adverse impact of the harvest is the fact that the most economically desirable and accessible rockweed areas, namely sheltered coastlines and embayments, are also generally the most important nursery areas for many species (Rangeley 1991a). In view of this, it has been suggested that the harvesting violates DFO's own policy on fish habitat conservation (Rangeley 1991a). The near-virginal state of present New Brunswick rockweed beds provides an ideal opportunity for an optimal environmental impact study and a detailed outline for such a study has been developed (Rangeley 1991b). During the current three year pilot study of harvesting in New Brunswick, large areas of embayments and sheltered islands have been set aside as study sites where harvesting is not permitted (Glyn Sharp, pers. comm.). It is anticipated that studies of these control areas in comparison with areas where commercial scale harvesting is being carried on will provide information about ecosystem impacts.

5.2.5 Aggregate extraction

Subsea sand and gravel deposits represent yet another marine resource that is arousing growing interest in the Atlantic provinces. Although aggregate extraction from coastal seafloor deposits has not yet been undertaken on a commercial scale anywhere in Canada, successful operations in Europe and Japan have already demonstrated its technical and economic feasibility. With increasing restrictions on access to terrestrial deposits there is growing interest in the extensive submarine deposits around Nova Scotia. Particular attention has recently focused on seemingly high quality sand deposits in Scots Bay adjacent to Cape Split in the upper Bay of Fundy (Day and Yetman 1995, and section 2.2.2 of this report). The Atlantic Geosciences Centre carried out an intensive survey of these and other aggregate deposits in the upper regions of the Bay of Fundy on board the R.V. Hudson in October of 1995. Studies carried out elsewhere suggest that there are a variety of potentially significant environmental impacts that may accompany suction mining of such deposits (Day and Yetman 1995). These concerns range from coastal erosion, destruction of benthic organisms, alteration in bottom habitats deleterious to benthic flora and fauna including the development of benthic fish eggs, and the formation of dense sediment plumes that could influence primary production as well as zooplankton populations. However, it is generally conceded that some of these impacts may be minimal in the upper reaches of the Bay, because of the intense turbulent mixing and the already high sediment load in the water column. However, some impacts may occur and detailed assessments will be needed to predict the likely environmental effects at a particular site.

5.3. Aquaculture

5.3.1 Introduction

One of the more dramatic phenomena that has taken place in the Bay of Fundy during the past decade has been the rapid growth and expansion of the aquaculture industry. The introduction and subsequent development of fish farming in the region has been described in some detail (Cook and

Black 1993, Saunders 1991, Cook 1988) as has the overall economics of the industry (Aiken 1989). Although interest to date has focused primarily on Atlantic salmon, several other species of marine finfish and shellfish are being farmed on a significant scale, and yet other species are thought to have considerable potential. The precipitous decline in groundfish stocks over the last few years, coupled with a rising international demand for high quality seafood contributed greatly to this rapid expansion of the aquaculture industry. This growth has been accompanied by intensive research on environmental constraints, grow out methods, nutrition and energetics, broodstock development and production, disease and parasite control, toxic algal blooms, and potential environmental impacts. Much of this work has been undertaken at DFO's St. Andrews Biological Station and at the joint government and industry sponsored Atlantic Salmon Technology Centre, an aquaculture demonstration and research facility set up in 1985 in SW New Brunswick.

5.3.2 Species in culture

The overwhelming focus thus far has been on the farming of Atlantic salmon, an industry largely concentrated in the Bay of Fundy, primarily in south western New Brunswick. Here production began in 1978 and after a slow start increased almost 14 fold between 1984 and 1988 (DFO 1990a). By 1990 there were 54 farms producing more than 8000 tons annually (Wildish *et al.* 1993) and in recent years salmon farming has become a $100 million industry representing the highest landed value of any finfish in the Scotia-Fundy region (Waiwood *et al.* 1994). Further rapid growth is projected in the future, involving expansion in a variety of other regions in the Bay, notably the Annapolis Basin.

"One of the more dramatic phenomena that has taken place in the Bay of Fundy during the past decade has been the rapid growth and expansion of the aquaculture industry."

An early focus of the aquaculture related research at St. Andrews was on the physiology and energetics of captive salmon, involving studies on food quality (Henderson 1988), optimum feeding regimes, factors influencing growth and maturation as well as endocrine and genetic influences on development. The aquaculture potential of transgenic salmon injected with a growth hormone gene is also being investigated (DFO 1993). The economic feasibility of using brackish well water to provide elevated growing temperatures in winter for the culture of salmon in shore-based tanks was also demonstrated (Anderson 1986). Other studies have focused on improvements in husbandry procedures and improved broodstock development (DFO 1990a) In recent years the emphasis of DFO aquaculture studies has shifted from fish physiology and energetics to enhancing cost effectiveness and environmental monitoring (DFO 1993).

The great success of the salmon aquaculture industry in the region has fueled interest in bringing a variety of other diadromous and marine species into culture. A new program was launched in 1988 at St. Andrews to evaluate and develop other marine fish, focusing initially on haddock and halibut. Sea trout are also routinely cultured at some salmon farms, but the production is several orders of magnitude less than that of salmon (DFO 1990a). DFO is also confident that "striped bass culture is now on the horizon" (DFO 1993) and has even sponsored a workshop to consider some of the issues associated with this development (Peterson 1991). Scientists at St. Andrews have recently carried out research on techniques for rearing striped bass from eggs to juveniles, on growth and survival in captivity, on the development of swimbladders in larval fish and on the effects of environmental conditions on juvenile growth. A number of pilot-scale studies of grow out methods are currently underway and it is anticipated that a commercial venture will begin shortly (Dick Peterson, pers. comm). Although bass are more tolerant of the low winter temperatures than are salmon (Hogans 1994) they appear to require warmer water than that normally found in sea cages for optimum growth, so their farming may eventually involve pond-based operations, and it is not yet clear whether this can be done economically. DFO is also investigating the feasibility of restocking the Annapolis and other suitable rivers with hatchery-reared striped bass (Dick Peterson, pers. comm).

Eel culture in the Maritimes is still in its infancy. Only one farm at present collects elvers and holds them for about 6 months before shipping the juveniles to Holland for final grow out (Dick Peterson, pers. comm.). There is a growing interest, however, in raising elvers to adult size before marketing them. However, one of the current problems hampering expansion is that 90% of the eels in culture are males, which are much smaller, and therefore less desirable, than females. Sex in eels is largely environmentally determined, so research is being undertaken at DFO St. Andrews to determine the effects of factors such as temperature and feeding regime, in the hope of eventually increasing the proportion of females in culture.

Haddock is also considered to have great potential for aquaculture in the Bay of Fundy region, as it has a good growth rate in captivity and also a high market value. Ken Waiwood of St. Andrews is currently carrying out research on various aspects of haddock culture. Although juveniles have successfully been reared from eggs, more information is required about the optimum conditions for development and about the process of swim bladder inflation in larvae. Other studies are considering their temperature tolerance and the development of suitable grow-out methods in sea cages.

"The salmonid aquaculture industry in the Maritimes is primarily hampered by the fact that the region has a cold-temperate climate with very pronounced seasonal fluctuations in temperature"

The prospects for culture of halibut are also deemed excellent as the species has a high value, adapts well to captivity and to crowding (Waiwood 1991) and in sea cages grows two to three times as fast as in the wild (Waiwood *et al.* 1994). However, a number of difficulties in larval rearing have first to be overcome, as there is an unacceptably high mortality between egg and juvenile stages. Techniques for stripping the eggs and fertilizing them have been successfully developed, and columnar incubator chambers have been used for hatching and early larval development. However, at present raising the fish from egg to market size is not cost effective as the early stages of rearing are complex and rearing techniques difficult (DFO 1990a, Waiwood 1989). This inability to produce juveniles routinely in large numbers is the principal impediment at present to commercial scale aquaculture of the species. The focus of recent research by scientists at St. Andrews has thus been on the rearing and first-feeding of larvae and developing cost effective grow-out procedures for a species that prefers lying on the sea bed to swimming in the water column (DFO 1993).

5.3.3 Potential constraints on aquaculture development

5.3.3.1 Tidal currents

Although moderate current velocities are essential for the effective flushing of wastes from cage sites, the very high water velocities generated by the extreme tides in the Bay of Fundy can pose major problems for finfish and invertebrate aquaculture operations in some coastal areas. For example, in the Annapolis Basin, large numbers of young salmon were killed by the exceptionally strong currents that immobilized them against the cage netting, and in another instance collapsed the floating cage. Also, rope culture of molluscs may not be feasible in most areas because of streaming of the suspended culture bags, necessitating the introduction of new bottom-based grow out technologies.

5.3.3.2 Winter temperature

The salmonid aquaculture industry in the Maritimes is primarily hampered by the fact that the region has a cold-temperate climate with very pronounced seasonal fluctuations in temperature (Wildish *et al.* 1993). It has been suggested that of all the limitations faced by the industry lethal temperature in particular is currently preventing rapid expansion of the industry (Saunders 1987, 1991). The lower lethal temperature for Atlantic salmon is about -0.7°C. This temperature is periodically attained in many coastal embayments such as Passamaquoddy Bay, where the water tends to be colder nearshore. The fact that the low temperature occurs throughout the water column precludes the use of technological fixes such as pumping warmer water from depth (MacPhee *et al.* 1994). Recognition of the threat of low temperature and ice in Passamaquoddy Bay during the early days of the industry resulted in the placement of most farms in deeper water areas around the Fundy Isles (Wildish *et al.* 1993). However, with the rapid expansion the industry has moved into more vulnerable inshore areas (Wildish *et al.* 1993). Low winter temperatures in 1983, 1987, 1989 and 1993 killed large numbers of caged salmon (Anon. 1992). To counter this the industry has developed comprehensive contingency plans for early harvesting and marketing of threatened stocks. This requires a regular monitoring program to provide early warning of lethal temperatures, such as has been set up in L'Etang Inlet (Trites and Petrie 1992). A similar thermal situation prevails in the Annapolis Basin, where the salmon farming industry is currently gaining a foothold. In winter, water temperature in the basin tends to be lower than that in the Bay of Fundy. Only the periodic influxes of warm Bay water into the Basin render conditions suitable for the overwintering of salmon. Reduced tidal exchange during neap tides contributes to the occurrence of lethally low temperature conditions. Models incorporating tidal exchange, air temperature and river discharge rates are currently being developed in the hopes of providing cage owners with timely forecasts of adverse temperature conditions (BIO 1995a).

5.3.3.3 Pollutants

One of the potential constraints to further expansion of the aquaculture industry is access to suitable areas of relatively unpolluted coastal waters. Many of the Fundy's coastal embayments are subject to the input of various pollutants from land-based sources. Concerns have already been raised about pulp mill effluents in L'Etang Inlet, wastes from a fish meal processing plant at Blacks Harbour, possible organic/nutrient loading from municipal sewage systems in the Saint John and St. Croix Estuaries, particularly during spring freshets (Wildish *et al.* 1990b), and more recently about unanticipated problems at the the Point Lepreau Nuclear Generating Station in southwestern New Brunswick. These and other pollutants are dealt with in greater detail in Chapter 3 of this report.

5.3.3.4 Diseases and parasites

The outbreak of diseases and infestations by parasites represent an ever present threat to the aquaculture industry. Confinement and high population densities cause stresses that render the fish more susceptible to disease, as well as facilitating the rapid spread of disease throughout the population. Emphasis to date has been on good husbandry practices, vigilant monitoring and application of effective control measures (Cook 1988). Much of the research and control measures to date have been directed at furunculosis (*Aeromonas salmonicida*) infections, particularly with regard to the use of chemotherapeutants (Mitchell 1992), identifying and controlling environmental risk factors (Mitchell 1992) and monitoring for latent stages of disease in fish hatcheries (Eaton 1988). Vibriosis, a disease of salmon usually associated with warm water temperatures in fall is generally controlled by the use of antibiotics administered in the feed (Buerkle 1993). Sealice (copepods of the genera *Caligus* and *Lepeophtheirus*) can be a problem on farmed salmon, particularly with warmer water temperatures (Hogans and Trudeau 1989a, b) and are usually controlled with Ivermectin (Burridge and Haya 1993). Widespread outbreaks of sealice infestation in SW New Brunswick during the past summer posed a severe threat to the industry and prompted pressures for the implementation of more potent chemical control measures than those currently permissible. Protozoan parasites may also be economically significant pathogens of farmed salmon (Cawthorn *et al.* 1990, 1991). The outbreak of diseases and parasites among farmed fish and the methods used to control them have raised a number of environmental concerns that have yet to be adequately addressed. There is particular concern about the possibility of the spread of a variety of diseases from caged to wild fish stocks as well as the potential proliferation of antibiotic resistant bacteria in coastal waters as a result of routine chemotherapeutant use. Furthermore, there is considerable uncertainty about the ecological impacts of the release of various highly toxic chemotherapeutants into the marine environment. The concern centers not only upon the possible adverse effects on wild organisms, but harvesters of other marine resources are concerned about the potential implications of local water and sediment contamination by chemotherapeutants for their industry.

5.3.3.5 Predators

Various species of predators can pose serious problems for aquaculture operations. Harbour seals and grey seals are attracted to salmon farms, where they often kill fish and damage pens (Saunders 1991, and section 4.7.1 of this report). The expanding grey seal population and the reductions in abundance of their normal wild prey may result in increased predation pressures on finfish farms. Eider duck predation has been identified as an important problem for the expanding mussel culture industry (Peter Hicklin, pers. comm.). Even an infestation of giant water bugs destroyed large numbers of juvenile striped-bass in one pilot scale culture operation (Dick Peterson, pers. comm.).

5.3.3.6 Toxic plankton blooms

The sporadic occurrence of marine phycotoxins in coastal waters (Martin and Wildish 1990, Martin *et al.* 1990) as well as in cultured and wild shellfish (Haya *et al.* 1989a, b) and finfish (Haya *et al.* 1989c, 1990) is a matter of continuing concern to both the fishing and aquaculture industries (section 3.2.4 of this report). As a result a great deal of effort has been devoted to developing an extensive monitoring program that processes samples rapidly enough to warn of impending toxic blooms (Wildish *et al.* 1990a, 1992b). Other studies have focused on the uptake and depuration of PSP toxins by marine organisms (Haya *et al.* 1993).

> ***"So far, aquaculture has not polluted Canada's waters"***
> — (DFO 1990a)

5.3.3.7 Habitat degradation

Fish farms confine large numbers of fish in a very small area, and as a result a large quantity of particulate and dissolved organic waste is continually released in a small area over an extended period. The nature and quantities of the wastes generated by fish farms of various sizes and types have been well documented (see references in Wildish *et al.* 1993). However, there is a continuing debate about the adverse impacts of these wastes on adjacent marine habitats and communities, in spite of continuing reassurances that "so far, aquaculture has not polluted Canada's waters" (DFO 1990a).

Sustainable aquaculture is itself clearly dependent on the continuing environmental quality and ecological integrity of the immediately surrounding coastal ecosystem (Freeman 1988). This has led to ongoing research to ascertain optimal stocking densities and flushing rates. There has also been a regular program of monitoring of water quality and of benthic habitats and communities under and immediately adjacent to most fish farms. Studies have also been directed towards designing effective monitoring strategies and identifying research needs in this regard (Wildish *et al.* 1990a).

In terms of the effects of aquaculture on seawater quality, the principal concerns have focused on the possible reduction of dissolved oxygen levels, both as a consequence of fish respiration and biological/chemical oxygen demand resulting from breakdown of organic wastes, and increased concentrations of dissolved nutrients such as ammonia and nitrates as products of fish metabolism (Wildish *et al.* 1993). There is concern that the added nutrients could foster eutrophication and possibly trigger microalgal blooms in the vicinity of the cages that would have lethal or sublethal effects on the fish stocks (Wildish *et al.* 1992b). It has indeed been possible to demonstrate significant localized declines in oxygen and increases in ammonia concentration in the immediate vicinity of fish cages, particularly in situations where tidal flushing is restricted (Wildish *et al.* 1993). As a consequence DFO scientists at St. Andrews have been carrying out studies on the effects of varying oxygen levels on the feeding and growth of salmon

(Chang 1994) as part of an ongoing program to determine optimum stocking densities in relation to various environmental conditions. However, it is generally assumed that in many coastal areas of the Bay of Fundy flushing and mixing processes are sufficient to minimize any such potential localized impacts.

The impacts of aquaculture wastes accumulating in benthic sediments are thought to be potentially more serious and have, as a result, been the focus of a great deal of research. Large amounts of particulate material are generated by fish farms in the form of uneaten waste feed and fish fecal pellets, and these ultimately descend to the sea floor where they accumulate as a "mariculture sludge", which in some respects resembles sewage sludge (Wildish et al. 1990c). The possible fates and biological effects of this particulate aquaculture waste has been the subject of various modelling studies (Hargrave 1994). These models appear to adequately describe initial depositional processes in the immediate vicinity of the cages, but are much less instructive about subsequent resuspension and lateral transport of the material by bottom currents. The decomposition of these accumulated organic wastes may result in a negative redox potential in sediments, release noxious gases such as ammonia, methane, carbon dioxide and hydrogen sulphide, and significantly increase the biological and chemical oxygen demand in the sediment and also in the overlying water (Wildish *et al.* 1990c, Hargrave *et al.* 1993). The concentrations of some of these noxious compounds can be sufficient to be toxic to infauna. Production of noxious gases varied seasonally, being most pronounced during the summer. Presumably as a result of this degradation in the benthic habitat, there have also been significant changes in benthic community structure in the vicinity of salmon farms (Lim 1991, Hargrave *et al.* 1993). An extensive survey of the sediments in the vicinity of all existing aquaculture sites in New Brunswick revealed that 15% exhibited high levels of benthic degradation while the other 85% were low to moderately degraded (Thonney and Garnier 1993). Impacts were most pronounced at sites with low rates of flushing. Although it has been clearly demonstrated that adverse impacts occur commonly at sites immediately adjacent to fish farms, there is less information and more controversy about the possible long-term impacts at potential depositional sites more remote from the farms as well as about the total area of coastal habitat that may be at risk from a given aquaculture operation.

5.3.3.8 Conflicts with other users

In addition to continuing debates about the impacts of aquaculture on traditional fisheries because of habitat degradation, there are ongoing conflicts over the physical displacement of fishermen from certain coastal fishing grounds by aquaculture operations, which by their very nature exclude virtually all other uses of the coastal areas that they occupy. Aquaculture in the Bay of Fundy has long faced opposition from those engaged in coastal fisheries, who fear exclusion from long-used fishing grounds as well as deleterious impacts on traditional marine resource species and their habitats (Stephenson 1990, Lawton 1993). Concerns have also been raised about the consequences of ecological interactions and genetic exchange between cultured and wild salmon stocks (Saunders 1991). This conflict has been particularly pronounced in the Annapolis Basin where the only suitable finfish aquaculture sites coincided precisely with fishing grounds that had long provided sustainable harvests of scallops, lobsters and flounder. Concerns centered chiefly on exclusion from traditional fishing areas, destruction of clam flats by aquaculture wastes and disturbance of lobster migration as a result of accumulations of "mariculture sludge" in critical areas.

