Ecosystem Overview Report for the Minas Basin, Nova Scotia

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Oceans and Coastal Management Report 2007-05

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CONTENTS

PART C – BIOLOGICAL SYSTEM

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LIST OF FIGURES AND TABLES

FIGURES

TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ACCDC	Atlantic Canada Conservation Data Centre
AGRG	Applied Geomatics Research Group (Lawrencetown, Nova Scotia)
AQI	air quality index
BoFEP	Bay of Fundy Ecosystem Partnership
C	carbon
CCME	Council of Ministers of the Environment
Cd	cadmium
CO	carbon monoxide
COGS	Centre of Geographic Sciences (Lawrencetown, Nova Scotia)
CSA	Canadian Space Agency
Cu	copper
dB	decibel
DDT	dichloro-diphenyl-trichloroethane
DOC	dissolved organic carbon
EOAR	*Ecosystem Overview and Assessment Report*
EOR	*Ecosystem Overview Report*
ESA	Species at Risk Act
g	gram
iBoF	Inner Bay of Fundy
l	litre
LFA	Lobster Fishing Area
MEQ	Marine Environmental Quality
n	total sample population size
NAPS	National Air Pollution Surveillance
NO_2	nitrogen dioxide
NPRI	National Pollutant Release Inventory
O_3	ozone
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PM	fine particulate matter
POC	particulate organic carbon
ppb	parts per billion

ppm	parts per million
ppt	parts per thousand
SARA	Species at Risk Act
SO_2	sulphur dioxide
SPM	suspended particulate matter
TRS	total reduced sulphur
US	United States
W	watt

EXECUTIVE SUMMARY

An *Ecosystem Overview Report* (EOR) is based on the existing knowledge of the geological, oceanographic and biological systems of a defined ecosystem. The EOR for the Minas Basin is part of a larger documenting approach developed by Fisheries and Oceans Canada called an *Ecosystem Overview and Assessment Report*, or EOAR, that also examines the activities, emerging activities and cumulative stressors on the ecosystem. These latter components are largely addressed in a recent document by Wilcocks-Musselman (2003) entitled *Minas Basin Watershed Profile*.

The Minas Basin EOR is intended to provide an overview of the major ecological components of the Minas Basin marine waters, as well as a contextual outline of the land encompassed in the surrounding watershed. It has been written for the Oceans and Coastal Management Division of Fisheries and Oceans Canada, in partnership with the Government of Nova Scotia and the Offshore Energy Environmental Research Association. This report is primarily intended as a background resource document for integrated management and planning in the Minas Basin watershed.

The Minas Basin is a macrotidal area of the Upper Bay of Fundy, Nova Scotia. Much of the basin is characterized by the shallow (~20 m), highly turbid waters that rise and fall through the world's highest tidal amplitude to expose vast intertidal mudflats and marshes in the Southern Bight and Cobequid Bay. In contrast, the Central Minas Basin and Minas Channel serve as a transition to the open waters of the Bay of Fundy. Through the deeper and clearer waters of these sub-watersheds a number of fish species migrate, including such species at risk as the Atlantic salmon and striped bass.

The expansive tidal flats that characterize the basin are home to some of the highest densities of invertebrates documented in the literature. Of the worms, arthropods, bivalves and gastropods that are present, it is a small amphipod called *Corophium* that has been the focus of much study. Living in the exposed areas of the tidal flats, it is a favorite food of hundreds of thousands of migrating shorebirds that stop in the Minas Basin during their annual migration. Although great numbers of some species of invertebrates exist, the muddy intertidal areas are generally described as a "high density–low diversity" assemblage.

Even though we have learned much about the Minas Basin through years of study and observation, our knowledge of the geological, oceanographic and biological systems of the Minas Basin is not complete, nor do we expect it ever to be. However, there are some information gaps that are more critical to address given our desire to manage our activities within the basin in a manner that does not impact upon its overall ecology. Biological gaps exist in lifecycle functions and spatial distribution of various species throughout the watershed. Oceanographic information gaps include an understanding of the sources and impacts of sound within the confines of the Minas Basin. Many ecosystem relationships between the biota and their physical environment, or between organisms, exist as gaps in our knowledge and inhibit our understanding of the food web and energy flows within the basin.

Future studies within the Minas Basin watershed should be based on three basic premises to support ecosystem management:

1. Studies should focus on ecological linkages (physical–biological or biological interactions) and move away from inventories and species-specific study.
2. Studies should generally be undertaken at the bay-scale watershed resolution.
3. Studies should be designed, in part, using environmental effects monitoring approaches that evaluate relationships between biota and their environment.

As a management tool, the EOR needs to be periodically reviewed and updated. This will ensure that the basis upon which decision-making is conducted remains current and that best management will be supported. There is a notable lack of reference to grey literature and internal government data (unpublished reports and databases) in this report. Analyses of these data should be considered for any future revisions of this document. Interviews were not conducted in the production of this report, and traditional ecological knowledge from First Nations, fishermen and community has not been explicitly incorporated. This document has not been reviewed by members of the scientific community prior to its printing. Although we have made every effort to accurately portray the works and knowledge on the Minas Basin ecosystem, errors may exist. Future EOR updates should consider peer review to limit such errors or misinterpretations.

SOMMAIRE

Un *Rapport d'ensemble de l'écosystème* (REE) se fonde sur les connaissances disponibles sur les systèmes géologiques, océanographiques et biologiques d'un écosystème défini. Le REE pour le bassin des Mines s'inscrit dans le cadre de l'approche de documentation mise au point par Pêches et Océans Canada, le *Rapport sur les aperçus et les évaluations de l'écosystème* (RAEE), qui examine également les activités en cours, les activités en développement et les agresseurs cumulatifs de l'écosystème. Ces derniers éléments sont largement discutés dans un récent document de Willcocks-Musselman (2003), intitulé *Minas Basin Watershed Profile*.

Le REE pour le bassin des Mines vise à donner un aperçu des principales composantes écologiques des eaux de mer de ce bassin, ainsi qu'un aperçu contextuel des terres ceintes par le réseau hydrographique environnant. Ce rapport a été préparé par la Division de la gestion côtière et des océans de Pêches et Océans Canada, en partenariat avec le gouvernement de la Nouvelle-Écosse et l'Offshore Energy Environmental Research Association. Il est principalement destiné à servir de document d'information pour la gestion intégrée et la planification dans le réseau hydrographique du bassin des Mines.

Le bassin des Mines est une zone macrotidale du fond de la baie de Fundy, en Nouvelle-Écosse. La majeure partie du bassin est caractérisée par des eaux peu profondes (~ 20 m), hautement turbides, soumises aux plus fortes marées du monde. La basse mer découvre de vastes battures de vase et des marais intertidaux dans la baie Sud et la baie Cobequid. Par contre, la partie centrale du bassin des Mines et le chenal des Mines servent de zone de transition entre le fond et les eaux libres de la baie de Fundy. Diverses espèces de poissons, dont des espèces en péril tels le saumon atlantique et le bar d'Amérique, empruntent les eaux claires et profondes de ces sous-bassins hydrographiques lors de leurs migrations.

Les vastes platins qui caractérisent le bassin abritent des densités d'invertébrés qui s'inscrivent parmi les plus fortes qui soient documentées. Des vers, arthropodes, bivalves et gastropodes présents, un petit amphipode appelé *Corophium* est l'objet de la majeure partie de l'étude. Trouvé dans les parties exposées des platins, il est une proie favorite de centaines de milliers d'oiseaux de rivage migrateurs, qui font escale dans le bassin des Mines durant leur migration annuelle. Bien que les vasières intertidales abritent une abondance d'individus de certaines espèces d'invertébrés, elles sont généralement décrites comme un assemblage « densité élevée - diversité faible ».

Bien que de nombreuses années d'étude et d'observation nous aient permis d'apprendre beaucoup de choses au sujet du bassin des Mines, notre connaissance des systèmes géologiques, océanographiques et biologiques du bassin n'est pas complète, et elle ne le sera jamais. Certaines lacunes sur le plan des données sont plus critiques que d'autres étant donné notre désir de gérer les activités que nous menons dans le bassin d'une façon qui n'a pas d'impact sur son écologie globale. Il existe des lacunes dans les données biologiques sur le cycle vital, les fonctions et la distribution spatiale de diverses espèces à l'échelon du réseau hydrographique; dans les données océanographiques, notamment en ce qui concerne la compréhension des sources et des impacts des sons dans les limites du bassin des Mines; ainsi que dans les connaissances sur le plan de nombreuses relations écosystémiques entre le biote et leur milieu physique ou entre des organismes, ce qui nous empêche de comprendre le réseau alimentaire et le flux énergétique dans le bassin.

Les études qui seront menées à l'avenir dans le réseau hydrographique du bassin des Mines devraient se fonder sur les trois prémisses fondamentales suivantes afin d'étayer la gestion écosystémique :

1. les études devraient mettre l'accent sur les liens écologiques entre les systèmes (interactions biologiques ou interactions physiques–biologiques) plutôt que sur des inventaires des espèces ou l'étude d'une espèce particulière;
2. les études devraient porter sur l'ensemble du réseau hydrographique de la baie;
3. les études devraient se fonder, en partie, sur des approches de surveillance des effets environnementaux dans le but d'évaluer les relations entre le biote et leur milieu.

En tant qu'outil de gestion, le REE doit être passé en revue et mis à jour périodiquement, ce qui permettra d'assurer que la base de savoir sur laquelle se prennent les décisions reste à jour de sorte à appuyer une meilleure gestion. Fait notable, aucune référence n'est faite dans le rapport à la littérature grise et aux données internes du gouvernement (bases de données et rapports inédits). L'analyse de ces données devrait être considérée, et les résultats inclus dans toute révision future du document. Aucune entrevue n'a été menée aux fins de la préparation du rapport, et le savoir écologique traditionnel des Premières nations, des pêcheurs et des collectivités n'y est pas explicitement incorporé. Le document n'a pas été examiné par des membres de la collectivité scientifique avant d'être imprimé. Bien que nous ayons tout mis en œuvre pour veiller à ce que les études et les connaissances sur l'écosystème du bassin des Mines soient fidèlement représentées, des erreurs peuvent s'être produites. Un examen par les pairs des mises à jour futures du REE permettrait de limiter le nombre d'erreurs et les fausses interprétations.

INTRODUCTION

1. PROJECT DEFINITION

THE MINAS BASIN INTEGRATED MANAGEMENT PROJECT

Founded during the late 1990s, the aim of the Minas Basin Working Group, a working group of the Bay of Fundy Ecosystem Partnership (BoFEP), is to devise integrated management plans for the Minas Basin watershed. The Minas Basin Integrated Management Project is best described as a process – one that is meant to be flexible and to evolve with age. It is a process of engaging citizens, groups and agencies in developing a comprehensive and sustainable management plan for the area's resources. It is hoped that this document will provide the sound ecological knowledge required for planning in the Minas Basin watershed.

The Minas Basin watershed ecosystem is of immense concern to many citizens in the area. A great deal of community involvement has occurred to date, consisting of five community workshops that discuss priority issues. Based on several community forums held in 2002, the top environmental priorities/concerns are (in alphabetical order):

1 agricultural practices;
2 development;
3 fisheries management;
4 forestry practices;
5 sewage treatment and water quality;
6 tourism and recreation.

This report provides a synthesis of existing documents, papers and research in the Minas Basin area, and a current snapshot of the knowledge of the Minas Basin ecosystem. Although efforts were made to include as much data as possible, it is likely that, due to time constraints, some information was unintentionally overlooked.

In tandem with this ecological overview is a socio-economic outline of the watershed written by Willcocks-Musselman (2003), which documented land-based activities and human resources. The socio-economic outline, in combination with this ecological overview, provides a comprehensive summary of the area's communities and ecosystem, and a solid basis for the development of a long-term ecosystem-based management plan.

1.1 CONTEXT AND PURPOSE OF REPORT

This *Ecosystem Overview and Assessment Report* is intended to provide an overview of the major ecological components of the Minas Basin marine waters and the land encompassed in the surrounding watershed. It was developed by the Oceans and Coastal Management Division of Fisheries and Oceans Canada, and is primarily intended as a background document for integrated management and planning in the Minas Basin watershed. The main structural components that define this ecosystem are presented, as well as a few of the more detailed characteristics that make the Minas Basin watershed or its subcomponents ecologically and biologically significant at a local, regional or global scale. The information provided in the report is not believed to be comprehensive since our knowledge of the environment is constantly evolving. However, the report identifies the relationships and components of the ecosystem for which we do have an understanding, and places them in an ecological, geographical and social context. Planning at the watershed level requires the compilation and integration of available ecological knowledge and information. This overview will thus be a useful reference for the continued development of integrated management plans in the watershed.

Outline of Report

Part A of this report details the physical properties of the Minas Basin ecosystem, with a focus on geology, geomorphology and sedimentology. Part B describes the oceanographic system, concentrating on atmospheric components and physical and chemical oceanography. Part C delves into the biological components of the ecosystem, beginning with a description of the marine flora and fauna, the species at risk and associated habitat types. Part D briefly assesses ecosystem relationships within the Minas Basin watershed, while Part E provides a detailed ecological assessment of the impacts of a range of industrial and human activities on the environment. Part F outlines the report's conclusions and recommendations, and highlights future monitoring and research needs.

1.2 Boundaries of Study Area

The Bay of Fundy, part of the Gulf of Maine, is a narrow funnel-shaped body of water that lies between Nova Scotia and New Brunswick, on the East Coast of Canada (see Figure 1.1). It is underlain by the Fundian Lowlands formation of Triassic sedimentary rocks. The bottom contours largely follow the coastline and reflect its origin as a former drainage system originating in the Minas Basin–Truro area. The head of the bay, or the Inner Bay of Fundy, is divided into Chignecto Bay to the north and the Minas Basin to the south, both of which are ecologically similar, with extremely high tidal ranges that expose large expanses of mud flats. The Outer Bay is the remaining portion that opens onto the Gulf of Maine. The Outer Bay lacks the intertidal mud flats and salt marshes of the inner reaches; its bottom consists, instead, of exposed bedrock and a coarse sand-and-gravel substrate winnowed by tidal currents (Davis and Browne, 1996b). This report largely confines itself to an overview of the Inner Bay.

The Minas Basin watershed, which forms the boundary of this study area, is comprised of the Minas Basin and several major watersheds surrounding it, including the Cornwallis River watershed in Kings County, the Avon River watershed in Hants County, the Shubenacadie River watershed in Hants and Colchester counties, and the Salmon River watershed in Colchester County (Willcocks-Musselman, 2003). It also includes smaller watersheds in the North Shore of the Minas Basin, including the Parrsboro area, and the South Shore of the Minas Basin around Noel in Hants County. The entire watershed, including the Minas Basin, is approximately 10,700 km^2 in extent (Willcocks-Musselman, 2003) (see Figure 1.5). These watersheds drain directly into the Minas Basin, which was formed by rivers eroding eastward from the Bay of Fundy. Since the Minas Basin is a semi-enclosed body of water, it is classified as an estuary (Pritchard, 1955).

Four distinct eco-regions comprise the basin: the Minas Channel, the Central Minas Basin, the Southern Bight and the Cobequid Bay (Percy, 2001) (see Figure 1.3). The spine of the Minas Channel is a 50 km-long, S-shaped 100 m-deep trench that curves around Cape Split and links the basin to the Bay of Fundy. At its westernmost end, flanked by Cape Chignecto to the north and Harbourville to the south, the channel is 24 km wide. It is narrowest (only 5 km wide) at its easternmost end between Partridge Island (near Parrsboro) and Cape Blomidon. Over much of its 75,000 ha area, the water depth averages only 25 m to 50 m at low tide; but the central trench is up to 115 m deep (Percy, 2001).