> ***"Aquaculture in the Bay of Fundy has long faced opposition from those engaged in coastal fisheries, who fear exclusion from long-used fishing grounds as well as deleterious impacts on traditional marine resource species and their habitats"***

Other concerns relate to the potential long-term ecological and genetic consequences for wild populations of finfish, particularly Atlantic salmon, of extensive interbreeding with escaped farmed stock. This is likely to be an ongoing issue particularly as innovations such as production of sterile fish, single sex populations and genetically engineered stocks become more widespread. There are also concerns that the highly concentrated stocks in fish farms may serve as foci for recurring outbreaks of fish diseases or parasites that might spread to local wild populations. A related issue is the poorly controlled use of a range of increasingly toxic chemotherapeutants in fish farms to control diseases and parasites, and the many unanswered questions concerning the impacts of these chemicals on the survival and marketability of wild finfish and shellfish stocks in the vicinity, as well as on other marine life.

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CHAPTER SIX

BAY OF FUNDY ECOSYSTEM ISSUES: A SUMMARY

J.A. Percy and P.G. Wells

6.1 Introduction

The Bay of Fundy is a unique, tidally-driven, coastal ecosystem with an abundance of valuable marine resources and many promising sites for aquaculture ventures. It is also a region with important marine habitats, abundant wildlife and impressive biodiversity. As a whole, the Bay faces a variety of critical problems and issues that impose unprecedented stresses on the marine habitats and communities that are integral to its ecological equilibrium and to the sustainable productivity of its resources. While many of these stresses are fairly recent in origin (*e.g.* persistent toxic chemicals), others date from the earliest European settlements in the region (*e.g.* dyking and drainage). Whereas many of the problems involve relatively localized impacts (*e.g.* sewage outfalls and beach closures, increased nutrient inputs from aquaculture), others form part of a much broader, regional context (*e.g.* wide-spread chemical contamination in the Gulf of Maine/Fundy system; the progressive loss of salt marshes since the 1600's; turbine mortality of migratory diadromous fish stocks), and a few have even broader global implications (*e.g.* threatened food resources for migratory shorebirds, death and disturbance of endangered right whales). Only recently has there been widespread public recognition of some of the more overt ecological consequences of these compounding anthropogenic stresses, and a general recognition by the scientific community that a more holistic approach is needed for an adequate understanding of their impacts. It has even been suggested that, unless action is taken very soon, we may ultimately face in the Bay of Fundy a degraded coastal environment comparable to that in some of the more heavily impacted areas of the North Sea (Gordon 1989).

> ***"Only recently has there been widespread public recognition of some of the more overt ecological consequences of these compounding anthropogenic stresses, and a general recognition by the scientific community that a more holistic approach is needed for an adequate understanding of their impacts."***

Some of the most urgent environmental problems/stresses that threaten the stability and productivity of the Bay of Fundy ecosystem that have been raised in the preceding chapters are listed in Table 6.1. Here, these issues are presented in the context of a largely intuitive overview of several features indicative of relative magnitude, significance and degree of understanding of the stresses and their impacts. The *"timeline"* is an estimate of the approximate duration in years that the particular stress has been significant in the region. The *"spatial scope"* attempts to differentiate between impacts that are purely local in consequence and those that are of Bay-wide, regional or possibly global significance. Similarly the *"temporal scope"* categorizes stresses according to the relative duration that their impacts are likely to persist once the stress is removed. The *"science/management"* category indicates whether the ultimate resolution of the problem is more dependent on more or better science (S), more or better management (M) or a combination of the two (S/M). The *"socioeconomic impact"* gauges the relative importance of the issue in economic and resource development terms, while the *"ecological impact"* represents a comparable assessment of its likely ecological significance. The *"level of understanding"* is a very subjective assessment of the adequacy of the available information about the issue and of the understanding of relevant processes and consequences. In each case the relative magnitude of the particular feature is indicated by a circle filled to varying degrees, with an open circle indicating a minimum and a filled circle a maximum for the

Figure 6.1a Summary of Bay of Fundy issues and their relative significance. *[See text for a description of the table headings and the symbols used].*

Issues	Timeline: years	Spatial scope	Temporal scope	Science/management?	Socioeconomic impact	Ecological impact	Level of Understanding
Fish stock declines (6.2.1)	10	●	◒	S/M	●	◒	◔
Resource use cascade (6.2.2)	10	◕	◒	M	◒	◕	○
Resource management paradigm (6.2.3)	50	◕	◒	M	◕	◒	◔
Changes in fish assemblages (6.2.4)	10	◕	◒	S	◒	◕	◔
Geomorphol./Oceanographic changes (6.2.5)	1000	●	◕	S	◕	◕	◔
Atmospheric/climatic changes (6.2.6)	50	●	◒	S	◒	◒	◔
Contaminants: terrestrial sources (6.2.7)	25	◒	◔	S/M	◒	◒	◒
Contaminants: ocean dumping (6.2.7)	25	◔	◒	S/M	◔	◔	◒
Contaminants: chronic oil release (6.2.7)	20	◔	◔	S/M	◔	◔	◕
Contaminants: long-range transport (6.2.7)	25	◒	◒	S	◔	◔	◒
Nutrient inputs (6.2.8)	30	◔	◔	S/M	◔	◔	◒
Natural toxins (6.2.9)	10	◔	◔	S	◔	◔	◒
erosion/siltation rivers/estuaries (6.2.10)	25	◒	◕	S/M	◒	◒	◒
Obstruction of rivers/estuaries (6.2.10)	25	◒	◕	M	◒	◒	◒
Turbine passage mortality (6.2.10)	15	◔	◒	S/M	◔	◔	◕
Saltmarsh/mudflat dynamics (6.2.11)	300	◒	◕	S/M	◔	◒	◔
Shorebird trophic links (6.2.12)	15	◔	◒	S/M	◔	◒	◒
Habitat disturbance: mudflats (6.2.13)	25	◒	◒	S/M	◔	◒	◒
Habitat disturbance: rocky shore (6.2.13)	20	◒	◔	S/M	◔	◒	◔
Habitat disturbance: benthos (6.2.13)	20	◕	◒	S/M	◔	◒	◒

Figure 6.1b (Continued) Summary of Bay of Fundy issues and their relative significance. *[See text for a description of the table headings and the symbols used].*

Issues	Timeline: years	Spatial scope	Temporal scope	Science/management?	Socioeconomic impact	Ecological impact	Level of Understanding
Habitat disturbance: saltmarsh (6.2.13)	300	◔	◕	S/M	◔	◒	◔
Aquaculture: spatial conflicts (6.2.14)	10	◔	◒	M	◒	○	◕
Aquaculture: habitat degradation (6.2.14)	10	◔	◒	S/M	◒	◒	◒
Aquaculture: stock interactions (6.2.14)	10	◔	◒	S	◔	◔	◔
Aquaculture: diseases/parasites (6.2.14)	10	◔	◔	S/M	◔	◒	◔
Ecotourism/recreation impacts (6.2.15)	10	◔	◔	M	◔	◒	◒
Marine transportation impacts (6.2.16)	20	◔	◔	M	◔	◔	◒
Coastal development impacts (6.2.17)	100	◒	◕	M	◒	◒	◔
Introduced species impacts (6.2.18)	10	◔	◒	S	◔	◔	◔
Marine mammals: fishery interaction (6.2.19)	20	◔	◔	S/M	◔	◔	◒
Marine mammal/aquaculture interaction (6.2.19)	20	◔	◔	S/M	◔	◔	◒
Cumulative effects (6.2.20)	100	◕	◕	S	◕	◕	◔
Synergistic effects (6.2.20)	100	◕	◕	S	◕	◕	○
Marine protected areas (6.2.21)	10	◔	◔	M	◔	◔	◒
Land-sea interactions(6.2.22)	50	◒	◒	S/M	◔	◒	◔
Integrated coastal zone management (6.2.23)	10	◕	◕	S/M	◕	◕	◔
Indicator/sentinal species (6.2.24)	10	◔	◔	S	◔	◔	◔
Protection of fossil beds (6.2.25)	10	◔	◔	M	◔	◔	◕

particular category. Three intermediate degrees are indicated by an increasing proportion of black fill in quarter-circle steps. Needless to say, this largely qualitative tabular synthesis is intended more as a catalyst and a framework for discussion than as a definitive statement about dauntingly complex phenomena. For a more detailed discussion of the background to these issues, the reader should refer to the relevant chapters in this report. The following is a brief summary of the principal environmental issues presently confronting the Bay of Fundy marine ecosystem.

6.2 Environmental Issues

6.2.1 Fish stock declines

There is little question that for many marine resource stocks one of the determining factors in recent sharp population declines has been over harvesting. As Jessop (1991) succinctly put it "Despite our modern technology of resource management, we have not yet solved the difficulties of managing people exploiting resources that they value". There is a continuing tendency for resource managers to permit harvests to rise to levels theoretically sustainable by healthy stocks under ideal environmental conditions, but leaving little if any scope for natural population declines associated with periodic suboptimal environmental conditions or other unpredictable ecological changes and stresses. The situation is further exacerbated by our limited knowledge about the cumulative influence of biotic and abiotic environmental factors on the growth and survival of young stages of most commercial species. Such uncertainties demand a more conservative approach to resource management than has generally been followed. Too often, maximizing economic efficiency and gain, rather than ensuring ecological sustainability, has been the guiding criterion in promoting harvesting technology and in determining harvest intensity.

> ***"There is growing recognition that a single species [management] approach is inappropriate and a threat to long-term sustainability."***

There is, however, mounting evidence that the unprecedented stock collapses of the past decade are prompting a reorientation of fisheries management policies and strategies to address the most crucial of these concerns (DFO 1992, 1994a).

> ***"Too often, maximizing economic efficiency and gain rather than ensuring ecological sustainability has been the guiding criterion in promoting harvesting technology and in determining harvest intensity."***

6.2.2 Resource use cascade

However, far too many stock management decisions are still more responsive to economic and political considerations than to the ecological imperatives critical to sustainability. Scientists and managers participating in a Moncton N.B. workshop on underutilized species concluded in their final report that "sociopolitical and economic pressures often force overexploitation in the face of inadequate or inappropriate research" (DFO 1994b). Our current approach to fisheries management too often resembles a "resource use cascade", with unsustainably high harvesting capacity being redirected from one species to another in sequence as each in turn is fished almost to depletion. The surge in exploitation of many so called "underutilized species" (*e.g.* sea urchins, sea cucumbers, bait worms, rockweed) is also occurring in an almost complete absence of reliable information about their standing stocks, sustainable harvest levels and, perhaps more worrisome to many, about their roles in overall ecosystem dynamics. Because they have been of little economic importance, they have been subjected to little if any research relevant to stock management decisions. There is concern also that species that have been traditionally harvested by small scale, "environmentally friendly" methods are more and more being overexploited by the use of large-scale, highly mechanized techniques that are extremely destructive to habitats and non-target species alike. In the haste to promote new and expanded fisheries, insufficient thought is being given to the potential ecological ramifications, particularly in relation to the recovery of those stocks that have already been depleted, and to marine wildlife in general.

6.2.3 Resource management paradigm

Fisheries management has traditionally involved managing individual species regionally, with only cursory if any consideration of ecological interactions with predator, prey or competitor species that are also being harvested — that is from a multispecies perspective. There is a growing recognition that a single-species approach is inappropriate and a threat to long-term sustainability. It has been suggested that within the Gulf of Maine system there has been a major shift in the balance among the various competitors, predators and prey over the past decade. During this period plankton-feeding sea herring tripled in abundance, dense schooling piscivorous mackerel increased by a factor of two to three, and there was a comparable increase in the number of sharks and skates. During this same period the traditional mainstays of the North Atlantic ground fishery, namely, cod, haddock and flounder, collapsed to all time low levels. Although the interactions among these various species are poorly understood, it seems reasonable to suspect that declines in abundance of primary food fishes from Georges Bank may be related to increases in abundance of less desirable species. Although the evidence for a significant shift in community structure is compelling, attempts at relating causes and effects are largely conjectural and may be impossible to measure or assess. From the point of view of resource users, the critical question is whether this change represents the establishment of a new ecological equilibrium or whether, in time, the ecosystem will revert to some semblance of its former community structure.

6.2.4 Changes in fish assemblages

There seems little question that excessive exploitation of particular fish stocks can alter the ecological equilibrium of marine fish assemblages. There is considerable debate regarding the nature and extent of such shifts in equilibrium that have occurred in east coast fish communities during the past decade. The bulk of the speculation has centered on the possibility of shifts in community structure from teleosts towards elasmobranchs and from demersal assemblages towards pelagic ones. There is speculation among some fisheries biologists, although little unequivocal evidence, that the current high levels in dogfish populations are somehow associated with drastic declines in some groundfish stocks in the region. The same question has been raised in terms of the demersal fish assemblages on Georges Bank. The concern is whether or not the ecological balance has been irreversibly changed towards elasmobranchs (a low value group commercially). The long-term ecological ramifications of such a shift in the whole system are unknown. A perhaps more important question from the fishing industry viewpoint has been how reversible any such community structural changes may be when fishing pressures are curtailed or redirected towards underutilized species.

> ***"There is speculation among some fisheries biologists....... that the current high levels in dogfish populations are somehow associated with drastic declines in some groundfish stocks in the region."***

6.2.5 Geomorphologic and oceanographic changes

There is difficulty in unequivocally linking many of the observed changes in marine communities and habitats directly to specific human activities in the region, because they are occurring against a backdrop of poorly understood natural variations in the marine environment. Some of these changes are gradual and progressive, while others involve cycles of varying periodicities. The precise nature of these changes and their ecological consequences are only poorly understood, the more so as their time scales increase. Such confounding natural phenomena include long-term changes in sea level, decadal or longer variations in tidal amplitude, fluctuations in the velocity and direction of currents, alterations in sediment dynamics, changes in coastal and seabed geomorphology, variations in terrestrial runoff and gradual changes in seawater temperatures and salinities. Clearly many of these phenomena are interrelated, and as well, some are undoubtedly influenced by regional or global-scale changes indirectly induced or exacerbated by human activities (*e.g.* global warming). Preliminary studies described more fully in Chapter Two by Greenberg and Petrie, indicate that in recent years, most physical oceanographic measurements made in the Bay have been within the range of long-term fluctuations. A notable exception is an apparent trend to increasing tidal amplitude in the Bay that has been attributed to the effects of rising sea level or the redistribution of sediments in the upper reaches of the Bay. The possible ecological ramifications of such large-scale natural environmental changes are described more fully in Chapters 1 and 2, and in Daborn and Dadswell (1988).

6.2.6 Climatic and atmospheric changes

A host of climatic and atmospheric changes are taking place simultaneously in the region of the Bay of Fundy, largely with unknown single or joint effects on its flora and fauna. These include: alterations in sea surface temperatures; increased amounts of UV-B radiation reaching land and sea surfaces; reduced stratospheric ozone, but localized areas of increased ground-level ozone; increased CO2 levels; and the presence of acid rain and toxic rain over much of the region. There is a particular concern about the possible influences of the UV-B radiation on diatom species and assemblages that overlay the mudflats in the basins of the Upper Bay.

6.2.7 Marine contaminants

Contaminant inputs into the Bay of Fundy are many and varied (*e.g.* industrial, terrestrial, airborne, radionuclides, municipal, domestic, agricultural). In coastal areas world-wide, contamination from land-based sources is increasingly degrading benthic and intertidal habitats that are important to many marine species at various stages of their life cycles. The sources, scope and nature of this contamination are considered in more detail in Chapter 3. The toxicity of many of these contaminants has been well documented, and many not only directly kill marine organisms at relatively low concentrations, but may also, at much lower concentrations, induce sublethal physiological and biological dysfunctions that subtly reduce the long-term survival of populations. Perhaps more immediately relevant from the viewpoint of resource harvesting, is the fact that in many areas, contaminants from municipal and industrial sources have severely reduced the harvestability of valuable stocks of shellfish because of the threat to human health. The most notable resource thus affected at present is the soft-shell clam, contaminated by sewage-borne bacteria. In addition, there is growing concern that the continuing build-up of contaminant levels in coastal habitats will further reduce the relatively limited areas that are suitable for future aquaculture developments. This is particularly significant in a highly competitive international industry, where habitat quality is an increasingly important marketing factor.

> ***"in many areas, contaminants from municipal and industrial sources have severely reduced the harvestability of valuable stocks of shellfish because of the threat to human health."***

Specifically, major sources of contaminants are industrial (especially pulp and paper) and municipal effluents; non-point terrestrial inputs from river basins; ocean dumping of harbour dredging spoils; chronic oil discharges from the Saint John Refinery and related industrial operations and shipping; aquaculture wastes inputs; and long-range toxics transport (biotic/abiotic routes). The inputs are well-known and well-characterized (Eaton *et al.* 1994; DOE, Dartmouth unpublished records), but with the exception of dredging spoils, the extent and degree of their individual and cumulative effects/impacts on Bay ecosystems are virtually unknown.

6.2.8 Nutrient inputs

Anthropogenic point sources of excess nutrients include the many aquaculture projects in the south-western part of New Brunswick, non-point riverine and agricultural sources, urban runoff, *etc.* The fate and effects from aquaculture inputs are reasonably well understood, and localized. The extent of this issue broadly for the Bay of Fundy has yet to be determined.

6.2.9 Occurrence of natural toxins

There are occasional problems with blooms of toxic dinoflagellates and other noxious microorganisms, and there are some uncertainties as to whether the frequencies of such outbreaks are increasing as the consequence of human activities around the Bay. Our awareness of, and concern about, such phenomena may simply be rising in proportion to the rapid spread of aquaculture operations in the region. These outbreaks result in closure of shellfish beds, reduced marketability of cultured shellfish, toxic effects on cultured finfish, and periodic human illness. The consequences of the periodic presence of such toxins in the food chains of the Bay for wildlife populations *(e.g.* ducks, seabirds) are largely unknown.

6.2.10 Physical stresses in rivers and estuaries

The anthropogenic stresses on most diadromous fish in Fundy region rivers and estuaries have been severe for many decades and have had devastating impacts on their populations. In certain areas, some species, such as the Tom cod in Frost Fish Creek and the Sturgeon in the Avon River, appear to have been almost completely extirpated. In almost all cases the environmental insults are multiple and insidious, making it virtually impossible to completely unravel causes and effects. At best we can simply tally those anthropogenic factors that appear to be the most serious. Agriculture, forestry and construction in the riparian zone have resulted in extensive erosion and siltation in most river systems, destroying large areas of critical spawning habitat for many species. Construction of causeways, barrages and other obstructions in virtually all rivers emptying into the Bay of Fundy, without adequate provision for fish passage, has severely disrupted fish spawning migrations. The installation of power generating turbines in some of these structures, such as the Annapolis Tidal Power Station, exacerbates the situation by imposing a continuing steady mortality on already stressed populations during their migrations. Many of the rivers, streams and lakes in the Fundy watershed, particularly those of south-west Nova Scotia, are undergoing excessive acidification, largely as a consequence of their location down-wind of major central and eastern U.S. industrial centres. This has had a devastating impact on the biota of many of these waterways, rendering them unsuitable as habitat for many diadromous and freshwater fishes.

6.2.11 Changes in saltmarsh/mudflat dynamics

Since settlement in the mid-1600's, there has been extensive reduction in the areal extent of the saltmarshes of the upper Bay, and many changes to sediment movement and deposition due to upstream dams, barrages and causeways. Changes in the carbon flow, and in the movement and deposition of sediments, in the upper basins have been a source of concern and study. These concerns are reviewed in Chapters 1, 2 and 4. The long-term fate of artificial sediment accumulations, such as at the Windsor causeway and below Moncton, has yet to be determined, and the overall impact of such depositions to the upper Bay's productivity and wildlife is unknown.