The Central Minas Basin, the Southern Bight and Cobequid Bay together form a triangle about 80 km long and 29 km wide at its broad western end. It narrows to a point in the estuary of the Salmon River near Truro, at the head of Cobequid Bay. The western border of Cobequid Bay falls on a line between Economy Point to the north and Burntcoat Head to the south. The division between the Southern Bight and the Central Minas Basin is not as well defined, running roughly from the midpoint of Cape Blomidon to Red Head. The depth of the Minas Basin is less than 25 m at low tide (an average of 14.5 m), although the deeper Minas Channel

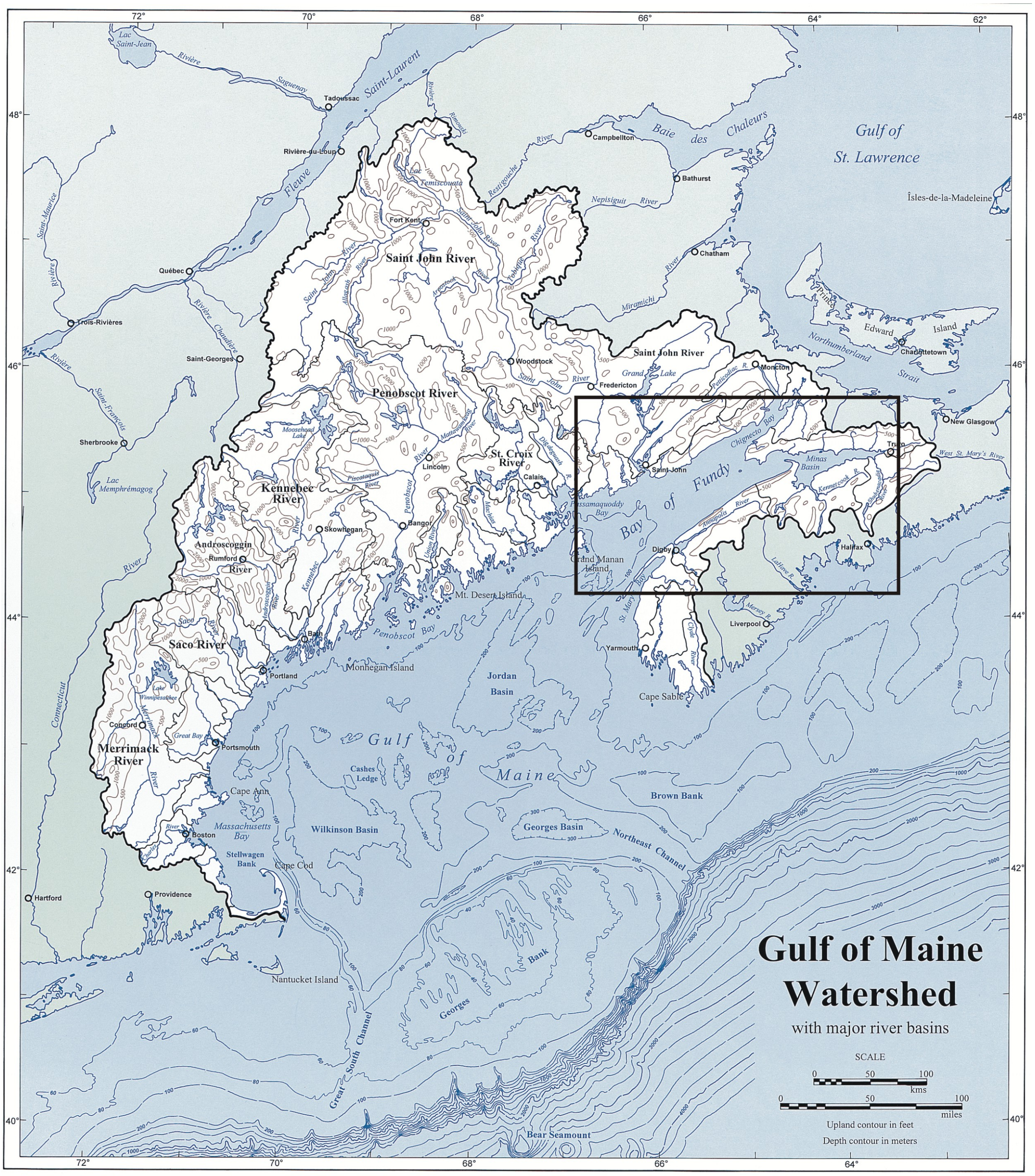


Figure 1.1 *The Gulf of Maine watershed, highlighting the Bay of Fundy*

Source: Gulf of Maine Council on the Marine Environment (www.gulfofmaine.org), modified by Lesley Carter

Source: Atlas Canada, www.atlas.gc.ca

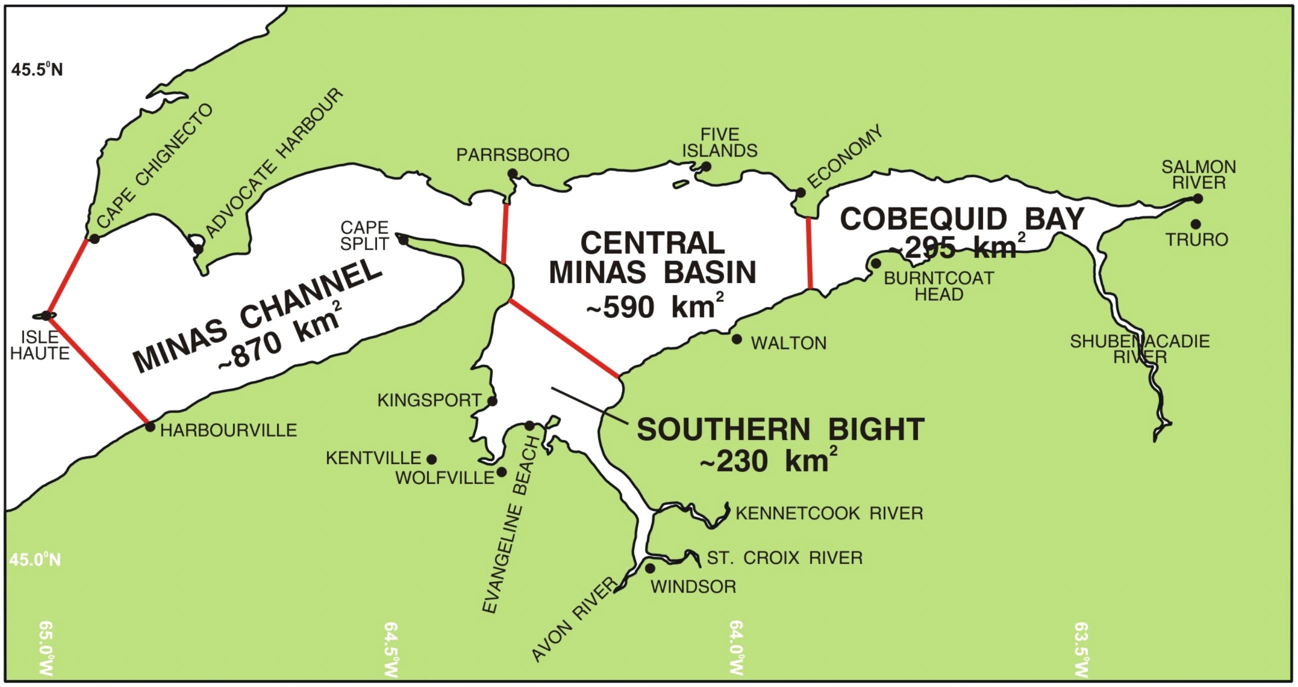


Figure 1.2 *The Minas Basin study area showing the location and approximate size of the four eco-regions, major rivers and coastal communities ; Source:* area calculations by Jennifer Hackett, DFO Coastal and Oceans Management Division (2002); map by Lesley Carter, adapted from Percy (2001).

trough is 100 m in depth (Percy, 2001). The total area of the Minas Basin, including its various estuaries, is approximately 1150 km^2, and combined with the Minas Channel, it comprises just under 2000 km^2 (Willcocks-Musselman, 2003). The area of the Minas Basin fluctuates with the tides: the waterline can recede as much as 5 km seaward, exposing almost 15,400 km^2 of intertidal zone (sand and mud flats, as well as salt marsh), or approximately one third of the water-covered area (Percy, 2001) (see Figure 1.4). The world's highest recorded tides have been measured here, at 16.27 m, with the average tide being 12 m. Most of the Minas Basin is less than 25 m deep at low tide, with an average of 14.5 m (Percy, 2001). In all, the length of the coastline of the Minas Basin, including the Minas Channel, is approximately 875 km (Willcocks-Musselman, 2003). While only four counties directly border the Minas Basin, the watershed has portions of seven counties within it (Colchester, Cumberland, Hants, Halifax, Kings, Lunenburg and Pictou). Approximately 180,000 people sparsely populate the watershed and coastline of the basin; Truro is the largest of the urban centres, with a population of 12,000.

More than half the area of the upper reaches of the Inner Bay of Fundy consists of intertidal mud or sand flats (Amos, 1987). The Triassic sandstone cliffs surrounding the Minas Basin give its coastal flats a higher sand and lower silt content than those in neighbouring Chignecto Bay, where the cliffs are mostly siltstone and shale. In the Minas region, fine silt and clay deposits occur in sheltered embayments where mudflats and salt marshes have formed. The area of the tidal flats in Minas Basin is about 35,800 ha in extent – almost half of it in Cobequid Bay and the rest equally divided between the Central Minas Basin and the Southern Bight (Thurston, 1990). The Minas Basin also contains about 1330 hectares of low salt marsh, almost 80% of which is concentrated around the Southern Bight, which is regularly flooded by the tide. Much of the basin's original high marsh has long been dyked and drained for agricultural use. The combined area of the Minas Basin and the Minas Channel is about 190,000 ha (Thurston, 1990). The watershed, or surrounding land area that drains into and thus influences this marine ecosystem, is nearly five times larger, almost 900,000 ha, encompassing over 20% of mainland Nova Scotia (Amos, 1987).

1.3 History of Research in the Minas Basin

During the 1800s and early 1900s, many zoologists did not include the upper reaches of the Bay of Fundy in their studies. Whiteaves (1901) published a still widely used marine species identification key and mentioned only six species from the Minas Basin (two sponges and four molluscs). Kindle (1917) reported on some intertidal and shallow water collections made at Kingsport and Cheverie Point, and added 12 species to the Whiteaves list. Shortly after, Leim spent the summers of 1919 to 1921 studying the life history of the shad in the basin, while at the same time doing as much general collecting as possible (Leim, 1924). After a 20-year gap, Baillie and Klawe in 1946 (in Berkeley and Berkeley, 1954) expanded upon knowledge of the polychaete species. Bousfield and Leim (1959) were the first to compile a substantial invertebrate faunal list for the Minas Basin and Minas Channel, with 195 invertebrate species catalogued (Yeo, 1977).

During the early 1970s, our knowledge of the Bay of Fundy greatly improved when feasibility studies on tidal power were conducted (Moyse, 1978) over an eight-year period (Daborn, pers. comm.). During the late 1970s, the National Research Council funded several large-scale studies to document the fauna of the intertidal flats at Scots Bay and the Southern Bight area (Gratto, 1978, 1979). Since then, studies have tended to be more ecological in nature, examining relationships between species and their surrounding environs. For example, Wilson (1988, 1989, 1991) investigated competition and predation in soft-sediment communities of the Minas Basin, and the effect of winter ice has been studied in detail by Gordon and Dadswell (1984), Gordon and Desplanque (1983) and Partridge (2000). Many studies have endeavoured to quantify human impacts, with emphasis on baitworm harvesting (Shepherd, 1993), flounder-trawling impacts (Brylinsky et al, 1994) and tidal barriers (Coon, 1999).

Investigations of specific ecosystem components are also being conducted alongside the more ecosystem-based studies. Contaminants (Chou et al, 2000; Jones et al, 2001), the endangered Atlantic salmon (Amiro, 2003), foraging site selection of migrating birds (Hicklin and Smith, 1984) and estimates of salt marsh productivity (Hargrave et al, 1983) are just a few examples.

1.4 The Minas Basin Ecosystem

General Overview

Cameron and Pritchard (1963, p306) define an estuary as "a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage". Given the semi-enclosed nature of the Minas Basin, along with its lower-than-seawater salinities, it can be classified as an estuary. The extremely high tides of the Minas Bay are primarily a result of its geography. Red sandstone cliffs and salt marsh dominate the shoreline. The maximum tidal range is 16.3 m at Burntcoat Head (Dawson, 1917), with the average being 11.9 m. At extreme low water, the area of the intertidal zone is approximately 400 km^2, or more than one third of the total area of the basin (see Figures 1.3 and 1.4). No other coastal marine area in the world of comparable size has such a large proportion of bottom exposed to the air at low tide (Bousfield and Leim, 1959).

The Minas Basin's extreme tidal range creates a physically stressed environment for organisms in several respects – extreme temperature fluctuations, susceptibility to drying out (desiccation) and potential exposure to predators (Craig, 1976). The Cobequid Bay area displays typical features of stress – relatively low species diversity, local heterogeneity and occasionally high specific abundance (Odum, 1971). A unique feature of the Minas Basin is that community structure and trophic pathways seem to be controlled by the dynamics of suspended sediments. In areas of high turbidity, primary production is hampered and high densities of suspension and deposit feeding organisms are found (Daborn, 1984). Temperature and salinity are the most important factors affecting distribution, followed by the sediments and their ability to support feeding and to provide suitable living grounds. Other factors are predation, erosion and sedimentation (Yeo, 1977).

Table 1.1 *Approximate area of the Minas Basin watershed*

Primary and sub-watersheds	Ocean area of watershed (km^2)	Land base of watershed (km^2)	Total area (km^2)	Percentage of Minas Basin watershed
Minas Basin Watershed	**1985**	**8715**	**10,700**	**100 %**
Minas Channel sub-watershed	870	550	1420	13.5 %
Minas Channel (north)	–	(300)	–	–
Minas Channel (south)	–	(250)	–	–
Central Minas Basin sub-watershed	590	750	1340	12.5 %
Central Minas Basin (north)	–	(550)	–	–
Central Minas Basin (south)	–	(200)	–	–
Southern Bight sub-watershed	230	3100	3330	31 %
Cobequid Bay sub-watershed	295	4315	4610	43 %

Source: Jennifer Hackett, DFO Coastal and Oceans Management Division (2002)

Area Description

The Inner Bay of Fundy differs substantially from the Outer Bay largely because of the effects of high tides and the more sheltered environments that characterize its shoreline. Here, tidal force is predominant and has established a macro-tidal environment (The Nova Scotia Musuem, 1996b). Tidal mixing tends to minimize seasonal variations in temperature and salinity. The Inner Bay is estuarine in character and is generally warmer than the Outer Bay because of the significant warming of water as it moves over mud flats, its restricted circulation and its high turbidity. Glacially derived suspended sediment levels, as well as sediments derived from coastal erosion, are high in the Inner Bay of Fundy, and are markedly higher in Chignecto Bay than in the Minas Basin. These sediments are principally sands and gravels, although intertidal and sheltered environments have muddy bottoms (Dalrymple, 1977; Amos, 1984). The sand comes from the wave erosion of sandstone cliffs along the shoreline and from glacial outwash deposits. It has been noted that phytoplankton productivity may be limited because suspended sediments make the water opaque (Dalrymple, 1977; Amos, 1984; Davis and Browne, 1996b). Nevertheless, waters are productive despite the high turbidity and reduced phytoplankton production due to the abundance of zooplankton, which feed on detritus from salt marsh grasses in suspension in the water (Davis and Browne, 1996b).

The Minas Basin, Chignecto Bay and Cobequid Bay have extensive areas of intertidal mud flats, owing to the high tidal range, coastal erosion and sediments washed in from several of the major watershed rivers: the Salmon, Shubenacadie, Kennetcook, Avon and Cornwallis rivers, which flow into Cobequid Bay or the Minas Basin, and the Petitcodiac River of New Brunswick, which flows into Chignecto Bay (Davis and Browne, 1996b; Willcocks-Musselman, 2003). Here, soft-bottom fauna such as soft-shell clams, intertidal snails, small crustaceans and polychaete worms, and the finfish that feed upon them, are prevalent. The coastlines of these basins have extensive salt marshes or dykelands. Beyond the mud flats in the subtidal zone, the bottom is variable in character, consisting in places of exposed bedrock, sand, gravel and mud. The strong tidal currents create sea-bottom sand waves several metres in height and hundreds of metres in length (Davis and Browne, 1996b). Here, rocky shore fauna such as mussels, anemones and urchins are found. In the intertidal zone of the Minas Basin, a complex series of sand waves, megaripples and sand bars reflects the locally strong tidal flows (Amos, 1984). These occur at Economy Point, Five Islands and the Avon River estuary, as well as wide areas subtidally. Large populations of coastal fish migrate into the Inner Bay for feeding and reproduction; others are resident throughout the year. Most of the American shad, for example, from east coast waters spend the summer in the basins of the Inner Bay. More than 40 species of fish are considered regular residents, including Atlantic herring; alewife; blueback herring; smelt; Atlantic tomcod; Atlantic silverside; windowpane; smooth and winter flounder; striped bass; Atlantic salmon; and American eel (Davis and Browne, 1996). Various seabirds occur throughout the Inner Bay of Fundy, including gulls and cormorants, as well as various birds of prey (such as ospreys and bald eagles), which use the coastal bluffs and nearby inland areas for nesting. Multitudes of shore birds visit the mud flats on their passage north in spring, and then return late in summer from Arctic breeding areas.

The Minas Basin area can effectively be divided into four eco-regions, shown in Figure 1.3: the Minas Channel, the Central Minas Basin, the Southern Bight and Cobequid Bay.