6.2.12 Disruption of sediment/*Corophium*/ shorebird links

The fact that profound changes may be occurring in the marine environment of the Bay of Fundy has perhaps been most strongly brought home by recent observations on the abundance, distribution and feeding behaviour of shorebirds, particularly of the massive semipalmated sandpiper populations that inhabit the upper Bay. Other studies suggest that the distribution and abundance of the birds' primary prey, the burrowing amphipod *Corophium volutator* has also changed significantly over the past couple of decades and the birds distribution and foraging behaviour appears to have altered correspondingly (Shepherd and Partridge 1994). Most disturbing is the suggestion that as a result of these changes the sandpiper populations are being forced to forage for substantially longer periods in order to acquire sufficient lipid reserves to sustain them on the long migration to South America. Preliminary studies

> ***"While the geographic extent and precise physical nature of these sediment changes require further investigation there is a growing suspicion that they may reflect a delayed response to decades-old barrage construction on most of the rivers in the region".***

suggest that the apparent changes in the *Corophium* populations are related to fundamental and widespread changes in conditions in the surficial sediments of their mudflat habitat. While the geographic extent and precise physical nature of these sediment changes require further investigation there is a growing suspicion that they may reflect a delayed response to decades-old barrage construction on most of the rivers in the region. It is also possible that large scale mudflat disturbances, associated with rapidly expanding baitworm harvesting operations in recent years, are also contributing to the observed changes in the fundamental characteristics of the sediments. This shorebird-*Corophium*-sediment interrelationship serves as one of the clearest representations of the myriad diverse, critical, and for the most part poorly understood, linkages between biological and physical oceanographic processes that exist in the Bay, and drives home the necessity of employing a truly multidisciplinary approach for scoping, investigating and resolving the marine environmental problems and concerns of the region.

6.2.13 Marine habitat alterations

There is growing concern about the long term consequences of various types of chronic disturbance of marine and estuarine habitats during resource harvesting and other activities. The trend to the use of large-scale, mechanized, more economically efficient harvesting methods almost always entails greater disturbance of more extensive areas of habitat. These concerns range from the impacts of heavy trawl gear on intertidal habitats (shown to be minimal) in the Minas Basin (Brylinsky *et al.* 1994) and subtidal ones elsewhere, to the impacts on benthic habitats and communities of proposed aggregate extraction from offshore areas near Scotts Bay. There are also many unanswered questions about the impacts on rocky shore habitats and the implications for intertidal, benthic and pelagic communities of intensive mechanical harvesting of rockweed beds, about the impacts on intertidal community structure and integrity of vacuum harvesting of periwinkles, as well as about the effects of intensive and repeated digging for baitworms on the stability and ecological integrity of large areas of Minas Basin mudflats. The scale and intensity of most of these activities have escalated dramatically during the past decade and more and more adverse ecological impacts are being observed and predicted. There have been disturbingly few, if any, studies of the longer-term ecological consequences of these harvesting activities or about the sustainability of the enhanced harvest levels.

6.2.14 Aquaculture impacts and conflicts

Fish farms concentrate fish in a small area and generate large quantities of particulate and dissolved organic waste. There have been concerns about the possible reduction of dissolved oxygen levels, both as a consequence of fish respiration and biological/chemical oxygen demand resulting from breakdown of organic wastes, and increased concentrations of dissolved nutrients such as ammonia and nitrates as products of fish metabolism (Wildish *et al.* 1993). These added nutrients could cause eutrophication and possibly trigger microalgal blooms in the vicinity of the cages with lethal or sublethal effects on fish stocks (Wildish *et al.* 1990a). However, it is generally felt that in most coastal areas of the Bay of Fundy, flushing and mixing processes would minimize any such impacts.

The effects of aquaculture wastes accumulating in benthic sediments are potentially more serious and have been the subject of extensive research as a result. The large amounts of particulate material generated by fish farms, in the form of uneaten waste feed and fish fecal pellets, ultimately descend to the sea floor, where they accumulate as "mariculture sludge", somewhat comparable to sewage sludge (Wildish *et al.* 1990b). The decomposition of these accumulated organic wastes results in a negative redox potential in sediments, releases noxious gases such as ammonia, methane, carbon dioxide and hydrogen sulphide, and significantly increases the biological and chemical oxygen demand in the sediment and possibly in the overlying water (Wildish *et al.* 1990b, Hargrave *et al.* 1993). The concentrations of some noxious compounds are at times sufficient to be toxic to infauna. Significant changes in benthic community structure have also been demonstrated in the vicinity of salmon farms (Lim 1991, Hargrave *et al.* 1993).

In addition to these continuing debates about the effects of aquaculture on traditional fisheries because of habitat degradation, there are also ongoing conflicts over the physical displacement of fishermen from certain coastal fishing grounds by aquaculture operations, which by their nature exclude all other uses in the areas that they occupy. Other concerns relate to the potential long-term ecological and genetic consequences for natural populations of finfish, particularly Atlantic salmon, of extensive interbreeding with escaped farmed stock. This is likely to be a continuing issue in light of such innovations as production of sterile fish, single sex populations and advances in genetic engineering become more widespread. There are also concerns that the highly concentrated stocks in fish farms may serve as foci for recurring outbreaks of fish diseases or parasites that might adversely affect local wild populations. A related issue is the growing use of a range of toxic chemotherapeutants in fish farms to control diseases and parasites and the many unanswered questions concerning the impacts of these agents on non-target organisms and on the survival and marketability of wild finfish and shellfish.

> ***"concerns that the highly concentrated stocks in fish farms may serve as foci for recurring outbreaks of fish diseases or parasites that might adversely affect local wild populations."***

6.2.15 Ecotourism and recreation

Ecotourism and outdoor recreation have increased steadily throughout the Fundy region in recent years and indications are that they will continue to be increasingly important components of the local economy of many coastal communities. Whale and seal watching in the vicinity of Brier Island and Grand Manan, birdwatching at many sites around the Bay, exploring the fossiliferous beaches at Parrsboro, deep sea fishing for marine species in many areas, sport fishing for various diadromous species in many rivers and estuaries, clam digging and a host of similar nature-related activities have become very popular with residents and visitors alike. While most of these activities are considered to be environmentally benign and generally sustainable, there is the ever present danger that the burgeoning popularity of a particular activity may ultimately put the underlying resource at risk. The possibility of adverse impacts of excessive disturbance on feeding whales and nesting seabirds have long been recognized and efforts are being made to minimize this risk. The growing use of all-terrain vehicles to explore beaches, mudflats and salt marshes and the potential long-term impacts of excessive traffic on some of these sensitive habitats has been less carefully considered, and is largely unregulated at present. Many of the adverse impacts of these recreational activities are subtle, and often not readily apparent until the cumulative effects of long periods of mild abuse suddenly appear. Because of the critical economic importance of many of these activities, and the likelihood that they will increase, it is vitally important that potentially adverse effects be identified and studied, so that effective action can be taken to mitigate their impacts on wildlife and habitats.

6.2.16 Marine transportation

The overall impacts of marine transportation on the Bay of Fundy ecosystem need to be clarified. This would include: describing the extent of impacts of increasing vessel traffic on marine mammal populations, particularly vessel strikes; the impacts of dredging requirements, as pollution sources; the fate and effects of oil spillages from shipping and offloading/onloading oil cargoes; the inputs of contaminants from the various fishing fleets, in ports and at sea, *etc.*

6.2.17 Coastal development

The extent and significance of impacts on shorelines and shallow coastal waters from cumulative coastal developments is little understood. Activities causing impacts include: house, campsite and trailer park developments on shorelines; wharf construction; groin construction *etc.*

6.2.18 Introduced species

An overall assessment of the effects of introduced species, either accidental or intentional, has not been conducted. It could consider the role of introductions in establishing present ecosystem structure; possible new influences of introductions on existing ecosystem structure; adverse effects of accidental introductions on resource harvesting and aquaculture operations (fouling, diseases and parasites).

6.2.19 Marine mammals: fisheries and aquaculture interactions

An assessment is required of the extent of predation by marine mammals on wild and farmed fish stocks, and the damage caused by them to fishing gear and aquaculture facilities. This would focus primarily on seals.

6.2.20 Cumulative and synergistic effects

The interactions of the diverse stresses discussed above, that may result in even greater degradation or "cumulative effects" over the long term, are poorly understood in the Bay and in most marine waters (Howells *et al.* 1990). Moreover, many of the observed stresses and perturbations could be affecting the Fundy system in completely unknown ways, perhaps through mechanisms such as discontinuities and synergisms (Myers 1995). In most instances it is the cumulative effect of many different stresses acting in concert that undermine the stability of a population in the long term. However, at present, our ability to assess and model the cumulative biological and ecological consequences of multiple environmental insults is limited. Attempts at quantifying the impacts of localized anthropogenic stresses on marine resources and habitats of the Bay are confounded not only by the fact that many of them are undoubtedly acting in concert, cumulatively or synergistically, but that they are also occurring against a backdrop of poorly understood, long-term, global-scale environmental changes, either anthropogenic or natural in origin, and random, linear or cyclic in nature. The possible influences on marine communities and ecological processes of long-term trends in tidal amplitude, current pattern, seawater temperature, ultraviolet radiation and freshwater run-off are discussed elsewhere.

> ***"The conservation of such palaeontological sites to ensure that there is an adequate opportunity for proper scientific study of their fossil bearing strata is a world-wide problem that is not readily soluble."***

6.2.21 Designation of marine protected areas

Marine protected areas should be considered in areas of unique wildlife and ecology (*e.g.* Brier Island), and of other natural attributes(*e.g.* fossils).

6.2.22 Critical land-sea interactions

The issue is one of determining how land-use in the several watersheds around the Bay is influencing its overall environmental quality and productivity. In particular, sediment budgets for the Bay and its upper basins should be determined, to aid in the better management of activities that change sediment inputs and distribution.

6.2.23 Integrated coastal zone management

The issue is how to patch together the many individual science, management and resource-use efforts around the Bay into a comprehensive program, interface it with the Gulf of Maine Program, and identify critical gaps in science, management and communication.

6.2.24 Indicator/sentinel species

Indicators of the health of various features of the Bay are needed, in order to create a long-term data/information bank to assess trends in the Bay, from habitat restoration to resource sustainability. The challenge is how to set this up and run it over a period of many decades.

6.2.25 Protection of coastal fossil outcrops

Fossil outcroppings are a natural resource that are not usually taken into acount in more traditional coastal zone management thinking. The conservation of such palaeontological sites to ensure that there is an adequate opportunity for proper scientific study of their fossil-bearing strata is a world-wide problem that is not easily soluble (Crowther and Wimbledon 1988). In the Fundy region the fossil cliffs at Joggins are internationally renowned for the quality and uniqueness of their vertebrate and other fossils and "constitute one of the most important palaeontological sites in eastern Canada" (Ferguson 1988). Although the cliffs are legally protected by the Special Places Protection Act there are concerns within the palaeontological community that the zone of protection is not adequate and that the protected status of the region is not sufficiently publicized or monitored. A brief description of the site and a more detailed discussion of these conservation concerns can be found in Ferguson (1988).

6.3. Scientific questions pertaining to the environmental issues

The following key questions arise from the preceding chapters in this report and are presented here, grouped by general discipline, primarily as a catalyst for further discussion and action.

6.3.1 Physical oceanography and sedimentology:

1. *Which physical changes are progressive and which are cyclical?*
2. *Are present numerical models adequate?*
3. *What are the predicted effects of sea level rise?*
4. *What historic and current human activities affect basic physical processes?*
5. *What are the predicted effects of increased UVβ?*
6. *What are the predicted effects of global temperature changes?*
7. *What other climatological changes may be of significance? (acid rain included)*
8. *Are perceived changes in sediment distribution/properties related to local or system-wide phenomena?*

6.3.2 Chemical environment

1. *What are current sources and trends in nutrient inputs?*
2. *What are the ecological effects of nutrient inputs?*
3. *Have there been real changes in phytotoxin occurrence or distribution in recent decades?*
4. *Are there any ecological effects of chronic oil contamination on wildlife in the Bay of Fundy?*
5. *Is our current understanding of sources and pathways of contaminants in biota of the Bay of Fundy adequate?*
6. *Are current research and monitoring activities of contaminant levels in biota of the Bay adequate to assess ecological health?*

6.3.3 Biological environment

1. *What are the critical habitats in the Bay of Fundy?*
2. *Which of the observed changes in species abundance (e.g. herring, zooplankton, phytobenthos, seaweeds) are cyclical and which are progressive?*
3. *Are any species changes chaotic?*
4. *What are the principal pathways of carbon flow?*
5. *What new research should be initiated on the benthos?*
6. *In what ways are our ecosystem models inadequate? (see Appendix 1)*
7. *How important is the biodiversity in the Bay of Fundy within the Gulf of Maine system? What are the principal potential threats to biodiversity?*

6.3.4 Marine resources

1. *Are the current declines in pelagic/demersal fisheries reversible?*
2. *What are the long-term implications to the Bay's natural ecosystems and energy flow of intertidal and subtidal resource extraction. (e.g. rockweed, baitworms, urchins, aggregate)*
3. *How do we close the gap between resource extraction ventures and sustainable management strategies, policies and regulations?*
4. *Are there unrecognized effects on wildlife species from changes in harvesting technology and declines in the commercial fish stocks?*
5. *How do we more effectively integrate science, management and community enterprises?*

6.3.5 Broader issues

1. *How well understood are the cumulative effects of the stressors on the Bay of Fundy ecosystem?*
2. *How well understood are the joint and possibly synergistic interactions among the stressors acting upon the Bay of Fundy ecosystem?*

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CHAPTER SEVEN

FUNDY MARINE ECOSYSTEM SCIENCE PROJECT: WORKSHOP SYNTHESIS

J.A. Percy, P.G. Wells, A.J. Evans and D.C. Gordon, Jr.

7.1 Introduction

The Fundy Marine Ecosystem Science Project Workshop was held at the Old Orchard Inn, Wolfville, Nova Scotia, from January 29th to February 1st, 1996. Fifty nine scientists and managers from various government agencies, academic institutions and private groups throughout the Fundy Region attended. The list of workshop registrants and their affiliations are tabulated in Appendix 3. The agenda for the workshop is presented in Appendix 2. The FMESP Steering Committee had decided early on that as much of the workshop discussion as possible would take place in plenary session to maximize the opportunities for information exchange. The workshop did, however, split into two working groups on the Wednesday afternoon and evening, to consider separately, issues specific to the upper and lower Bay. Summaries of the deliberations of each of these working groups are presented in section 7.3.3 below.

> *"this workshop.....was to serve as a catalyst for stimulating the further research that is so urgently required in order to address the large number of issues that threaten the integrity of the Bay's ecosystem."*

The FMESP Steering Committee also decided that this workshop should not restrict itself to being merely a forum for reviewing recent information on the oceanography, ecology and wildlife of the Bay of Fundy, important as this is. Even more importantly, it was to serve as a catalyst for stimulating the further research that is so urgently required in order to address the large number of issues that, alone or cumulatively, may threaten the integrity of the Bay's ecosystem. To this end, participants in the workshop were urged to identify areas where further research is particularly needed, as well as to suggest potentially fruitful research approaches that might further enhance both the quantity and quality of data available. The ideas put forward are summarized in the discussion that follows, and many of the recommendations form the basis for the proposed action plan for fostering scientific research in the Bay of Fundy region that is outlined in section 7.4 below.

7.2 Why a Bay of Fundy research initiative?

The Bay of Fundy is a marine region of great ecological and economic importance. It is internationally renowned for its exceptionally high tides and an ecosystem that is widely recognized as being unique in many ways. Some of the unusual natural features of the Bay, in addition to its high tidal amplitude, include high suspended sediment concentrations, light limitation and its ecological importance to many migratory species of fish, birds and marine mammals, particularly the endangered North Atlantic Right Whale. Its wildlife is internationally recognized and forms an important component of the region's rapidly growing ecotourism industry. In addition, its valuable fisheries resources have long been vital to the economy of many coastal communities, and new initiatives in aquaculture, harvesting of previously underutilized species, marine-oriented ecotourism and sub-sea mining are further expanding this dependency on the Bay's marine resource base.

However, in recent years the environmental integrity of the Bay has been compromised on many fronts. The most pressing of these environmental concerns are briefly described in Chapter 6. There is a growing public awareness that all is not right with the Bay, and that prompt action is required to

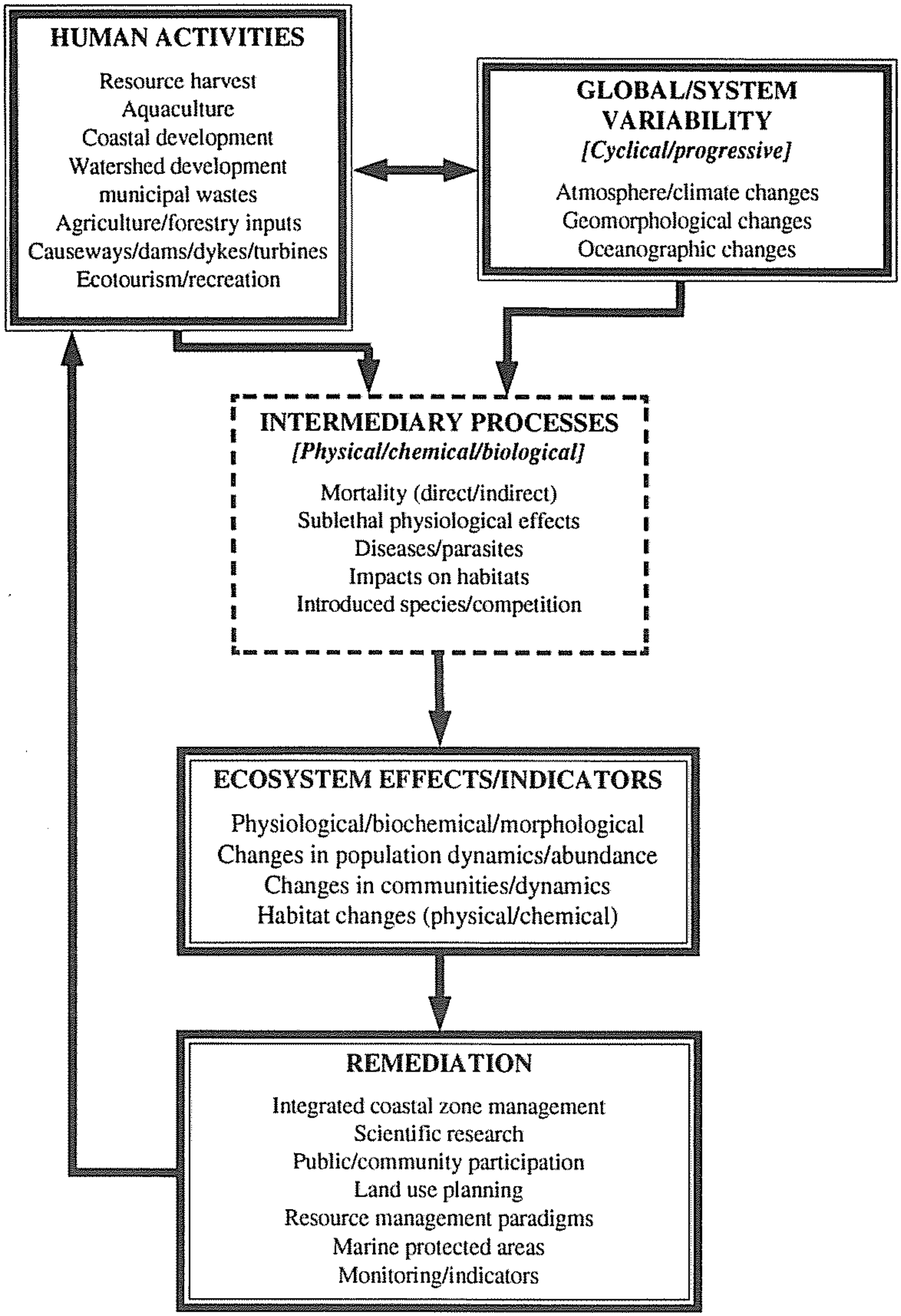


Figure 7.1 Linkage between stresses (human and natural), ecological processes and effects, and remediation activities in the coastal zone.

restore it to health. Within the region's scientific community there is a palpable sense of urgency with regard to developing an understanding of the nature, and underlying causes, of the environmental changes that are occurring. With a few exceptions, the recent science has been largely the purview of individual investigators and programs, and not driven by any single unifying theme or imperative; it has not yet been well integrated. As well, there is a growing recognition of the urgent need for formulating comprehensive, scientifically sound, coastal zone management initiatives to arrest or reverse the more undesirable trends and ensure the sustainability of the Bay's many resources in perpetuity. We must act soon, and we must act decisively, aided by the new Oceans Act.