Minas Channel

The Minas Channel is S-shaped, approximately 50 km long and links the Minas Basin with the Bay of Fundy proper. The outer end, from Cape Chignecto to Harbourville, is 24 km wide. Moving east, the channel narrows to about 4.8 km at its inner end, from Cape Sharp to Cape Blomidon. Here, along the shores of the east–west peninsula of Cape Split, heavy rip tides occur, especially at the exposed rocky outcrops. Tidal currents of up to 5.5 m/s in such a constricted area have scoured the bottom to depths of almost 120 m (Dalrymple, 1977).

According to Bousfield and Leim (1959), only 13 km^2 of intertidal area exists due to the heavy tidal currents that have carved steep shorelines. The average channel depth is between 25 m and 50 m, and Bousfield and Leim's (1959) survey found waters that are fairly uniform at 13˚C to 15˚C, with shore salinities from 30.5% to 30.9%. Waters are less turbid here than in the Minas Basin, with a Secchi disk depth of an average of 3 m. Heavy rip tides, reduced wave and surf action, and a 14 m-extreme tidal range are all found here.

Moving east, the Minas Basin and Cobequid Bay together form a triangular body of water approximately 80 km long and 29 km wide at the western end. Most of the basin is less than 25 m deep.

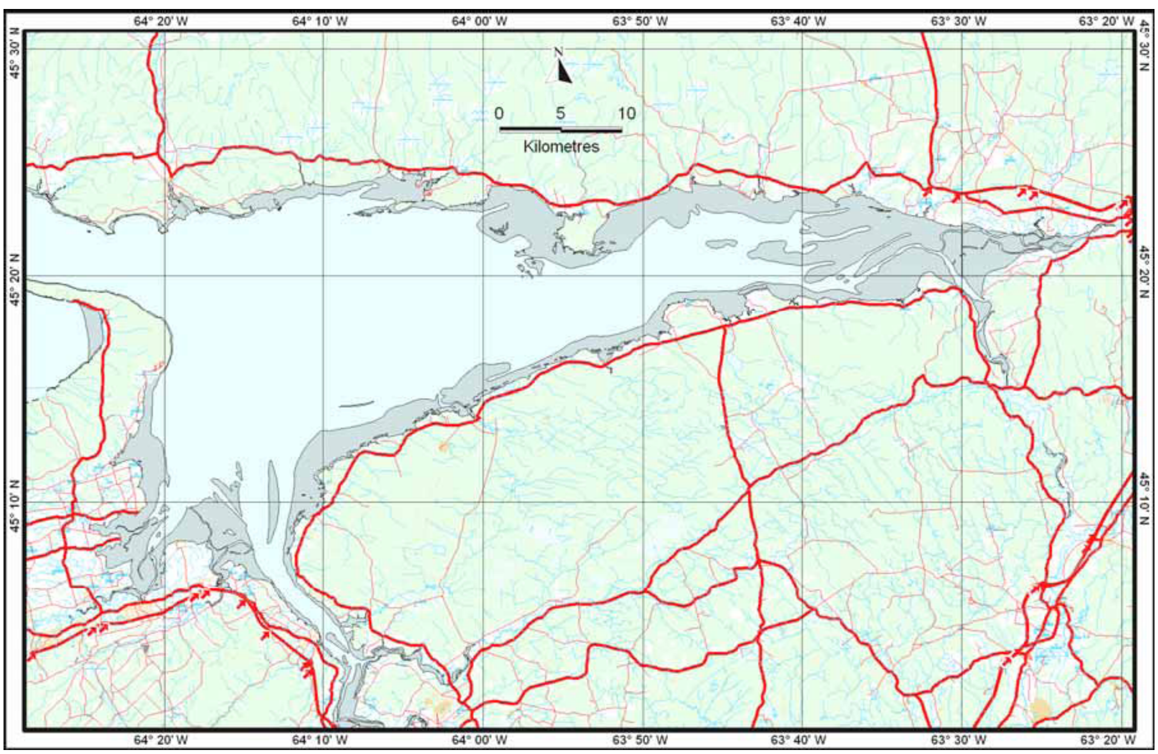


Figure 1.3 *Minas Basin watershed showing the extent of the tidal flats exposed at low tide*

Source: Stanley Johnson, Fisheries and Oceans Canada (adapted from Natural Resources Canada NTDB 1:50,000 digital map series)

Central Minas Basin

Bousfield and Leim's (1959) survey found the Central Minas Basin to have surface temperatures of up to and above 15˚C, shore salinities just under 30% and more "lake-like" wave action, with little to no surf. The average depth is 15 m to 20 m below lowest low-water level (CHS Chart D7-4010). Extremely turbid waters with Secchi disk depths of less than 1.5 m produce the highest tides of 16.3 m (extreme tide). The Central Minas Basin extends southward and eastward into two distinct subregions, the Southern Bight and Cobequid Bay.

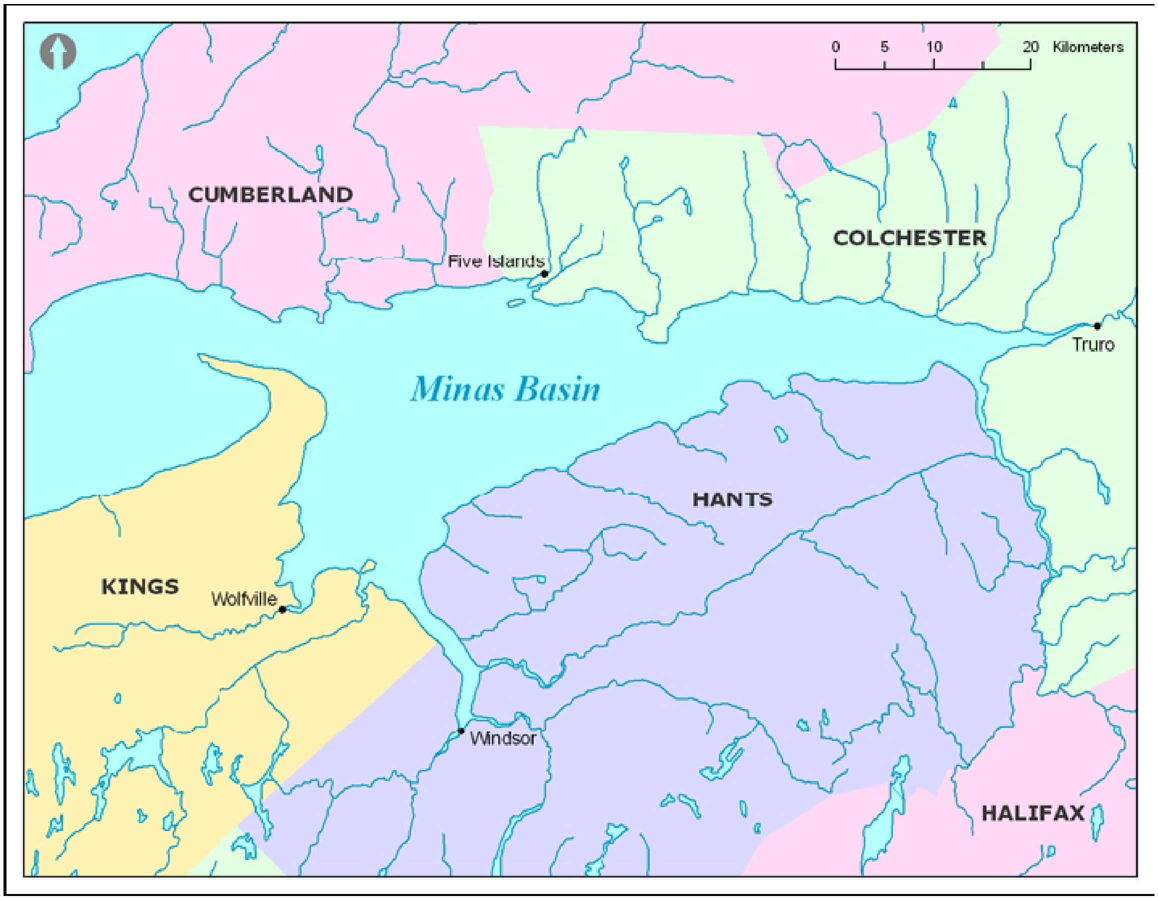


Figure 1.4 *County boundaries surrounding the Minas Basin, Nova Scotia*

Source: van Proosdij and Dobek (2005)

Southern Bight

The Southern Bight is formed by the convergence of several rivers: the Kennetcook, St. Croix and Avon rivers at the southern end, and the Gaspereau, Cornwallis, Canard, Habitant and Pereau rivers in the western end. Extensive mudflats with large *Corophium* populations are found here, which attract large numbers of migrating semipalmated sandpipers (*Calidris pusilla*) every summer. This area is also where most of the commercial groundfish and bloodworm harvesting takes place.

Cobequid Bay

Cobequid Bay is 30 km long, with a relatively constant width of 8 km (Dalrymple, 1977). Cobequid Bay drains many rivers, of which the Salmon and Shubenacadie are the largest. Warm freshwater from the rivers and solar heat absorbed by the tidal flats results in warmer temperatures and lower salinity in these areas. Endemic populations of organisms can be found whose normal range is south of the Bay of Fundy or in the warmer waters of the Gulf of St. Lawrence. Some of these endemic species are separated from their nearest outside populations by distances exceeding that of normal larval transport range (Bousfield and Leim, 1959).

2. METHODOLOGY OF STUDY

In order to evaluate the ecosystem of the Minas Basin area and the land encompassed in the surrounding catchment, we included the entire Minas Basin watershed and examined the area at a major subwatershed and basin-scale level. The Minas Basin watershed is comprised of the Minas Basin and several major and minor watersheds surrounding it: the entire catchment covered in this report comprises approximately 10,700 km^2 (Willcocks-Musselman, 2003) and covers four distinct eco-regions: the Minas Channel, the Central Minas Basin, the Southern Bight and the Cobequid Bay. These areas, which may be considered for future management units, have both terrestrial freshwater and marine components and together constitute the whole of the Minas Basin watershed.

The report is based on existing documents, papers, research, and cartographic and aerial photographic evidence from the Minas Basin area, and provides an ecological overview of the Minas Basin ecosystem. No primary fieldwork was conducted for this report; rather, it provides a synthesis of exisiting information as a basis for long-term ecosystem-based management plans.

2.1 INFORMATION USE AND RELIABILITY

As much as possible, this report relies on scientific literature and peer-reviewed information. However, where gaps exist, scientists familiar with the Minas Basin watershed have been asked for personal comment, manuscript reports have been used and non-peer reviewed literature has been assessed. These sources have been used with caution, and the most widely supported scientific understandings of the ecosystem are presented. In addition, information published in the proceedings of the 1999, 2002, 2005 and 2006 Bay of Fundy Ecosystem Partnership (BoFEP) workshops on understanding change in the Bay of Fundy and on assessing key ecological and social issues provides context and supplements other scientific literature (Ollerhead et al, 1999; Wells et al, 2004; Percy et al, 2005).

In certain sections of this document, the inclusion of internal government data would have been helpful and, in some cases, may have been the main source of data. However, references to grey literature are notably lacking (e.g. internal government reports) in this report, as are unpublished data in various forms (including internal databases) due to the inaccessibility of the authors. A major effort would be required to summarize and interpret these data, which should be a consideration for any future revisions of this report.

PART A – GEOLOGICAL SYSTEM

3. GEOLOGICAL COMPONENTS

The Bay of Fundy lies between New Brunswick and Nova Scotia and extends northeastward from the Gulf of Maine. The main body of the bay is almost rectangular, with an average width of 56 km and a length of 190 km from the mouth to Cape Chignecto (Dalrymple, 1977). From here, the bay splits into two arms: one turns northwards as Chignecto Bay, with Shepody Bay and the Cumberland Basin at its head (the Upper Bay); the other moves eastward and comprises the Minas Channel, the Minas Passage and the Minas Basin (the Inner Bay) – with Cobequid Bay at its eastern and the Southern Bight at its southern end (see Figure 1.3).

The Minas Basin and Cobequid Bay form a roughly triangular body of water with a length of 62 km and a maxium width of 26 km at the west end; they are separated from the Minas Channel by the Cape Blomidon–Cape Split peninsula. The narrow Minas Passage (4.8 km wide) is the only connection between the Minas Basin and the outer parts of the Bay of Fundy (Dalrymple, 1977).

3.1 BEDROCK FEATURES AND LANDSCAPE DEVELOPMENT

The geology of the region surrounding the Minas Basin is complex and spans more than 1.2 billion years. The oldest rocks in the area are Ordovician sandy and shaly flysh of the Meguma Group (Denton and Hughes, 1981; Stea et al, 1992a, 1992b) – these rocks are tightly folded and well indurated (hardened), but are poorly exposed. The next youngest sequence of rocks forms the Cobequid Mountains that lie to the north of the Minas Basin (Dalrymple, 1977). This sequence, believed to be of Silurian to early Devonian age, is composed of immature sediments with a major volcanic component (Stevenson, 1958; Denton and Hughes, 1981). Multicoloured shales, argillites and sandstones, as well as minor basic volcanics, are found here, with many of the rocks severely sheared. This sedimentary sequence has been intruded by late Devonian granites and syenites from the Acadian Orogeny (Dalrymple, 1977). The southern edge of the Cobequid Mountains is formed by the Gloosecap Fault (Scott and Medioli, 1980; Grant and Ling, 1984), a long-lived structure with unknown displacement and tectonic features.

Carboniferous sediments comprise large parts of the area on both sides of the Minas Basin (see Figures 3.1 and 3.2). Here, rocks of Mississippian age have been divided into two groups, both deposited in a fault-bounded grabens or trough (the Bay of Fundy is believed to be a half-graben basin) (Dalrymple, 1977). The Horton Group, composed of arkosic sandstones, conglomerates and shale (see Figure 3.3), is thought to be a marginal alluvial fan facies (Dalrymple, 1977; Denton and Hughes, 1981). The Windsor Group is made up of finer-grained clastics, as well as evaporates (including gypsum, anhydrite, salt and limestone) that occupied the central parts of the grabens (Dalrymple, 1977; King and Fader, 1986). The predominant rock types, then, are conglomerates, sandstones and shale, with minor coal and limestone; all Carboniferous rocks, furthermore, are folded and well indurated (Miller and Milligan, undated). Outcrops near the Glooscap Fault are strongly sheared.

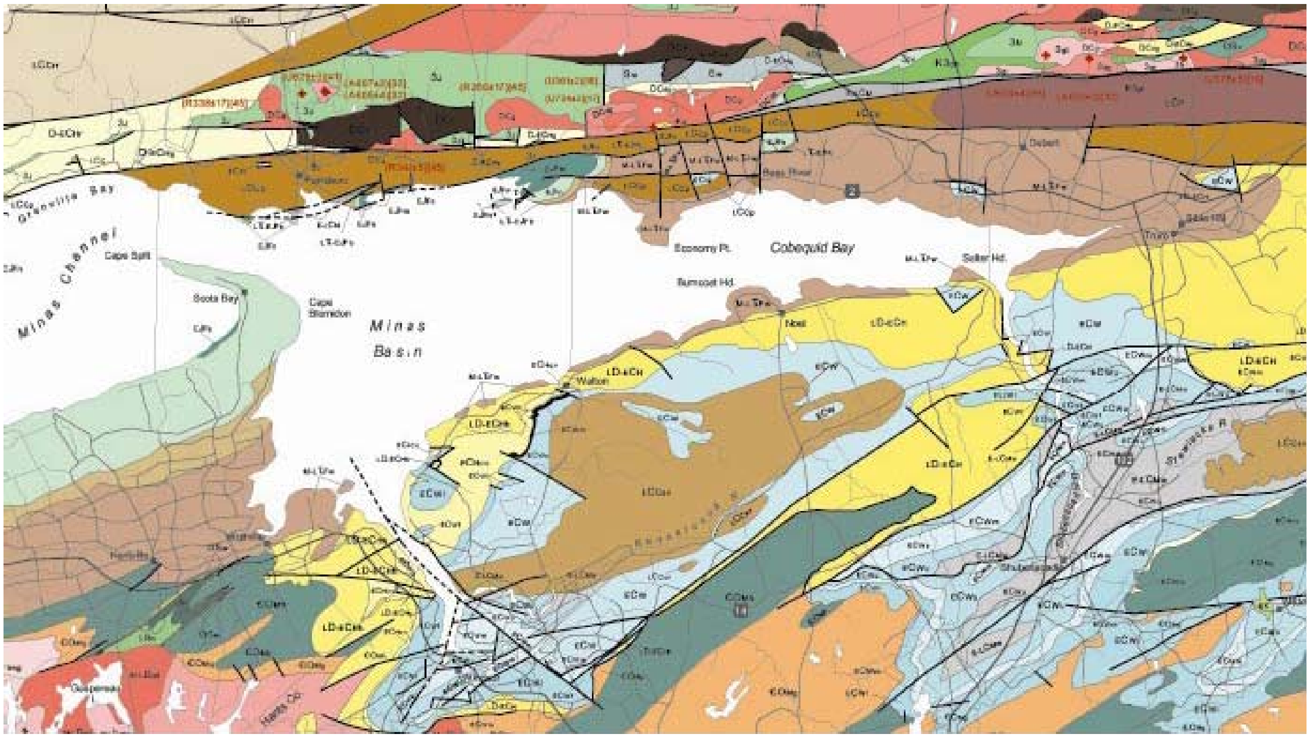


Figure 3.1 *Geological map of the Minas Basin*

Source: adapted from Perry-Giroud (2005)

A simplified chronological sequence for the geology surrounding the Minas Basin is provided in Figure 3.2.