A graphic overview of the general linkages between some of the environmental stresses, ecological impacts and remedial actions that served as a unifying framework for much of the workshop discussion is presented in Figure 7.1. This diagram emphasizes that the observed changes in the ecosystem are a reflection of both human activities in the coastal zone and inherent natural system variability acting in concert, factors that are often difficult to separate and are often interacting (Myers 1995, *see Chapter 5 references*). These environmental stresses, be they natural or anthropogenic, are subsequently responsible for a wide array of intermediary physical or ecological responses that are translated into the many observable ecosystem level effects that we recognize as undesirable changes in the system as a whole. An array of potential remediation options can be invoked to halt or reverse some of these undesirable trends, and are primarily focussed on regulating environmentally harmful human activities in the coastal zone.

Much of the present scientific interest in the system is focussed on quantifying the linkages between human activities/system variability and the poorly understood intermediary processes and ecosystem changes, as well as on identifying useful and meaningful indicators of ecosystem change. On the other hand, the management interest is, understandably, primarily focussed on the linkages between possible remediation options and human activities, recognizing that little can be done about the effects of natural system variability. Figure 7.1, however, clearly demonstrates the connectedness and interdependence of these social, scientific and management pursuits and thus emphasizes the importance of close cooperation and ongoing communication between scientists studying the Bay of Fundy processes and managers responsible for conserving the Bay of Fundy resources. This interaction was a continuing subtext throughout the workshop, and is considered at greater length in section 7.3.2 below.

7.3. Information needs and research directions.

7.3.1 Workshop synthesis

During the allotted two and a half days, workshop participants ranged freely over a broad scientific landscape encompassing many disciplines, particularly geology, oceanography, biology and ecology. Their deliberations raised many interesting scientific and resource management issues and identified a wide array of challenging opportunities for individual and cooperative action. The discussions took place in plenary sessions, in informal evening presentations as well as in the two working groups. The "gist" of these discussions were captured in the detailed notes of several rapporteurs, in the working group overview presentations by Peter Lawton and Sherman Boates and in Don Gordon's summarizing presentation "Reflections on Bay of Fundy Research". Additional worthwhile suggestions concerning future directions were contributed in the final four presentations dealing with aspects of the general theme "Expanding the Vision", by Dave Townsend, Mick Burt, Sherman Boates and Steve Hawboldt. The rapporteurs notes of these various presentations have been drawn upon extensively in preparing this synthesis. A variety of other forward-looking recommendations pertaining to specific issues are to be found in many of the chapters prepared for the workshop background report, revised versions of which now comprise chapters 1-6 of this document. In order to avoid undue repetition, and to ensure a unified presentation of the diverse ideas generated during the workshop, this chapter attempts to distil the principal conclusions and recommendations from all these sources. The principal goals are:

i) to identify the important marine physical, chemical, biological or ecological processes that have been inadequately studied in the Bay of Fundy system, and thus contribute to our inability to account for major ecosystem perturbations in the region

ii) to recommend multidisciplinary research initiatives to narrow some of the more important data gaps

iii) to put forth ideas for sustaining the cooperative spirit and momentum of the workshop as well as broadening its participant base

During the workshop sessions there were many presentations and ongoing discussions about recent research results in various fields. Most of this more factual material will not be reiterated here, but has instead been incorporated into the appropriate sections of the original workshop background papers which have been extensively revised in the light of points raised during the workshop, as well as written comments submitted later by participants and others.

> ***"better communication and cooperation between research scientists and environmental managers is crucial ...... both have important roles to play in preserving the integrity of the Bay of Fundy ecosystem."***

7.3.2 Resource management and science

Workshop participants wholeheartedly agreed that better communication and cooperation between research scientists and environmental managers is crucial, and that both have important roles to play in preserving the integrity of the Bay of Fundy ecosystem. Science-driven and management-driven research share much in common, although their basic objectives tend to be different. It is important to understand and appreciate the different roles and perspectives of each. Research scientists are primarily interested in building a general knowledge about environmental processes, and science-driven research focusses primarily on these processes and attempts ultimately to understand the functioning of the entire ecosystem. Research scientists can thus be proactive and must usually plan their activities over time scales of several years. Environmental managers, on the other hand, tend to be more issue oriented, and because of their regulatory role are forced to be more reactive. They need instant answers to practical scientific questions, even if those answers are little more than gut reactions. If managers do not respond rapidly, development proposals can still proceed without the benefit of environmental input. Science is only one of the variables that has to be considered in the decision-making process. It was disappointing that more environmental managers, especially from protection and conservation, were not able to attend the FMESP workshop. This probably reflected their heavy workload rather than a lack of appreciation of the importance of science, or of interest in finding out what is going on within the research community. The managers who did attend found the workshop to be informative and rewarding. We need to explore other more practical formats than two and a half day retreats to facilitate the exchange of information between research scientists and environmental managers in the Fundy community.

An important role of scientists, especially those employed in government laboratories, is to provide scientific information and advice to environmental managers. In general there are three levels of response to most such requests. Quite often the information required can be conveyed over the phone, or in a few written pages that take only a few hours at most to produce. However, frequently it is necessary to compile data, do a literature review and prepare a more comprehensive synthesis of information. This often involves several scientists and can take several weeks or longer to produce. Both of these levels of response are dependent on having a body of well-trained and experienced scientists who understand basic environmental principles, are involved in research and know where to go for additional information when needed. Much of the necessary experience comes from actively engaging in various kinds of science-driven research. On occasion, the management questions being asked cannot be answered with existing information, either in-house or in the scientific literature, and there is the need to undertake new research projects. Such management-driven projects tend to be much more focussed on specific issues and therefore consider only a limited number of processes and a more restricted spatial domain (they are site specific). Nevertheless, as with science-driven research projects, it is important to combine theoretical and empirical approaches. Examples of specific issues currently driving management oriented research in the Bay of Fundy include the environmental impacts of contaminants, phycotoxins, aquaculture trawling and the interaction between shorebird populations and mudflat characteristics. If well designed, management-driven research can still yield important scientific contributions. Much of the government research being conducted today in the Bay is of this nature, and some is funded under special, but short-term, initiatives such as the 1990 Green Plan. However, we are falling rapidly behind in our science-driven research, and the extensive scientific expertise that still exists today in the region is largely the result of past substantial investments in science-driven research.

7.3.3 Upper Bay and Lower Bay

Although many of the initial concerns that sparked the concept of a Fundy Marine Ecosystem Science Project originated largely in the upper Bay, it is generally recognized that a broader, Bay-wide approach will be needed to resolve these issues. In fact, one of the constant refrains throughout the workshop was that all parts of the Bay are interconnected and that we must view it as a complete, holistic ecosystem. However, in addition to an understandable tendency to discuss Bay of Fundy issues along largely disciplinary lines, there is an equally strong proclivity to consider issues geographically within the Bay. Thus, during the workshop, participants divided into two working groups, one focussing on the upper Bay and the other on the lower Bay because it was clear that some issues are of greater import in one region than the other. In the upper Bay, for instance, most of the interest focussed on factors influencing sediment dynamics and the implications for benthic and shorebird ecology. In the lower bay, on the other hand, the suite of interests tended to be much broader, encompassing fisheries management concerns, and impacts of resource harvesting, aquaculture development, seafloor mining, toxic chemical inputs and other wildlife conservation issues. The following synopses attempt to distil the distinctive, geographically specific aspects of each of the two working group deliberations, while reserving the more general considerations, with implications for the Bay as a whole, for the subsequent sections of the chapter.

7.3.3.1 Upper Bay Working Group

There was general agreement that some major changes have taken place in the ecosystem of the upper Bay during the past few decades. There have been changes in both the distribution of sediments and in its properties, with accompanying evidence of large-scale erosion in some areas and deposition in others, suggesting the movements of large amounts of material within the Upper Bay. Although shorebird distributions in the region have changed considerably, possibly in relation to the sediment changes, it is not yet clear how widespread this phenomenon is, or whether the populations are increasing or decreasing, and whether or not the birds are finding it increasingly difficult to feed and thus acquire sufficient lipid reserves during their brief sojourn in the Fundy area. There do appear to have been substantial changes in the abundance and distribution of their principal prey, *Corophium volutator*, on some mud flats, but it is not yet clear how widespread or permanent these changes are. In addition, in recent decades there have been precipitous declines in fish populations in many rivers and estuaries. The Petitcodiac River was particularly singled out for comment, in view of recent proposals to partially restore the tidal regime in the river.

Although many of the changes in the upper Bay system are unequivocal, the causes of these changes are a matter of ongoing debate. Several possible natural and anthropogenic factors need to be examined more closely. The natural perturbations include rising sea level, changing tidal amplitude and changing oceanographic conditions (*e.g.* lower temperature) in the lower Bay. Some of the anthropogenic influences that undoubtedly play a role include the the centuries old dyking of large areas of salt marsh, the more recent construction of dams and causeways, commercial digging for mudflat invertebrates, trawling for fish and various other coastal zone developments.

The working group emphasized that a modelling approach is essential to gaining an understanding of the ecosystem processes that are occurring in the upper Bay, and that these models need to link physical oceanographic to sedimentological to biological processes. In particular there is need for a hydrology/sediment model that can predict and simulate sediment distribution patterns given different physical scenarios. Such models are necessary for assessing the relative importance of "natural" and anthropogenic influences in the region. Making the subsequent connections to ecological processes will be a much more challenging exercise. In terms of ecological modelling, three general approaches were identified:

> ***a modelling approach is essential to gaining an understanding the ecosystem processes that are occurring in the upper Bay....... these models need to link physical oceanographic to sedimentological to biological processes.***

i) Ecosystem scale models that focus on phosphorus, carbon, nitrogen and toxic contaminant budgets

ii) Simulation models, similar to the Cumberland Basin model, that focus on processes (these are useful for developing a sense of how the overall system works but are of limited value in resolving most management issues)

iii) Management issue oriented models that focus on specific species (e.g. Corophium-shorebird trophic links) or on specific ecological issues (e.g. impacts of an aquaculture farm on nearby habitats)

There is also a need to re-examine some of the old data and to obtain specific types of new data in order to refine estimates of the nature and extent of the changes that are occurring, and to gain insights into the likely causes of these changes and their further potential consequences.

7.3.3.2 Lower Bay Working Group

The lower Bay working group identified three particular issues for further discussion:

a) toxic chemicals in the environment and biota
b) ecological impacts of resource harvesting and aquaculture
c) ecosystem analytical methods, indicators and causes of change

The question of sedimentary dynamics, a major issue in the upper Bay, was briefly discussed but was not felt to be as important an issue in much of the lower Bay. Nevertheless, it was recommended that there be further research into the fate of sediment-bound radionuclides and other contaminants in the depositional areas southwest of Point Lepreau. Only the deliberations on toxic chemicals and ecological impacts of harvesting are considered separately here. Most of the points raised during the discussions of analytical methods and indicators of change were of more general applicability and are considered in various other sections below, particularly in section 7.3.4.4 on research methodology and new initiatives.

7.3.3.2.1 Toxic chemicals

In terms of toxic chemicals in the marine environment, a major concern involved the widespread use of antibiotics and pesticides in aquaculture. There is an increasing use of various chemotherapeutants to mitigate disease, parasite and fouling problems at aquaculture sites. There are questions about the accumulation of these compounds in benthic invertebrates, particularly those that are harvested, as well as about the possibility of development of more resistant strains of parasites and disease agents that require ever more potent remedies. There is also the possibility of amplification of disease problems in natural fish stocks. For most of the toxic compounds being used now, we know next to nothing about dispersion, residence times and routes and rates of bioaccumulation in non-target organisms. Apparently, a number of government agencies are currently conducting research on some of these issues, but there is great difficulty in accessing relevant information. There is clearly a need for more openness and more study with regard to this issue.

Inputs of heavy metals and organochlorines from various sources were considered a significant problem in many parts of the lower Bay. There appear to be conflicting signals in the measured body burdens for some anthropogenically derived materials. Long-range atmospheric transport appears to be an important consideration for some of these materials, although we know little about the sources of many of these compounds. Certain of the more important chemicals (*e.g.* mercury) have already been targeted recently for particular study, but there is a need for greater data exchange among different research groups. It was felt that EMAN (*Environmental Monitoring and Assessment Network*) nodes could be extended to facilitate such exchange. The fact that many migratory species (e.g. shorebirds, whales and fish) probably pick up a significant part of their body burden of contaminants elsewhere complicates efforts at local trophic level analysis.

The Point Lepreau Environmental Monitoring Program has been reduced as a result of funding cuts, and fewer indicator species and sample types are being analysed. Although reduced in scope, the program provides a long-term time series for radionuclide levels in several sample types in the marine, terrestrial and atmospheric environments. As a result of discussions at the meeting, it was felt that a food chain model, similar to that outlined in Chapter 3 for organochlorines, could be constructed using existing data for radionuclides. This might provide additional useful insights into the accumulation of isotopes through trophic levels.

> ***"All too often the potential impacts of a given activity are assessed in isolation, without due consideration of the possible cumulative, joint, and possibly synergistic, interactions with all other exploitative and developmental activities taking place in the region."***

The periodic outbreaks of natural toxins associated with specific phytoplankton blooms are a problem in some Fundy coastal areas. There was support for continuation, and even expansion, of DFO's phytoplankton monitoring program in the Quoddy region because of its importance in terms of public health, and to a number of industry sectors. The principal uncertainty at present appears to concern the role of increasing nutrient loading in coastal areas on the frequency and severity of toxic algal outbreaks. The interactions between toxins and wildlife health remains uninvestigated as well.

7.3.3.2.2 Resource harvesting and aquaculture

In the short time available it was not possible to consider the impacts of individual resource harvests but only to make some general observations. An important point, too often overlooked by resource managers, is that harvesting of any species will have ecological implications not only for the target species itself but for a diverse array of other ecosystem components and functional processes. This ecological "domino" or "ripple" effect has not been a significant consideration in the traditional resource management paradigm. This can be largely attributed to the fact that our very limited understanding of the nature and magnitude of many of the key ecological linkages makes it difficult to predict the full range of cascading ecological consequences of continually extracting a high proportion of the standing stock biomass of any given resource species. Recent trends to expand harvesting at the lower trophic levels, and to so called "key" species that may play a critical role in structuring habitat (*e.g.* rockweed), may only serve to exacerbate the situation, since a broader range of impacts may be magnified up the food chain to top-level predators (*e.g.* wildlife).

There was considerable concern also about the cumulative impacts of marine resource use activities that were characterized as either extractive (*i.e.* taking things out of the system, *e.g.* fishing , aggregate extraction) or additive (*i.e.* putting things into the system *e.g.* aquaculture production). All too often the potential impacts of a given activity are assessed in isolation, without due consideration of the possible cumulative, joint, and possibly synergistic, interactions with all other exploitative and developmental activities taking place in the region. There was a strong recommendation that decision makers should consider cumulative impacts on ecosystems of specific development proposals, in additional to nominal impacts. In this context there is a requirement for the development of new techniques to model impacts, particularly for the identification of proxy variables (*e.g.* low oxygen demand) by means of which multiple activities can be assessed as cumulative stresses. On the management side, there is a clear need for a more inclusive assessment process for new development proposals for both extractive and additive marine resource activities. A new regional peer review process for resource development proposals, recently initiated by DFO, needs to be monitored for its effectiveness in taking into consideration science, industry and community concerns.

In addition to the growing alarm about chemotherapeutant use in aquaculture discussed above, concerns were also raised about the spread of diseases and parasites and the effects of escapements on wild populations. Although the burgeoning ecotourism industry is touted as being environmentally friendly, there are also concerns that excessive growth may have adverse impacts on the wildlife of special interest as well as on other populations. Ecotourism activities should be carefully monitored to assess impacts on wildlife populations and habitats, and appropriate management procedures implemented to minimize impacts.

7.3.4 General information needs and research directions

In addition to the above regionally oriented issues and information requirements dealt with by the two working groups, there were many points raised throughout the workshop that are applicable to research and resource management needs in the Bay as a whole. From a research scientist's perspective, there seem to be three basic questions to address in determining the priorities for future research in the Bay. The first is, what changes are occurring in the Bay of Fundy ecosystem? The second is, why are these changes occurring, and are they part of the natural variability or are they due to human activities? The third is, what more do we need to know; what are the important information gaps and how can they most effectively be filled? From the perspective of an environmental or resource manager these three questions might be expressed a little differently. What is the problem? What is the cause? How can we fix it? Many of the changes that seem to be occurring in the system have been documented, or at least identified, in the earlier chapters of this report. Similarly, recent advances in our knowledge about the Bay's ecosystem have been reviewed in some detail. One of the objectives of the workshop, and a principal focus of this chapter, is to try and identify what new information is needed in order to address some of the critical issues summarized in Chapter 6.

In comparison with many marine areas, the Bay of Fundy is a data-rich region and there is a good general understanding of its basic environmental processes and its natural resources. This can be attributed to the numerous government laboratories and universities in the region and to the many research programs, dating back almost 100 years, driven primarily by basic science, fisheries science and concerns, and past proposals for tidal power development. Increasingly, however, the Bay of Fundy is being influenced by human activities. For example, contaminants are widely distributed in water, sediments and biota; these include metals, organics, nutrients and micro-organisms. Engineering works such as dams, dikes and causeways have caused major physical and habitat impacts. Over-fishing has contributed to the depletion of many important resource species and certain fishing practices have resulted in destructive by-catches and altered benthic habitats. However, despite our relative wealth of scientific information, we don't fully understand the long-term significance of these many impacts. In fact, the principal impetus for FMESP was the realization that many changes now taking place in the ecosystem of the Bay cannot be explained on the basis of our current scientific understanding of its fundamental processes, and certainly should not be addressed in isolation from the whole ecosystem.

Clearly information needs and recommended research directions are in reality two sides of the same coin, and inevitably the two themes were interwoven during the workshop discussions. They are similarly treated in the following synopsis, which for purely heuristic reasons has been divided along the traditional disciplinary lines of oceanography, geology, sedimentology, biology, ecology and resource management. In adopting this convenient and conventional approach, however, there is an ever-present danger that one of the most emphatic and recurring messages of the workshop will be obscured; namely, that in the Bay of Fundy, perhaps more than in other marine areas, oceanographic, sedimentological and biological processes are inextricably intertwined and must be considered together for a proper understanding of ecosystem dynamics and health. However, we are not yet at the stage where we can emulate particle physicists in contemplating a unified "theory of everything", and must instead be content with highlighting some of the more obvious and important of the interdisciplinary linkages.

> ***"in the Bay of Fundy, perhaps more than in some other marine areas, oceanographic, sedimentological and biological processes are inextricably intertwined and must be considered together for a proper understanding of ecosystem dynamics and health."***

7.3.4.1 Oceanography

Perhaps the underlying message emanating most from this workshop is that in the Bay of Fundy, physical processes, particularly the intense tidal regime, drive the ecosystem dynamics. We have an excellent overall understanding of the physics of the Bay and are fortunate to have a suite of well-tested and state-of-the-art numerical models at our disposal. However, fine-tuning of these models can and should take place, in particular to improve their applicability to intertidal regions and to account for changes in bathymetry and shoreline configuration. The importance of adopting such a modelling approach for the investigation of oceanographic processes was reiterated throughout the workshop. Sound physical oceanographic models are essential for a better understanding of the functioning of the entire system, and have many scientific as well as management applications. Achieving such an understanding is complicated by the fact that the Bay is a highly variable system. It was generally felt that with respect to most oceanographic features "we are in variable times", and that there is a need to look more carefully at the naturally occurring variability range of different oceanographic properties before it will be possible to ascertain the effects of human activities on the ecosystem. Sea level has fluctuated markedly since the most recent glaciation, and while there is some uncertainty as to the exact rates, both sea level and tidal amplitude continue to increase today. Much of the variability is cyclical in nature, such as the annual cycles of light, temperature and ice, as well as numerous tidal cycles of differing periods such as the 18.6 year nodal cycle. Other changes tend to more progressive (at least in the human time-frame) in nature, such as sea level rise. Some variability may represent relatively rapid changes in the state of the ecosystem, due either to natural causes or human-induced impacts. The high degree of natural variability makes it difficult, if not impossible, to discriminate changes in the system due to human activity. In addition, oceanographic conditions in coastal areas, such as the Bay of Fundy, are often strongly influenced by offshore oceanographic events. The dynamics of many of these offshore-inshore interactions, such as periodic intrusions of deep cold water layers or of warm core rings from the Gulf Stream, are generally poorly known, and largely unpredictable, at present. They can, nevertheless, have profound impacts on the biological community structure and production of near-shore ecosystems.

It is generally recognized that the high tidal amplitude in the Bay of Fundy ensures that the water is well mixed vertically in much of the region. However, it is becoming increasingly clear that in some areas significant stratification of the water occurs, particularly during the summer months, and that this may have important implications for both pelagic and benthic biological production. The spatial distribution and temporal occurrence of these zones and their linkages to biological processes are poorly known at present, and should be the focus of concerted multidisciplinary study in the near future. In addition, there is a need to examine the influence of the 18.6 year cycle in tidal amplitude on the degree and extent of stratification and mixing in different areas of the Bay.

7.3.4.2 Geology and sedimentology

There was general consensus that while physical oceanographic processes play a critical role in structuring the marine environment in the Bay, it is the dynamics of the sediments that are the key to understanding the functioning of its ecosystems, particularly in the Upper Bay. In terms of its sediments, the Bay of Fundy is not in equilibrium and the bottom and shoreline are still eroding and shifting in many places. The Fundy system contains a large amount of unconsolidated sediment which can be redistributed as a result of storms, ice, changes in sea level and engineering works. This redistribution can be between the upper and lower Bay as well as between the intertidal and subtidal zones. Many of the observed environmental changes in the Bay reported at this workshop may be related to sedimentological processes. Sedimentology was an important issue in 1976 when scientists first gathered in Wolfville to consider the potential impacts of tidal power development. Despite a considerable research effort in the past twenty years, the study of sedimentation processes remains a significant issue today, and it was identified as still one of the highest priorities for research in the Bay as a whole. In particular there is a need to develop better sedimentation budgets that encompass larger geographic areas but with finer scale resolution. It is critically important to identify and delineate areas of erosion and deposition and develop models for predicting the movement of sediments among the various compartments. We need better hydrology and sediment models that can predict and simulate sediment patterns, given different physical scenarios, particularly in order to assess the relative importance of "natural" and anthropogenic influences on sediment dynamics. It was generally felt that the necessary further step of relating sediment dynamics to the regulation of biological production processes, so critical for wildlife, will be an even more challenging exercise.

The extensive dune fields off the Nova Scotia coast in the inner Bay were deemed worthy of extensive study, particularly in light of recent proposals to extract large volumes of the high quality aggregate for industrial use. We need to know what caused these sand waves to form and what dynamic processes are currently at work in their vicinity. It was felt that extensive and periodic surveys using multibeam technology would be helpful in ascertaining existing conditions as well as in studying the nature and rate of changes in bottom morphology that are occurring in many parts of the Bay.

The importance of particle dynamics in relation to the transport and ultimate fate of contaminants within the marine environment was stressed on a number of occasions. Particular concern was expressed about the accumulation of contaminants in certain depositional areas, such as in the vicinity of Grand Manan Island, that are particularly important in terms of marine resource harvesting and wildlife aggregations. It was felt that coring insuch areas could provide valuable information about the history of both sedimentary processes and contaminant inputs in the region.

7.3.4.3 Biology, ecology and resource management

For most animal and plant populations in the Bay our knowledge of population and community dynamics is still too meager to distinguish between natural population cycles and progressive shifts in species assemblages. In only a few cases have we been able to detect shifts in distribution or population size of certain species and even then, identifying the underlying causes of the observed change has proven problematical. Given the known rich biodiversity of the Bay, it is evident that we need to focus our efforts to enhance understanding of its many populations and their dynamics. A number of taxonomic groups were identified as meriting particular attention in the short-term.

Because of the need to develop a better understanding of the Bay as a complete ecosystem, it is recommended that field studies focus on the base of the food web, in particular on primary production processes. Highest priority should be given to a study of phytoplankton which are responsible for most of the primary production in the Bay; very few direct measurements have been made. Second priority should be given to macrophytes, since not only are they important primary producers in the lower Bay but they also provide valuable, possibly 'critical', habitat. They are also being intensively commercially harvested and the ecological impacts of this practice are not fully understood. Third priority should be given to mudflat algae, particularly diatoms, which not only provide food for invertebrates but also affect sediment properties. In fact, the whole question of the role of biological communities on the stability of mudflats was felt to be important in various areas of both the upper and lower Bay. It is also important to collect more data on community respiration which can be compared with primary production to determine whether specific areas are autotrophic or heterotrophic. The production and export dynamics of saltmarshes are relatively well known.

A variety of other significant data gaps was identified in our knowledge of the benthic community and its processes, although little attempt was made to priorize them in terms of importance. The fates of the large production of benthic seaweeds are not well known, particularly in relation to the pathways and rates of utilization. As described in chapter 5 there are suggestions that the degradation of macrophyte detritus may be important to some marine communities. Also, information about the distribution, standing crop and productivity of rockweed beds as well as on the significance of their role as nursery areas and feeding areas for many marine species is urgently needed in light of continuing harvests of rockweed in various parts of the Bay. As mentioned, benthic diatoms appear to be important in the ecology of the upper Bay mudflats, and more information is needed about their rates of production. In addition, little is known about the importance of resuspension of these benthic diatoms into the pelagic zone, particularly in the upper Bay where phytoplankton production is low. In view of their importance in local food webs, especially involving shorebirds, ongoing studies on the ecology of *Corophium* should be continued. Further studies on the ecology of most of the larger benthic invertebrates are needed, particularly those that have recently been targeted for increased harvesting as "underutilized species". At present there is not enough ecological information available about most of these species upon which to base sound management plans. In areas of middle and lower Bay there is a need for research on the influences of stratification and mixing processes on the nature and magnitude of benthic production. Virtually nothing is known about the operation or the importance of the benthic microbial loop anywhere in the Bay.

> ***"information about the distribution, standing crop and productivity of rockweed beds as well as on the significance of their role as nursery areas and feeding areas for many marine species is urgently needed in light of continuing harvests"***

The plankton community too, is poorly understood, particularly in terms of processes and rates. We do not yet adequately understand the linkages between many physical oceanographic processes and phytoplankton production and population dynamics. In view of the burgeoning aquaculture industry around the Bay and the continuing inputs of nutrients from a variety of terrestrial sources ,there is a critical need for continued monitoring of nitrogen and other nutrient inputs into the system and assessments of their effects on primary production and other processes, particularly in sheltered embayments and estuaries. Although the general structure of zooplankton communities has been well studied as part of larval fish surveys, we still know relatively little about distribution patterns, population dynamics and cycles of production of the key species. We know even less about the ecology of the smaller zooplankton species which have largely eluded the relatively coarse plankton nets used in the larval surveys. Similarly, we know almost nothing about the functioning of the microbial loop in the Fundy pelagic zone.

Because of their economic value, most of the biological research in the Bay has for decades been focussed largely on relatively few commercially important species. In spite of this, there is still considerable room for improvement in our knowledge of the ecology and life history of most finfish and shellfish species. The populations of many resource species have collapsed and our knowledge base is, in most cases, too inadequate to unequivocally identify causes or to propose effective remedial action. For instance, considerable effort has been devoted to enhancing the recovery of decimated salmon stocks in many Fundy rivers with little success, and we do not understand the factors that are hampering stock recovery. The current status of both shad and striped bass populations need to be monitored closely, and the population ecology of sturgeons in the upper bay and spiny dogfish in the Bay as whole should be carefully studied. The environmental factors controlling the distribution patterns of larvae of such fish as herring, tomcod and smelt need to be better studied, particularly in the upper Bay. Although the lobster populations of the outer Bay have been intensively studied, the productive populations and their habitats in the vicinity of Alma in the inner Bay have received little attention. The issue of expanding rockweed harvests and the likely broader ecological impacts of this activity were raised on a number of occasions. Clearly there is great concern that our present knowledge of the biology of rockweed and its role in the life cycles of many important resource species is inadequate to assess the impacts of harvesting. In view of this, a very conservative management approach and careful monitoring of harvesting impacts would appear to be the most appropriate strategies. There is widespread concern about the impacts of aquaculture operations on coastal ecosystems, and most of these have been summarized in Chapter 5. The principal focus of concern at the workshop was on the almost complete lack of information about the ecological impacts of widely used toxic chemotherapeutants for disease and parasite control, the long term effects of deposition of "mariculture sludge" and nutrient release, and the effects of concentrated aquaculture cages on coastal migration patterns of several fish species. We also know very little about the possible consequences of the proposed intensive mining of submarine aggregates on the benthic habitats and communities of the inner Bay. Before such extraction is approved a detailed environmental assessment of the area should be carried out.

A variety of critical wildlife issues in various parts of the Bay were raised during the workshop. The most pressing of these were the concerns about the stability of the food supply for intertidal-feeding shorebirds on the mudflats of the upper Bay. These concerns and the evident linkages between biology, sedimentology and oceanography in relation to this problem have been dealt with in detail in Chapter 4 and elsewhere in this document. The apparent large scale redistributions of phalarope populations in the vicinity of the mouth of the Bay in recent years were also cause for great concern and further highlighted the fact that our knowledge of zooplankton dynamics (a principal food source) in the region is not adequate to determine if the changes in bird distributions reflect major changes (*e.g.* reductions or movements) in zooplankton communities. Similarly, intensive monitoring of whale populations at the mouth of the Bay in recent years has also demonstrated a significant shift in the distribution of right whales; this is yet another observation that we are totally at a loss to explain, but it might also be related to changes in zooplankton communities, oceanographic properties, both or as yet unidentified factors. It was also noted that our knowledge of the role of the very large seabird populations in the pelagic food web in the outer Bay is totally inadequate.

7.3.4.4 Research methodology and new initiatives

In addition to discussing information gaps, workshop participants put forward a number of suggestions regarding general research approaches and innovative data gathering methods that should be incorporated into any future research program that is developed. Foremost among these ideas was the insistence that the Bay of Fundy and greater Gulf of Maine ultimately should be viewed as a single, holistic system and that studies must be designed with this in mind. In the time available it was not possible to fully develop the many suggestions put forward, but the following observations may be generally applicable to a variety of scientific initiatives in different parts of the Bay.

> *"In terms of basic scientific research we have largely been living off the investments that were made in earlier years."*

3.3.4.4.1 Use of existing data

There was agreement that most of the marine research carried out in the Bay during the preceding decade or so has been driven primarily by practical, localized, resource management oriented concerns, often of a short-term nature. Much of this research has not been conducive to the resolution of broader, more fundamental questions of ecosystem dynamics and health that involve longer time frames. This has contributed directly to our present inability to adequately understand the causes of the many ecosystem perturbations now apparent in the Bay of Fundy. In terms of basic scientific research we have largely been living off the investments that were made in earlier years. Although new research initiatives are required to resolve many of the more critical issues, it was also recognized that many useful insights into some problems might be achieved by a reexamination of existing data or samples from a variety of sources. Most data sets have many potential applications in contexts far beyond those for which they were originally collected. It was emphatically stated that we should not waste valuable resources gathering data that already exist in someone's files. There is a need for some effort to be put into the identification, evaluation and exchange of data sets already in existence. In many cases it may simply be a matter of asking new questions or analysing and synthesizing existing information in new ways. For example, it was suggested that the extensive, but scattered, body of data on the concentrations of various contaminants in the flesh of different marine species could be integrated and analyzed in a food web context and the results compared with comparable information from other regions, such as the Gulf of St. Lawrence. It also was thought that useful time-series information about trends in contaminants in marine food webs in the region could be obtained by analyzing samples from suitable museum specimens collected over many decades. The extensive collection of skins of marine birds held by the New Brunswick Museum was cited as an example of this approach.

> *"Although new research initiatives are required.......... it was also recognized that many useful insights into some problems might be achieved by a reexamination of existing data or samples."*

There are many other earlier data sets, or sample collections, that might also be usefully reappraised in the light of present information needs. A few that were suggested included: a) the extensive collections of oceanographic and nutrient data from various parts of the Bay held by the Marine Environmental Data Service (MEDS) in Ottawa; b) Oxygen data from many Fundy stations collected by the Marine Chemistry Division of BIO; c) Extensive zooplankton samples collected by DFO scientists from St. Andrews in conjunction with annual herring larval surveys; d) seabird census data collected by CWS that could be reanalyzed for evidence of cycles in reproductive success related to known oceanographic cycles. We need to thoroughly re-evaluate these and other historical data sources with a view to distinguishing between the effects of cyclic phenomena and progressive trends, and between natural and man-induced changes.

A variety of non-traditional sources of useful information was also suggested as being worthy of consideration. For example, old photographs taken in coastal areas might yield useful information about changes in coastal geomorphology, particularly in relation to modifications in saltmarshes or mudflats. Written records of various types might also yield useful information about past environmental conditions in different coastal areas. On several occasions the point was made that much useful information about long-term changes in the marine environment could almost certainly be gleaned from discussions with resource users themselves, and with other knowledgeable long-time residents of coastal communities. We must find effective ways to mine this extensive vein of traditional environmental knowledge (TEK). Although there was general recognition that such local information is potentially valuable in identifying long-term changes, there was some concern about how such information, primarily of an anecdotal nature, could be dealt with in the more rigorous scientific context.

7.3.4.4.2 Monitoring

There was a consensus that various types of long-term environmental monitoring should form an integral part of any comprehensive scientific program on the Bay of Fundy marine ecosystem. The collection of long-term data sets for key ecosystem variables is essential to understand system changes, be they natural or human-induced. Although various monitoring programs have been carried out in the past, it was felt that these were often done in isolation and that it would be preferable to integrate better the monitoring and research programs. There is a particular need for more standardized monitoring of marine populations to ensure comparability of data sets collected in different places at different times. One way of doing this might be through the establishment of a marine biodiversity monitoring working group. The importance of obtaining long-term data sets was stressed on several occasions and there was considerable concern that recent budgetary restraints may be curtailing some important monitoring programs. It is important that existing programs be continued and we should lobby hard to keep these programs alive by continually emphasizing their scientific and regulatory value to managers. However, at present, much of the data being collected for the Bay of Fundy is scattered and difficult to locate and access. A key element in any comprehensive monitoring program must be the development of suitable readily accessible repositories for archiving data and samples collected over extended periods. We need to act promptly to ensure the integrity and accessibility of existing long-term data sets and the maximum utility of ones yet-to-be collected.

A number of existing types of monitoring programs were cited and several new ones proposed. Oceanographic conditions at carefully selected sites need to be monitored regularly in order to better understand their influence on marine communities. Groundfish and pelagic surveys should be continued and samples should be processed in such a way as to maximize the ecological information obtained. To better monitor changes in ecosystem health, some participants suggested routine examination of populations near the base of the food chain. For example, zooplankton sampling, particularly of the smaller species, should be carried out routinely at standard stations. Also, the current phytoplankton monitoring program should be expanded and should look closely at the potential links between the occurrence of toxic species and nutrient inputs into an area. Others suggested that good indicators of ecosystem health could also be found near the top of the food chain, and that long-term synoptic monitoring of seabird populations might be effective as an integrative indicator of ecosystem stresses. Another such biological indicator, currently being used, involves monitoring of the fat content of herring during processing at fish plants, as an indicator of varying nutritional conditions in the environment. Many other such integrative indicators of ecosystem structure and function need to be developed and applied. Some of the suggestions for monitoring involved the assessment of rates of accumulation of various contaminants in different habitats and populations over time. Programs such as the Gulf of Maine Mussel Watch contaminant monitoring program should be expanded to encompass other Bay of Fundy sites. It was also felt that the St. John River plume should be regularly monitored for contaminants. As well, the sediment depositional area near Grand Manan/Passamaquoddy was thought to be a potentially useful monitoring site for contaminants transported along the New Brunswick coast. Historical depositional records in core samples from the Quoddy salt marshes might be particularly revealing in this regard.

Other suggestions included a systematic study of representative intertidal transects around the entire Bay, but with particular emphasis on the upper reaches. These transects should cross beaches, saltmarshes and mudflats and be sampled at a frequency sufficient to resolve seasonal cycles. This study should build upon sites for which data already exist. Processes/variables that should be measured across these transects include erosion/deposition (by surveying of saltmarsh/mudflat elevations and profiles), grain size, water content, flocculation state, chlorophyll, organic matter and key invertebrates such as *Corophium volutator*. Such a program will quantify changes in intertidal properties at a large number of locations over the entire Bay, and will indicate whether the observed changes are local or part of regional trends.