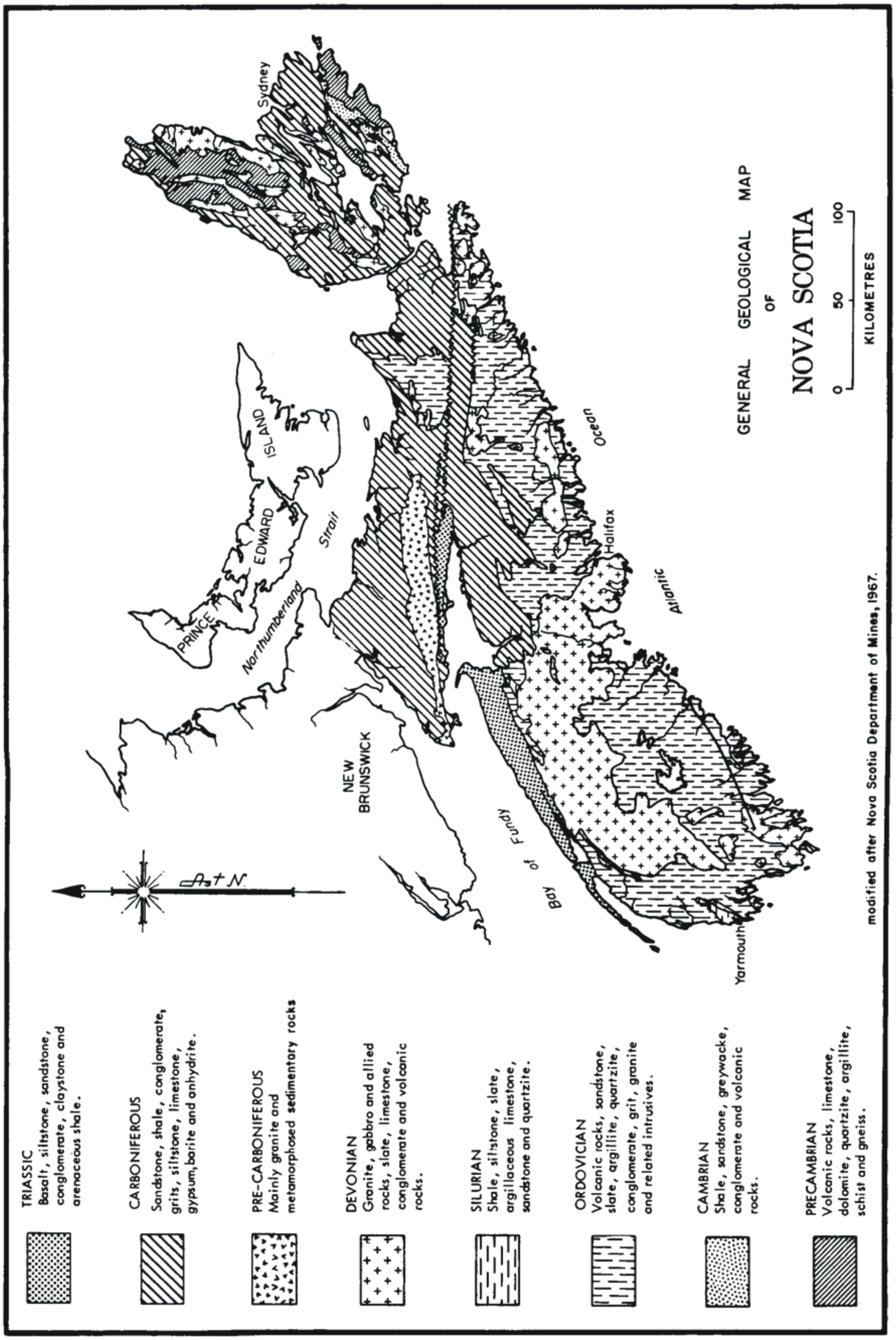


Figure 3.2 *General geological map of Nova Scotia, featuring the Inner Bay of Fundy*

Source: Nova Scotia Department of Mines and Energy

Figure 3.3 *The sandstones and mudstones at Blue Beach along the Evangeline Trail, deposited along the shores of Mississippian lakes: A close look reveals preserved ripples (indicative of water), mud cracks (indicative of drying conditions), 350 million-year-old raindrop prints, and fossil plants, fish scales and amphibian footprints*

Source: photo by Peter Wallace; inset by Heinz Wiele (specimen courtesy of Gordon Oakey), 2004

The Minas Basin and Cobequid Bay were carved out by rivers that eroded eastwards from the Bay of Fundy, cutting a channel along the Minas Passage Fault between Cape Split and Cape Sharp (Stea et al, 1992a, 1992b; Davis and Browne, 1996b). The shape and profile of the entire Bay of Fundy were greatly affected by repeated glaciations during the Pleistocene, when four major ice-flow phases occurred; these have been determined by mapping striations and other ice-flow indicators, such as glacial deposits, throughout Nova Scotia (Grant, 1977; Scott and Medioli; 1980; Denton and Hughes, 1981; Grant and King, 1984; King and Fader, 1986; Stea and Brown, 1989; Stea and Mott, 1989; Stea et al, 1992a, 1992b). Evidence of the first and most extensive phase of ice flow in Nova Scotia is provided by patterns of glacial striations (grooves formed by the ice) and erratics (boulders transported from rock sources far away): ice sheets moved eastward and then southeastward across the Bay of Fundy. The vast majority of drumlins in Nova Scotia were formed during this phase. The second major ice flow was southward and southwestward; the southward dispersal of distinctive Cobequid glacial erratics occurred during this phase. A major glacial advance from the north also established much of the drumlin topography in southern and eastern Nova Scotia and produced the north–south and northwest–southeast alignment of geomorphological features. During the third phase, an ice divide in southern Nova Scotia precipitated a northward flow across the northern mainland; it was during this phase that granites from the South Mountain batholith were transported northward onto the North Mountain basalt cuesta. During the fourth phase, remnant ice caps formed over the Chignecto Peninsula and southern Nova Scotia, marked by moraines, ablation till and glaciofluvial sediments. The ice flow during this last phase was strongly funnelled into the Bay of Fundy (Grant and King, 1984; King and Fader, 1986; Stea and Brown, 1989; Stea and Mott, 1989; Stea et al, 1992a, 1992b; Davis and Browne, 1996b).

The floor of the Inner Bay of Fundy, therefore, is smooth and striated like a glacial pavement, and is covered by a mantle of loose material up to 10 m thick, some of which is glacial till (see Figure 3.4) (Amos, 1984; Davis and Browne, 1996b; Stea, 2003). Geological and seismic data indicate that up to 12,000 m of sediments fill the main Fundy Basin, approximately 6000 m fill the Chignecto sub-basin, and perhaps 3000 m fill the Minas sub-basin (Hubert and Mertz, 1980, 1984; Mertz and Hubert, 1990; Wade and MacLean, 1990; Brown and Grantham, 1992). The strata in these basins are generally undisturbed, except along the faulted margins (see below) and where the Cobequid–Chedabucto Fault crosses the Fundy Basin (see Figure 3.10) (Davis and Browne, 1996b).