7.3.4.4.3 Modelling

The value of models as heuristic and analytical tools was emphasized on many occasions during the workshop. Simple conceptual models are particularly useful for identifying important ecological linkages, identifying information gaps and developing research strategies. It is particularly important that such models be introduced early in the research planning exercise. A number of such conceptual models that were developed by Mike Brylinsky and others to stimulate discussion during the workshop are illustrated in Appendix 1. These and similar models could also serve as a general framework for the development of further interdisciplinary research programs in the region.

> ***"what is really required for a better understanding of the functioning of the Bay of Fundy system is a suite of suitable numerical models encompassing and integrating information from a range of disciplines."***

Useful as conceptual models are, there was general consensus that what is really required for a better understanding of the functioning of the Bay of Fundy system is a suite of suitable numerical models encompassing and integrating information from a range of disciplines. A number of recommendations regarding the modelling of various oceanographic processes are outlined in section 2.1.8. Such oceanographic models are fundamental to the understanding of a wide range of physical and biological processes occurring in the Bay.

It is also important to expand sediment modelling activities in the region. Building upon existing physical oceanographic models, we need to develop new, high-resolution numerical models of sediment processes that cover the entire Bay. Such models will improve our knowledge of areas of erosion and deposition as well as sediment transport processes. They could also be used to explore the effects of changing different forcing functions such as sea level, shoreline configuration and sediment supply as well as the effects of engineering structures such as dykes and causeways on sediment dynamics.

It is recommended that a number of highly aggregated ecosystem modelling approaches should also be pursued. These could begin with the development of biogeochemical budget models of important elements such as carbon, nitrogen and phosphorus, for different spatial scales ranging from specific habitats to the entire Bay. Serious consideration should also be given to carrying on the ecological modelling initiative that began with the Cumberland Basin ecosystem modelling project during 1983-1985. This project was an excellent learning exercise for all involved and the experience could easily be applied to other subsystems of the Bay. We should also think of developing ecosystem models on the scale of the entire Bay in collaboration with others. For example, European scientists have been developing a model for the entire North Sea ecosystem, and U.S. scientists are developing similar ecosystem models for the Gulf of Maine.

7.3.4.4.4 New technologies

New information handling technologies should be fully utilized to archive, organize and disseminate the large amounts of data on the Bay of Fundy ecosystem that are currently difficult to locate and access. Numerous geo-referenced data bases and Geographic Information System (GIS) mapping projects under development in the region were mentioned during the workshop and these initiatives should be sustained and expanded. New data presentation techniques and powerful new analytical programs being developed will be particularly important in making reliable scientific information available to both scientists and managers in a timely and useable manner.

> ***"The general consensus among participants was that the workshop was a valuable exercise and that a mechanism should be developed to continue this initiative and sustain its already considerable momentum."***

The workshop gave strong support to the idea of initiating a program to map the seafloor of the entire Bay of Fundy using new multibeam bathymetric mapping technology. Examples of the type of information that can be gained on fine-scale bathymetry, sediment type, bedforms and habitat were dramatically presented during the workshop, and Figure 2.14 illustrates what is possible in terms of graphic representation of bottom topography. There was a strong recommendation that the use of such powerful geological survey tools be integrated with biological sampling programs to provide a better understanding of benthic community structure and dynamics. If resources cannot be found initially to carry out a multibeam survey of the entire Bay in the near future, priority should be given to Chignecto Bay because of the importance of shoreline mudflat habitat to wildlife and suggestions of recent changes in lobster and scallop habitat. Ideally these mapping surveys should be repeated about every five years in order to detect temporal changes in sediment distribution and other features.

Although not discussed in any detail there was general recognition that many of the new remote sensing techniques, particularly satellite imagery, will have an important role to play in any major research program undertaken in the Bay. There is a need for the development of more proxy indicators of environmental change that take advantage of these new powerful technologies.

7.3.4.4.5 Marine protected areas

Many of the discussions during the workshop referred to the need for the establishment of marine protected areas. This is a rapidly evolving concept worldwide and should be incorporated more fully into the future management of the Bay. If we are to conserve the Bay's ecosystem, we need more effective and enforceable controls on human activities such as harvesting, transportation and recreation, and designated marine protected areas appear to be one feasible way of doing this. Recent efforts to protect areas frequented by Right Whales at the mouth of The Bay (Chapter 4) appear to be meeting with some success and should be pursued. More research is required to identify other critical habitat areas that should be subject to some degree of protection.

7.3.5 Sustaining the momentum

The general consensus among participants was that the workshop was a valuable exercise and that a mechanism should be developed to continue this initiative and sustain its already considerable momentum. Hopefully, further funding can be found to support the ongoing development of the Fundy Marine Ecosystem Science Project (FMESP), now called the Bay of Fundy Ecosystem Project (BoFEP), and to maintain a secretariat that can facilitate communications and cooperation among the many interested research and other groups. However, as important as it is to foster communication, it is even more important to stimulate action immediately to ensure that some of the critical information needs identified during the workshop are addressed in a timely and effective fashion. To this end, a proposed action plan has been formulated to provide some guidance for our activities during the coming months, years and decades. Some of the important considerations and constraints inherent in developing such an action plan are first briefly outlined.

7.3.5.1. Developing an action plan

First and foremost, the long-term goal of research in the Bay of Fundy should be the protection and conservation of the ecosystem in perpetuity. The ecology of the system is unique and many of the wildlife species are of hemispheric importance. But, that is not to say that some of the abundant natural resources of the Bay should not be harvested. However, the exploitation of the living resources must be managed in such a way that it stays within the natural limits of the Bay to produce them. Exploitation should be sustainable over the longer term and not be driven by narrow, short-term economic interests.

The workshop recognized the importance of trying to unify many of the current disparate research efforts in the Bay in support of a common general theme. One such unifying theme that was suggested is the effect of rising sea level on the entire Fundy system. While there may be debate about rates, there is no doubt that both mean sea level and tidal amplitude continue to increase today. This was in fact the theme of a joint meeting organized by the Fundy Environmental Studies Committee and the New England Estuarine Research Society in 1985. Because of the nature of the Fundy shoreline, especially in the upper reaches, the Bay of Fundy may be one of the coastal regions most sensitive to sea level rise in Canada. Rising sea level is affecting sediment dynamics which in turn may be responsible for many of the changes observed in the Bay today. Sooner or later, the extensive dyke system will be breached causing widespread damage, especially in those areas where dykelands are being used for more than agricultural purposes. With the current interest in climate-change research, additional funding might be available if this theme, with clear practical relevance in a number of areas, was pursued.

> ***"the exploitation of the living resources must be managed so that it stays within the natural limits of the Bay to produce them. Exploitation should be sustainable over the longer term and not be driven by narrow, short-term economic interests."***

7.3.5.2 Fostering research

There was a general consensus that, realistically, in the present economic climate it would be virtually impossible to procure funding for mounting a major integrated research program focussed on the Bay of Fundy. Conditions were much different in 1976 when many scientists convened in Wolfville to discuss the potential impacts of tidal power development. Back then, there was a single high profile issue around which to rally; there was a large body of young scientists and students looking for new projects to pursue, and, most importantly, financial resources for research were much more abundant. Today, we undoubtedly have a higher overall level of expertise because of the experience gained in conducting research in the Bay over the past twenty years, and advances in marine science itself. However, many scientists are retiring and there is limited fresh blood coming into the regional scientific community to take their place. It was, therefore, heartening to see many new and younger faces at the workshop, but we desperately need more to maintain our level of expertise. We all know how tight research funds are today, and most of those available are targeted for rather narrow, management-oriented research projects. However, some funds are there, only we must work harder to get them; an entrepreneurial spirit is essential. It will be important to develop partnerships with both industry and community groups. It is also important that we do a better job of selling the benefits of scientific research to both decision-makers and the general public.

7.3.5.3 Communication and cooperation

It is clear that the Bay is not an isolated entity and that it is essential to foster communication with the many other regional scientific groups that are working on comparable issues in adjacent marine and terrestrial areas. A variety of such cooperative linkages were identified during the workshop. It is particularly important to continue to nurture the association with EMAN (Ecological Monitoring and Assessment Network) and work to ensure that the entire Bay of Fundy system be included as a study site for this nation-wide program. We must also continue to collaborate with our many U.S. colleagues through initiatives under organizations such as the Gulf of Maine Council on the Marine Environment and the Regional Association for Research on the Gulf of Maine (RARGOM). In fact, we can learn much from recent research initiatives in the Gulf of Maine, a region facing many comparable problems (Sherman *et al.* 1996, see Chapter 3 references).

7.3.5.4 Involving the public

The people who live around the Bay are becoming increasingly concerned about the growing evidence of degradation of the marine environment and reductions in many marine resource populations. In addition, many of the burgeoning environmental groups in the region are adopting a leadership role in identifying and publicising the issues and voicing the concerns articulately to government agencies and politicians. However, there are many complex scientific issues involved in the debates, and it is important that scientists participate fully by providing reliable information in a timely manner and in a form that will be most meaningful and useful to the public and to decision makers. We thus need to develop more effective communication products that convey to the public-at-large the science underlying the environmental issues in the Bay and the important role that future scientific research can play in addressing them. Several recent excellent natural history and environmental atlas publications on the Bay of Fundy and the Gulf of Maine are a promising start in this direction. A series of informative fact sheets on selected Bay of Fundy issues, written with a minimum of technical jargon, were cited as one such promising communication tool; ten of these have since been completed. Disseminating comparable information electronically in the form of an appropriate home page on the Internet was another recommendation.

It was also strongly felt that it would be useful, at some point in the near future, to convene a more broadly based workshop on Bay of Fundy issues, that would involve representatives from environmental groups, resource user groups and community groups as well as participants from the scientific community. This might be a useful first step also in identifying means of acquiring and assessing some of the traditional environmental knowledge referred to earlier. In addition, this might also be a suitable venue for emphasizing that communities and volunteers can play a particularly important role in collecting scientific data useful in monitoring and other research programs, a particularly relevant consideration in this era of government and university down-sizing. It was subsequently suggested that perhaps a series of regional workshops could be convened in various communities around the bay as an initial step and that these could ultimately lead into a more comprehensive Fundy-wide conference (comparable to Coastal Zone '94 in format?) timed to coincide with the International Year of the Oceans in 1998. Such an initiative might be supported by a number of government agencies in view of its community consultative approach, and its potential for multiple partners from all sectors.

7.3.5.5 Fundy workshops

In addition to the possibly biennial workshops for scientific information exchange and the public forums referred to above it was also felt that regular, informal small-scale workshops dealing with particular scientific issues would be necessary elements in planning, implementing and sustaining many of the multidisciplinary research initiatives recommended here. Workshops on the development of models linking various scientific disciplines were considered particularly important and should take place as early as possible in the development of any research program being proposed.

> ***"It was also strongly felt that it would be useful .... to convene a more broadly based workshop on Bay of Fundy issues, that would involve representatives from environmental groups, resource user groups and community groups as well as participants from the scientific community."***

7.4 FUNDY ECOSYSTEM PROJECT - A PROPOSED ACTION PLAN (April 1996)

GOAL: Effective coastal zone management of the Bay of Fundy ecosystem based on sound scientific understanding achieved through an holistic, community-wide research and monitoring program.

OBJECTIVES:

1. An holistic understanding of the Bay of Fundy ecosystem, including ecosystem responses to natural changes and anthropogenic activities.

2. An holistic approach to the management of the Bay of Fundy ecosystem and its resources.

3. An holistic approach to the resolution of coastal issues in the Bay of Fundy ecosystem.

STRATEGIES:

1. Document existing scientific and community-based knowledge of the resources and processes of the Bay of Fundy ecosystem.

2. Coordinate and/or conduct necessary research and monitoring on ecosystem processes, utilizing the skills and resources of the full Bay of Fundy community.

3. Disseminate scientific knowledge as widely as possible throughout the Bay of Fundy community.

DELIVERABLES:

1. A current and comprehensive data base directory on processes and resources of the Bay of Fundy ecosystem, maintained in digital format, and available to all interested parties.

2. A world wide web site to facilitate access to and dissemination of knowledge about the Bay of Fundy ecosystem.

3. Effective mechanisms for incorporating community-based knowledge, skills and opinions into the wise management of the Bay of Fundy ecosystem.

4. An effective mechanism for planning and coordinating research conducted by contributing organizations, agencies, institutions and individuals.

5. Public documents conveying the current state of knowledge and understanding of the Bay of Fundy ecosystem prepared in a form that is appropriate for the general community.

6. Specific research projects aimed at resolving knowledge gaps regarding processes, resources and stressors of the Bay of Fundy ecosystem.

Table 7.1 Bay of Fundy Ecosystem Project: Initial Projects (April 1996)

PROJECT	PRIORITY	PROPOSED SPONSORS*
1. HYDRODYNAMICS		
a) A new FMG circulation model	H	NR/AGC, DFO
b) Greenberg Model (Shepody/Petitcodiac)	H planned	NR/AGC, DFO
c) Tidal surge prediction	H	CHS/DOE(AEB)
2. SEDIMENT DYNAMICS		
a) Changes in supply of fine-grained sediments *(e.g. swath/multibeam survey)*	H planned	DFO, NR/AGC
b) Sediment deposition (e.g. Petitcodiac-Chignecto area; Annapolis Basin)	H	DFO, NR/AGC
c) Long-term changes in salt marshes	H ongoing	NR/AGC, DFO,Univ.
d) Changes in shore profiles/rates of recession	M	NR/AGC
3. BIOLOGICAL/ECOLOGICAL		
a) Invertebrates and sediments		
i) Biostabilization	M ongoing	Univ.
ii) Shorebird behaviour	H planned	DOE, ACWERN, Univ.
iii) Corophium behaviour	H planned	Univ.
iv) Lobsters in Chignecto	M	DFO
v) Sediment quality surveys	H ongoing	DOE, Univ.
b) UVβ /diatoms/epibenthos	H	DOE, Univ.
c) Phalarope distribution and abundance	M	DOE, Univ.
d) Northern Right Whales	H	DFO, GoM, Univ.
e) Distribution of benthos - water column stability	M	DFO, Univ
f) Whale/zooplankton/phalarope linkages	M	DFO, DOE
g) Changing community composition: pelagics/groundfish	M	DFO
h) Toxic substances dynamics (e.g. OC's, Hg)	M	DOE
4. COMMUNITY - SCIENCE COOPERATION		
a) Community workshops	H	DFO, DOE, CG
b) Specific initiatives (e.g. shorebirds; sediment dynamics; sediment monitoring; seaweeds; shellfish monitoring/regulatory	M	DFO, DOE, CG
c) Acquisition of non-formal ecosystem information	M	DFO, CG
d) Communications/education initiatives	H	DFO, DOE, GoM, CG
5. RESOURCE IMPACTS AND CONFLICTS		
a) Ecotourism effects (e.g. whales, seabirds)	L ongoing	DFO, DOE
b) Aquaculture impacts	H ongoing	DFO, DOE
c) Fishing impacts (e.g. draggers)	H ongoing	DFO, NR(AGC)
d) Coastal structures (e.g. dams, dykes and dumps)	H ongoing	DFO, NR(AGC)
e) subsea aggregate mining	H ongoing	NR, DFO, DOE
f) Rockweed harvesting	H ongoing	DFO, Prov.
g) Baitworm harvesting	M ongoing	DFO, DOE, Prov.
h) Seals/fisheries interactions	M ongoing	DFO
6. LAND-USE CHANGES *(Important issues beyond this scoping exercise)*		
a) Land-use patterns		
b) Marine protected areas		

* **NR** (Natural Resources Canada); **AGC** (Atlantic Geoscience Centre); **DFO** (Department of Fisheries and Oceans; **CHS** (Canadian Hydrographic Service); **DOE** (Environment Canada); **AEB** (Atmospheric Environment Branch); **Univ.** (various universities); **ACWERN** (Atlantic Canada Waterfowl Ecology Research Network) **CG** (Community groups); **GoM** (Gulf of Maine Council); **Prov.** (NS and NB Provincial Government Departments)

7.5 Related initiatives:

7.5.1 Short-term (0-2 years)

1. *A key element in sustaining further development of an integrated research approach to Bay of Fundy issues is to ensure the continuity of FMESP or a comparable group as a coordinating body for the program. The original program steering committee should be expanded to fill this role and clear terms of reference developed to guide its activities. In addition, a small but active secretariat should be established to act as a clearing house for information pertaining to Bay of Fundy scientific issues and to facilitate communications among the various groups with an interest in the Bay.*

2. *Initiate meetings with research managers and marine resource managers in various government agencies to a) brief them on the results of the Workshop and the proposed action plan, b) obtain their input regarding priority conservation and protection issues and their scientific information requirements, and c) seek their ongoing support in developing and implementing the program.*

3. *Set up a series of ad hoc project working groups to a) promote closer cooperation and better integration among existing research programs having areas of common interest and b) develop new multidisciplinary research proposals to address some of the priority issues raised during the Workshop and identify effective means of implementing such studies.*

4. *Convene a series of scientific issues-oriented, informal workshops to a) assess specific information requirements, b) promote cooperation among existing research projects in the region and c) facilitate the development of innovative new research projects as required.*

5. *Initiate discussions with key environmental organizations throughout the Fundy region with a view to jointly convening a series of regional public workshops to discuss environmental issues and explore ways of meaningfully involving communities in projects seeking to better understand and conserve the Fundy marine ecosystem.*

6. *Set up a working group to explore ways of acquiring, assessing and using traditional environmental knowledge to evaluate long-term changes in the Bay of Fundy ecosystem, and consider means of promoting and facilitating the involvement of knowledgeable volunteers in the long-term monitoring of key marine ecosystem indicators in their local area.*

7. *Set up a Fundy Ecosystem Project home page to facilitate the exchange of information among participants. This could provide access to the updated Bay of Fundy Bibliography developed for the Workshop and serve for disseminating information about developing research programs and Fundy coastal zone issues.*

8. *Prepare a series of non-technical fact sheets on selected Bay of Fundy issues. These would be circulated to schools, community and environmental groups, and other interested parties and would provide concise, up-to-date scientific information about the issues in an interesting, straightforward fashion. In addition, the same information should be made available on-line by means of a suitable home page on the World Wide Web.*

9. *Pursue with the appropriate agencies the concept of having the entire Bay of Fundy formally designated as an EMAN site.*

10. *Pursue with the Gulf of Maine (GOM) program the concept of a formal northern program of a Bay of Fundy component of GOM.*

7.5.2 Medium-term (2-10 years)

11. Investigate the possibility of holding a major, broadly-based conference on Fundy Issues in 1998 to coincide with the International Year of the Ocean.

12. Evaluate the results of completed multidisciplinary research programs and identify areas for further integrated research and funding.

13 Promote the establishment of a coordinated long-term monitoring program, involving research scientists and trained volunteers, to facilitate the early detection of significant changes in key ecological processes and populations.

7.5.3 Long-term (>10 years)

14. Prepare decennial State of the Bay Reports, that in addition to reviewing environmental trends in the Bay, also recommends further remedial actions for ensuring the continued integrity of the Bay's ecosystem and the sustainability of its resources.

"further scientific research can be most effectively carried out as part of a more integrated and cooperative program involving a variety of disciplines"

7.6 Concluding remarks

By all accounts the Bay of Fundy Workshop was a stimulating experience for all who participated. A great deal of new information was presented and many thought provoking suggestions generated during the two and a half days of deliberations. Hopefully, the essence of these proceedings and most of the recommendations have been captured in the present document.

The sense of urgency with regard to many of the critical issues confronting the Bay was palpable throughout the workshop. Clearly there are many researchers in a variety of disciplines eager to confront the scientific challenges posed by this most difficult, yet intriguing of ecosystems. Perhaps one of the most valuable and yet intangible benefits of the workshop was the recognition by many participants of the many linkages between various research activities now being carried out in different disciplines in different parts of the Bay. There was a recognition that the Bay is a holistic and interconnected system and that the many individual, highly focussed, and apparently isolated, research programs currently in progress, in fact, generate ripples of implications that extended inexorably to the farthest reaches of the Bay. A corollary of such a recognition is that further scientific research can be most effectively carried out as part of a more integrated and cooperative program involving a variety of disciplines.

It is to be hoped that the present document and accompanying action plan will serve as catalyst in fostering a broad array of new scientific studies designed to increase our understanding of the Bay of Fundy ecosystem and thereby assist in conserving and protecting its renewable resources for future generations. The momentum has been imparted to the process and it is up to all who participated in the workshop to take up the challenge and ensure that it does not falter.

"........the present document and accompanying action plan will serve as catalyst in fostering a broad array of new scientific studies designed to increase our understanding of the Bay of Fundy ecosystem and thereby assist in conserving and protecting its renewable resources for future generations"

APPENDIX ONE

CONCEPTUAL MODELS FOR REFERENCE AT THE WORKSHOP

M. Brylinsky

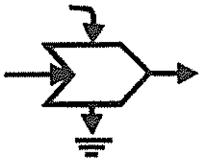
The following examples of conceptual models, though not a comprehensive set, were provided as an aid to discussion during the workshop. They attempt to summarize in a very general way our current knowledge about the major processes that control the various physical, chemical and biological systems within the Bay. The models are a combination of compartment type models, representing what are thought to be the major components of the Bay, and hierarchical models representing the processes thought to control the input and output of each component. They have been purposely kept as simple as possible. The models raise numerous questions some of which may or may not be important to the issues facing the use of the Bay's resources. Our goal is to identify the most important questions and to determine the information required to answer them.

Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.

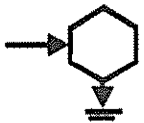
Source. Outside source of energy delivering forces according to a program controlled from outside: a forcing function.

Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows: a state variable.

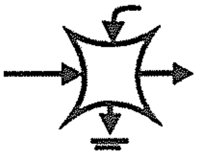
Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



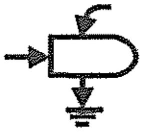
Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



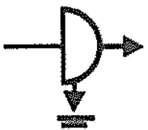
Consumer. Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



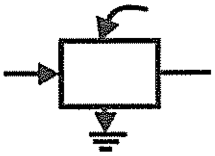
Switching action. A symbol that indicates one or more switching actions.



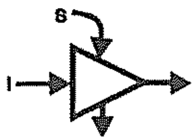
Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.



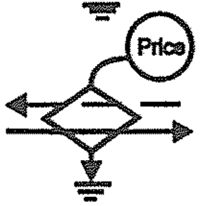
Self-limiting energy receiver. A unit that has a self-limiting output when input drives are high because there is a limiting constant quantity of material reacting on a circular pathway within.



Box. Miscellaneous symbol to use for whatever unit or function is labelled.



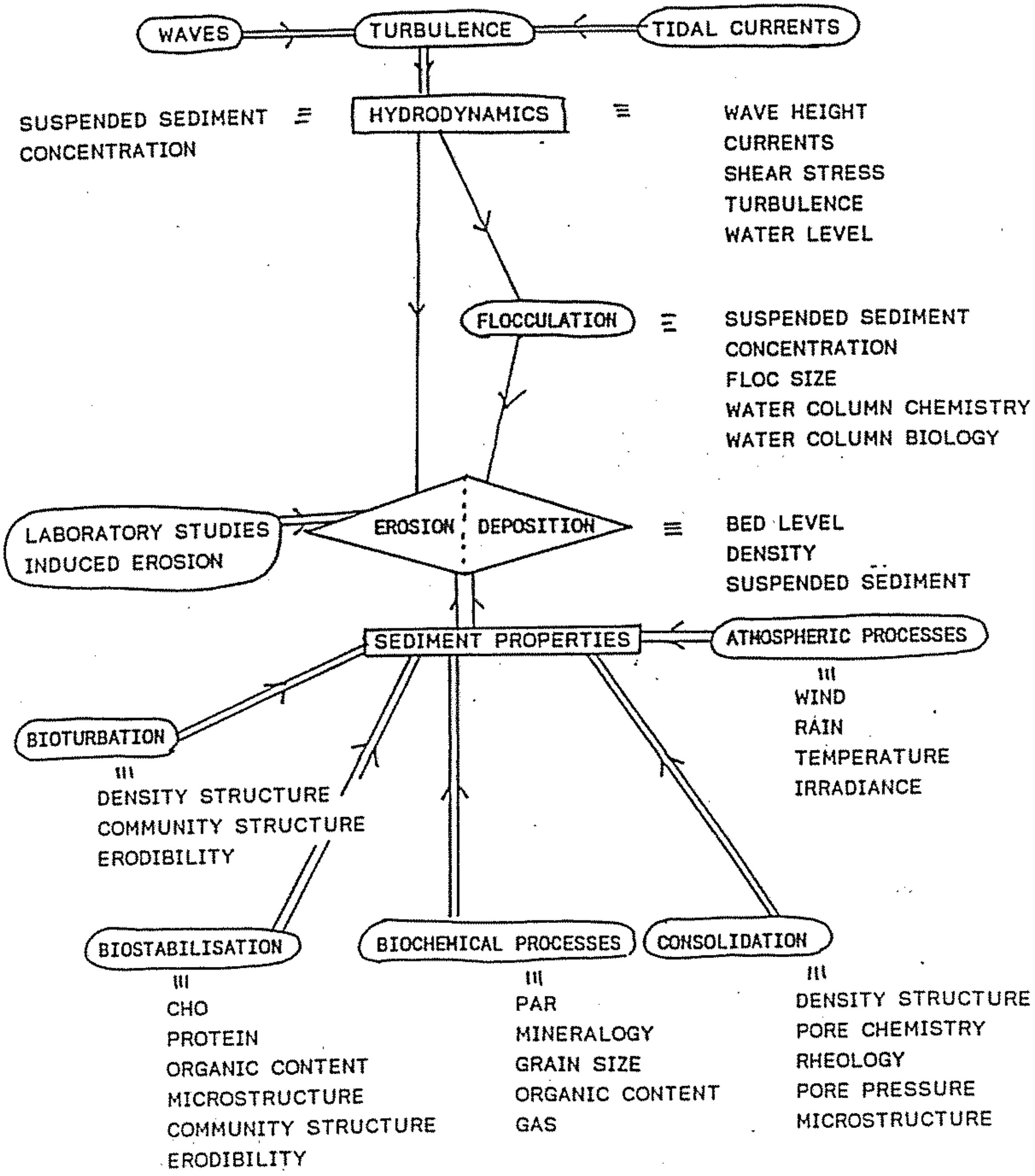
Constant-gain amplifier. A unit that delivers an output in proportion to the input I but changes by a constant factor as long as the energy source S is sufficient.



Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed). Price is shown as an external source.

Legend Some of the symbols of the energy circuit language with qualitative descriptions.

(Modified from : Odum, H.T. 1983. Systems ecology: An introduction. Wiley, New York).



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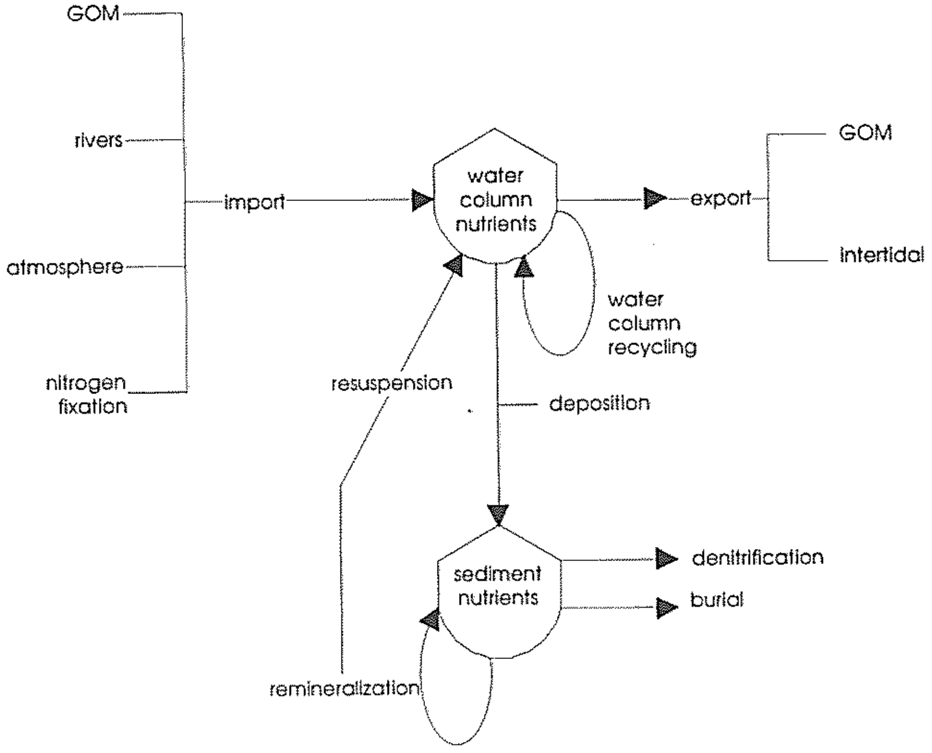
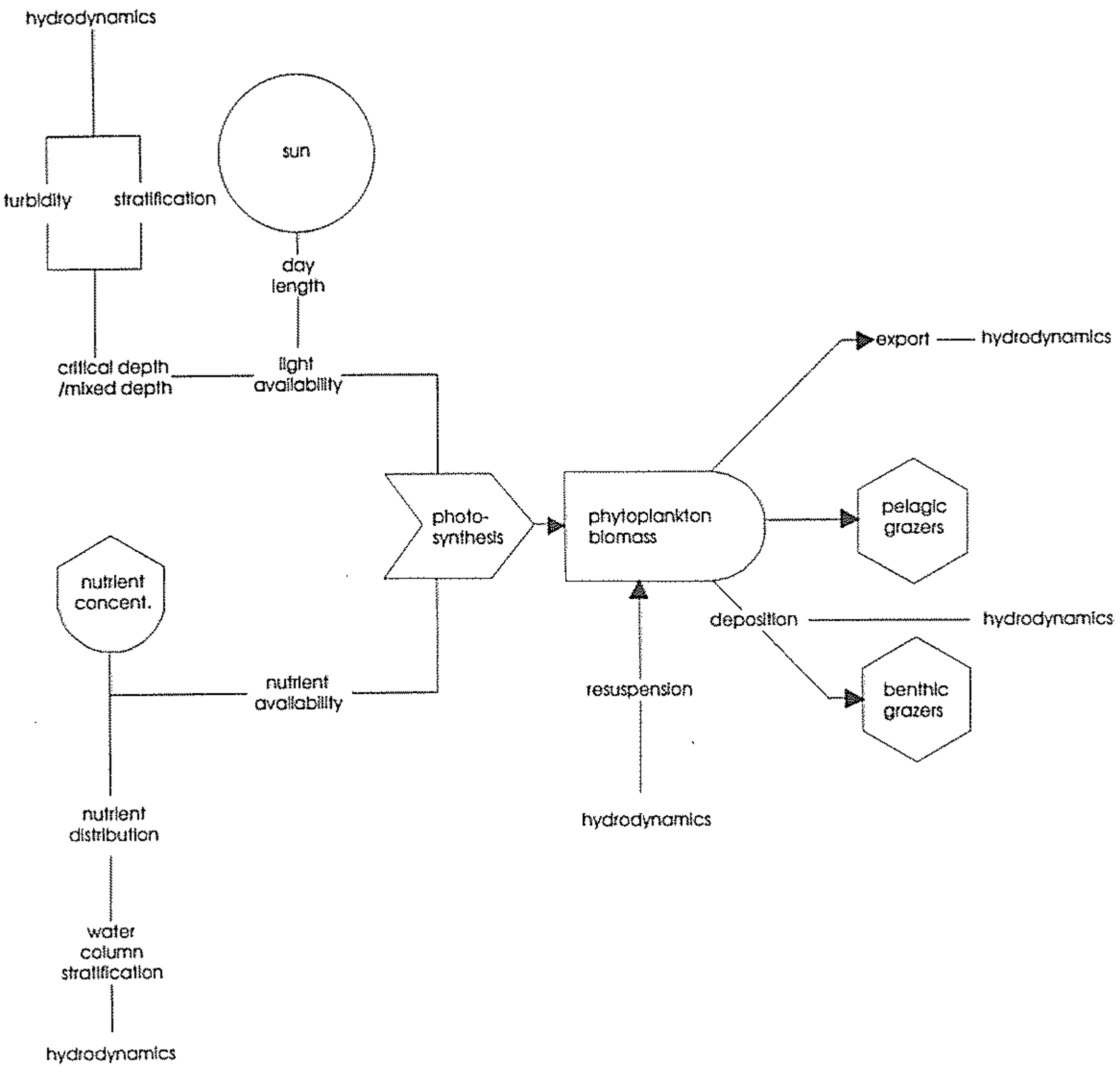
[1] BOLD FACE = PROCESSES, STANDARD FACE = PARAMETERS OR VARIABLES

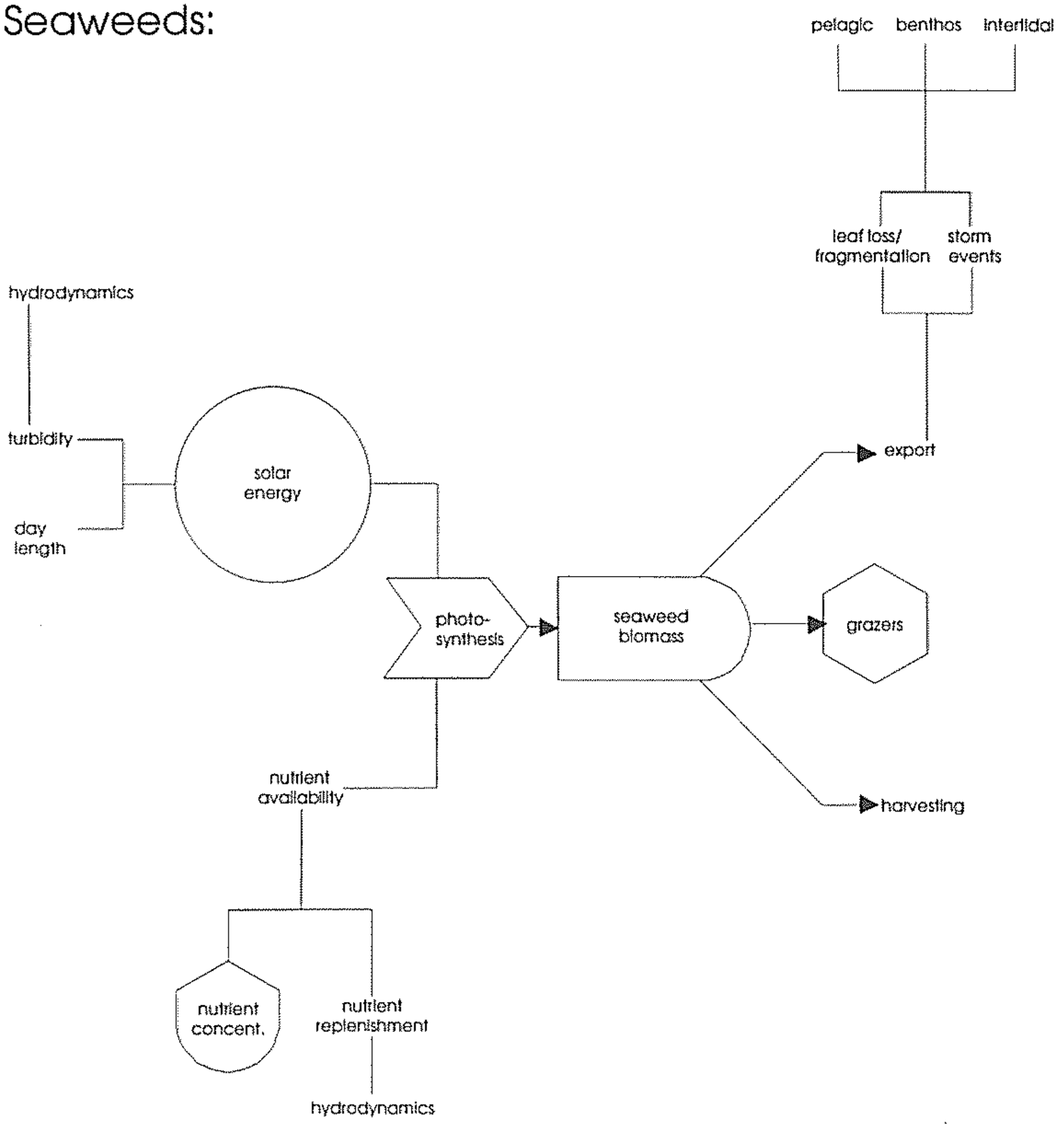
Nutrients:


GOM
rivers
import
atmosphere
nitrogen fixation
water column nutrients
export
GOM
intertidal
water column recycling
resuspension
deposition
sediment nutrients
denitrification
burial
remineralization

Phytoplankton:



Seaweeds: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benthos
intertidal
leaf loss/ fragmentation
storm events
hydrodynamics
turbidity
solar energy
day length
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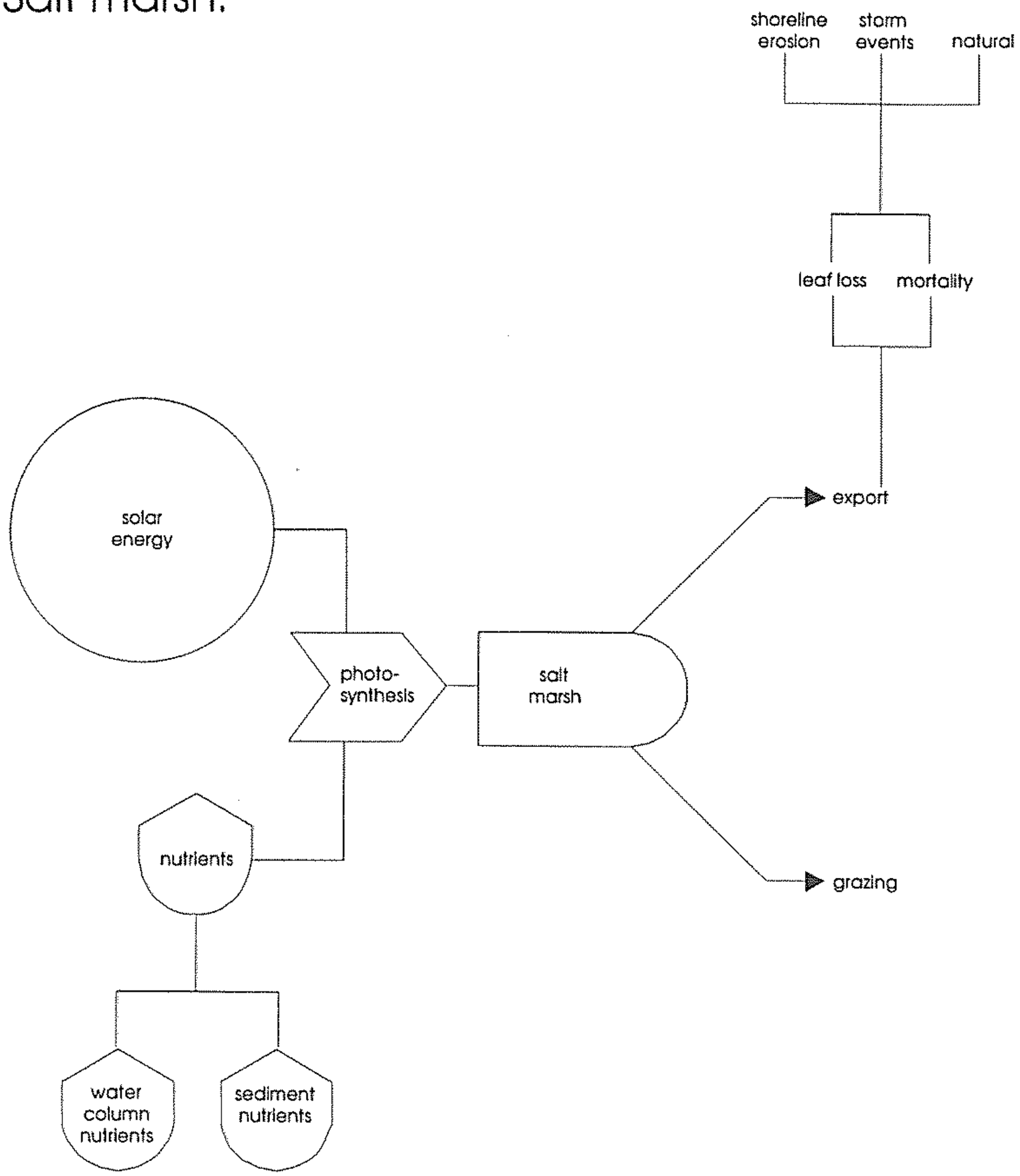
grazers
nutrient availability
harvesting
nutrient concent.
nutrient replenishment
hydrodynamics

Salt marsh: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water column nutrients
sediment nutrients

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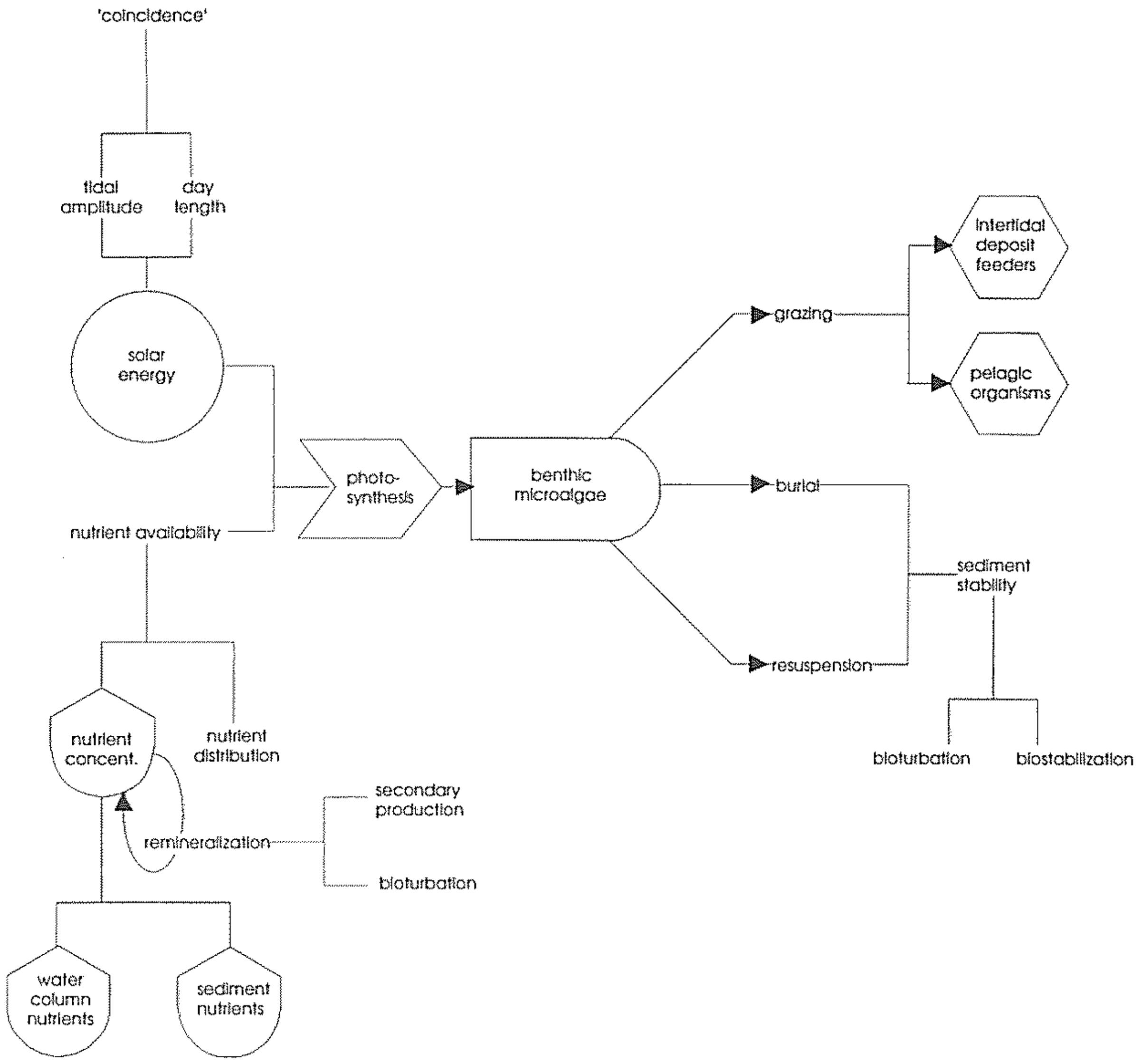

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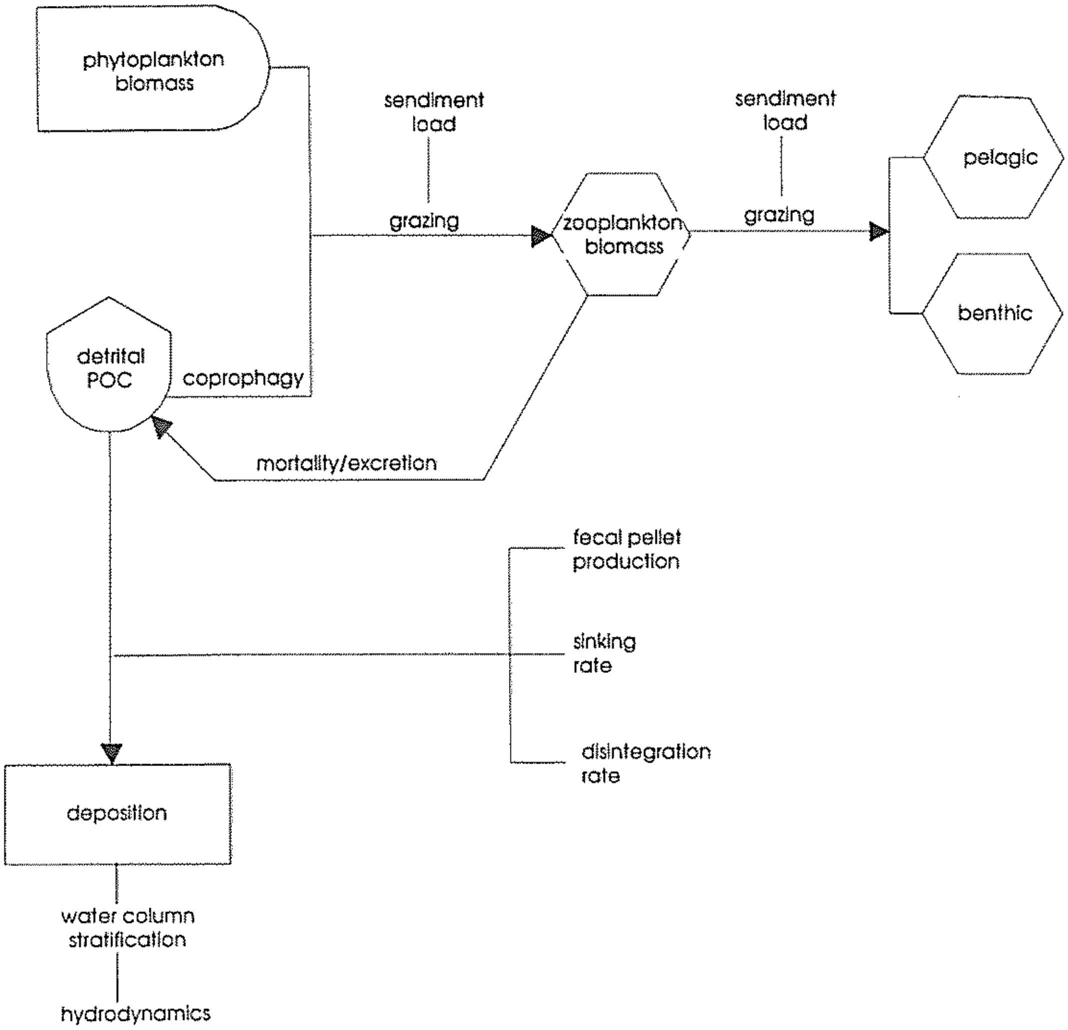

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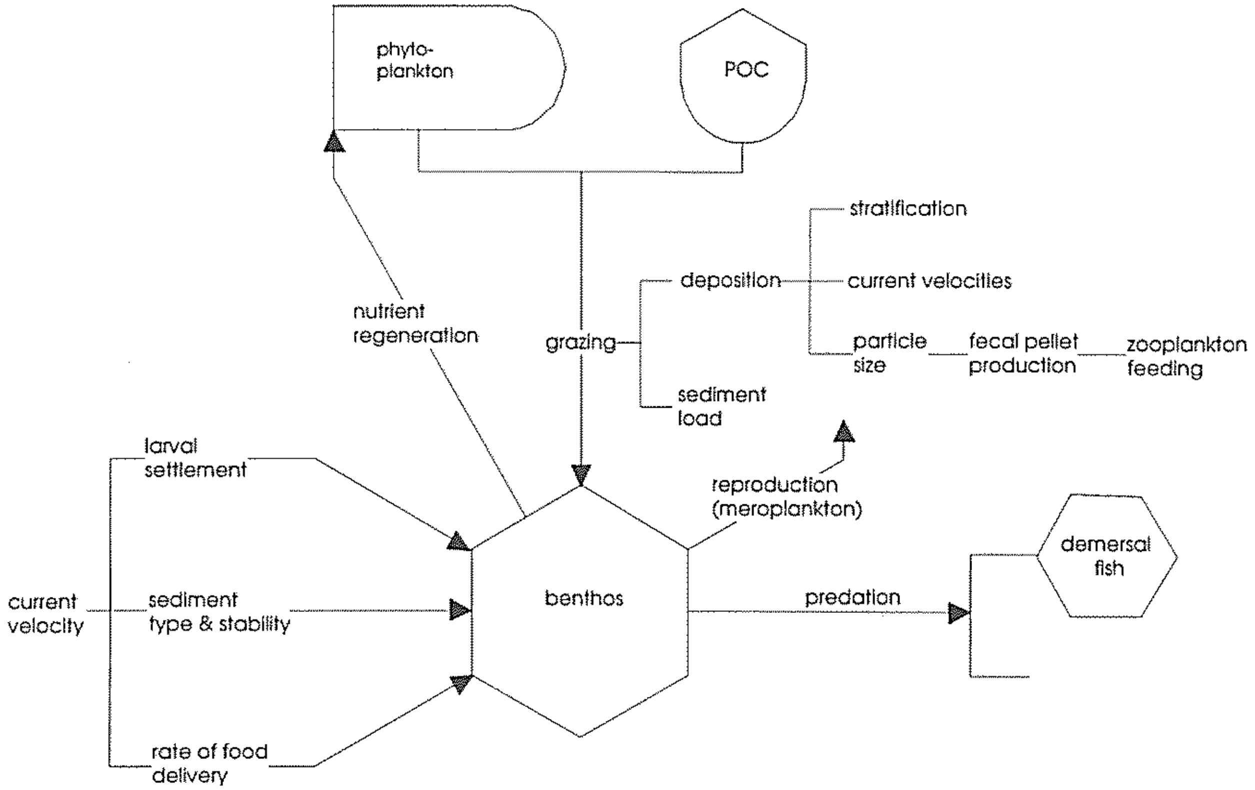

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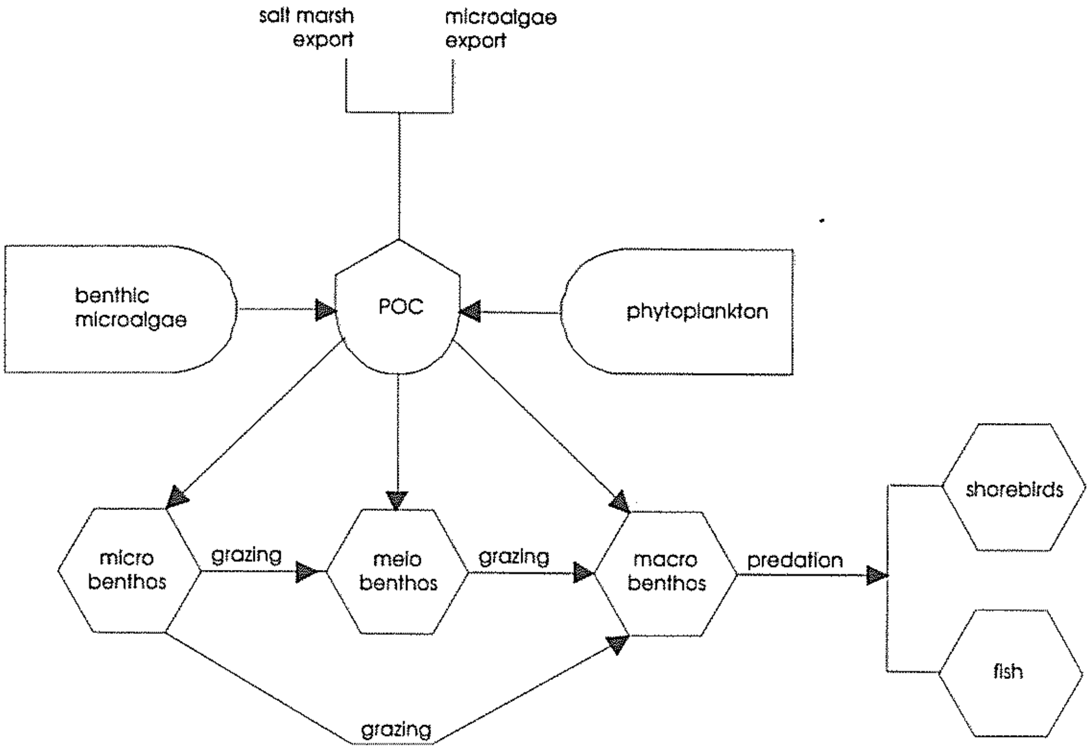

APPENDIX TWO

WORKSHOP AGENDA

January 29 - February 1, 1996

January 29

Monday evening
6:00 Registration
8:00 Monday evening social (cash bar)
Informal Fundy slide shows by participants (TBA)
Bring your slides - an opportunity to show and tell

January 30

Tuesday morning ***Moderator: Peter Wells***
8:00 Registration
9:00 Introduction *(Peter Wells)*
9:30 Science overview *(Graham Daborn)*
10:30 Break
10:45 Issues and problems confronting the Bay
Presentation and discussion *(Jon Percy, Louise White)*

12:00 Lunch *(provided)*

Tuesday afternoon **Moderators: *Mike Brylinsky, Don Gordon***
1:00 Conceptual models of processes
    Physical *(Dave Greenberg, Brian Petrie)*
    Geological *(Gordon Fader, John Shaw)*
    Sedimentological *(Graham Daborn, Tim Milligan)*
    Chemical: nutrients *(Paul Keizer)*
    Chemical: contaminants *(Paul Keizer, Peter Wells)*
    Biological *(Mike Brylinsky, Mike Dadswell, Peter Hicklin, Graham Daborn, Wayne Stobo)*
5:45 Initiate working groups for "Science and management needs for the Bay" *(Peter Wells, Graham Daborn)*

6:00 Dinner *(own arrangements)*

Tuesday evening
8:00 "Science and management needs for the Bay": working groups (reports to be given on Thursday morning)

January 31

Wednesday morning **Moderators:** ***Louise White John Pringle***
Peter Hicklin, Richard Elliot

9:00 Research in support of management needs
Marine resources *(Jon Percy, Wayne Stobo)*

10:30 Break

10:45 Habitat interactions and issues
a) Inner Bay: mud flats, salt marshes, pelagic zone, benthic zone
(Sherman Boates, Don Gordon, Mike Brylinsky)

12:00 Lunch *(provided)*

Wednesday afternoon **Moderators:** ***Louise White John Pringle***
Peter Hicklin, Richard Elliot

1:00 Habitat interactions and issues *(continued)*
b) Outer Bay: rocky shore, upwelling areas pelagic zone, benthic zone
(Dave Wildish, Wayne Stobo......)

3:30 Break

4:00 Science and management needs for the Bay: working groups *(cont.)*
(Reports to be given on Thursday morning)

Wednesday evening
Free evening - dinner (own arrangements)

February 1

Thursday morning ***Moderators: Peter Wells, Graham Daborn)***

9:00 Working groups report on *"Science and management needs for the Bay"*: What is to be done? Who is to do it? Partners and funding?

10:00 Reflections on Bay of Fundy research *(Don Gordon)*

10:30 Break

10:45 Expanding the vision: where do we go from here?
(Steve Hawboldt, Mick Burt, Sherman Boates, Dave Townsend)

12:15 Closing comments *(Graham Daborn, Peter Wells)*

APPENDIX THREE

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APPENDIX FOUR

FUNDY MARINE ECOSYSYEM SCIENCE PROJECT BIBLIOGRAPHY

Throughout the FMESP exercise a collection of scientific papers, spanning 1983 to the present, has been compiled*. This collection is housed at the Acadia Centre for Estuarine Research (ACER) library, Acadia University. Their titles, authors, sources and keywords have been entered into a bibliographic database (Papyrus). Also on this database are references obtained by literature searches of CD-ROM databases such as ASFA, WAVES, BIOSIS and POLLTOX.

The computerized database can be downloaded in compressed ASCII format from the Acadia Centre for Estuarine Research home page. The URL is:

http://ace.acadiau.ca/science/cer/rcp/home.html

The ACER home page can also be reached through the home page of Acadia University by following the link *"The Faculty of Pure and Applied Science"*. The URL for Acadia University is:

http://www.acadiau.ca/

* **Note:** *The reference collection and database are not, at present, exhaustive literature searches of all research done in the Bay of Fundy since 1983.*