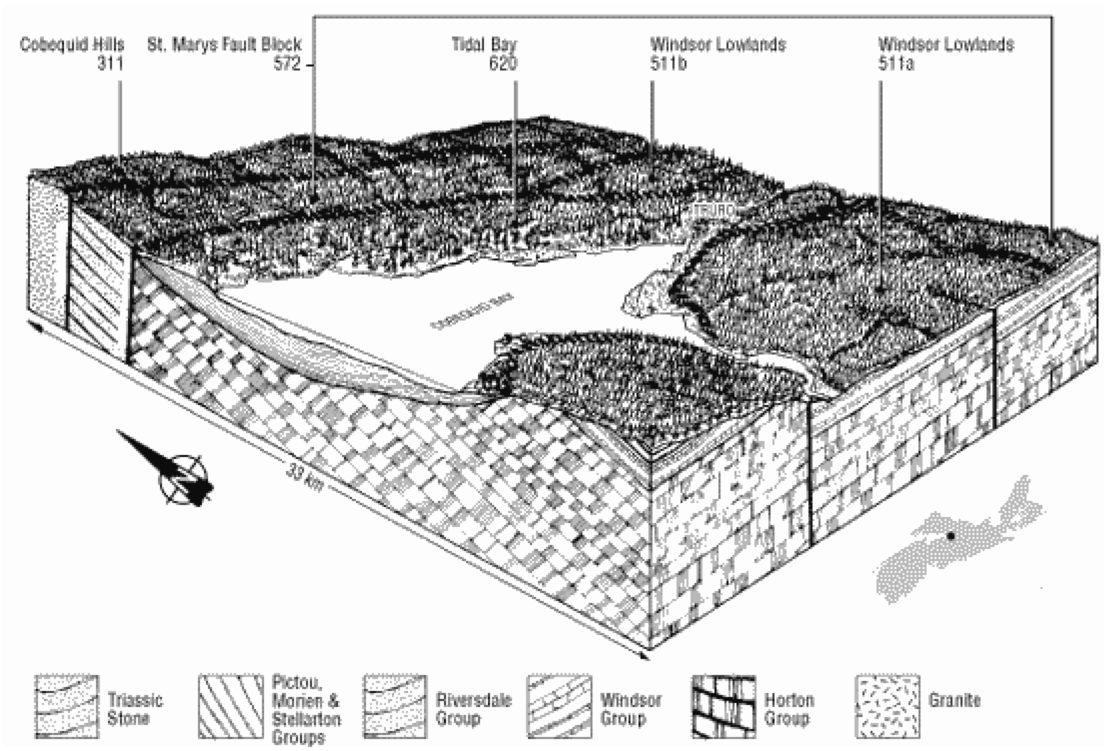


Figure 3.4 *Soft red Triassic sandstones fringing Cobequid Bay are surrounded by the somewhat more elevated and resistant Carboniferous rocks of the Windsor Lowlands: A westerly extension of the St. Mary's Fault Block forms a dissected shoulder to the Cobequid Hills, from which short, steep rivers drain into the bay*

Source: Davis and Browne (1996b, p164)

The distinctive red beds (see Figures 3.4 to 3.8) that fringe the Minas Basin and Cobequid Bay, and extend beneath the Annapolis–Cornwallis Valley, belong to the Triassic Lowlands (Scott and Medioli, 1980; Grant, 1989; Stea et al, 1992a, 1992b; Davis and Browne, 1996b) and are made up of weakly cemented and easily eroded sandstones and sandy shale, overlain by glacial deposits of varying character of the Wolfville and Blomidon formations (King, 1976; Grant, 1989; Stea et al, 1992a, 1992b). These red beds, which are nearly horizontal and form a low area with gentle undulations, were deposited under arid conditions in a narrow hill-fringed basin while Nova Scotia was still part of the Panagaea (Davis and Browne, 1996b). On the north side of Cobequid Bay, they reveal their greatest width, but then end abruptly at the Portapique Mountain Fault. The early deposits that washed down from South Mountain and the Cobequids were coarse sands that were later consolidated into a crumbly, friable sandstone (of the Wolfville formation). Much of the basin was then flooded with lava as volcanoes became active in the Fundy region. Later faulting and subsidence created a spoon-shaped depression or trough (otherwise known as the half-graben structure) in which the sandstones, shales and basalt dip at 5° to 10° towards the centre line of the Minas Basin. This trough is now largely occupied by the sea (Grant and King, 1984; King and Fader, 1986; Scott and Medioli, 1989; Davis and Browne, 1996b). From aerial photographs, it is possible to discern that the northern side of the trough, or half-grabens, is downfaulted. The master fault is believed to be the Cobequid Fault (see Figures 3.9 and 3.10); but the boundary of the Triassic deposits is the Portapique Mountain Fault (Grant, 1977; Grant and

King, 1984; Davis and Browne, 1996b). Along this northern margin the strata are more steeply inclined than those to the south, and in places are even more gently folded.

Figure 3.5 *Triassic rocks and red sediment of the Minas Basin in Economy on the north shore of the Central Minas Basin.*

Source: Perry-Giroud (2005)

Figure 3.6 *The fertile Annapolis Valley is underlain by red Triassic sedimentary rocks formed in lakes and rivers over 200 million years ago; these rocks form the cliffs, for example, at Blomidon in the Southern Bight*

Source: photo by Martin Gibling, 2004

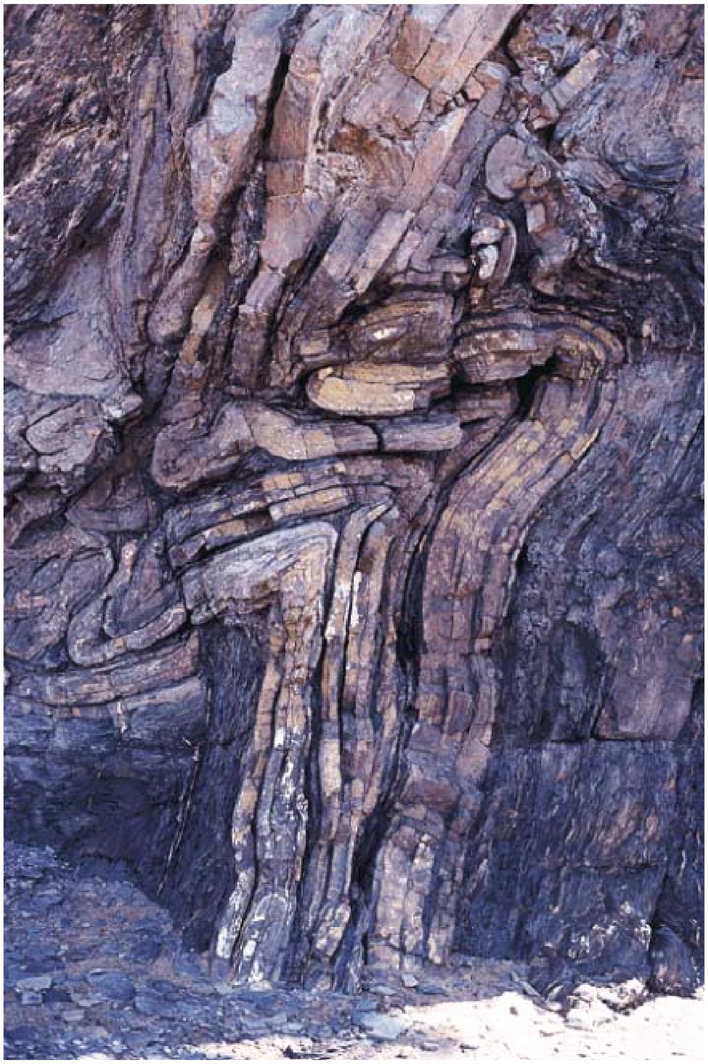


Figure 3.7 *Tightly folded Mississippian sandstones and mudstones at Rainy Cove in the Southern Bight, overlain by almost flat-lying red Triassic sandstone beds and conglomerates (pebble rocks)*

Source: photo by Rob Fensome, 2004

During the long period of erosion up to and including the Cretaceaous, much of the original basalt was removed. Some still remains as a "protective cap" on the sandstones (Grant, 1989; Davis and Browne, 1996b); but to the north, east and south, wide bands of soft sandstone were uncovered. Rapid erosion then ensued as a river system developed in the trough, followed by glacial scouring and, finally, by invasion of marine waters. Much of the Triassic Lowlands region is now covered by water. The Shubenacadie and Salmon rivers, which flow into Cobequid Bay (see Figure 1.3), have drowned estuaries and buried river channels beneath the riverbed deposits (Davis and Browne, 1996b). In the Truro area, the incised channels of the North and Salmon rivers, cut in the sandstone bedrock, are filled with fluvioglacial outwash sands and gravels derived from the major ice-flow phases (Grant and King, 1984; King and Fader, 1986; Stea and Brown, 1989; Stea and Mott, 1989; Stea et al, 1992a, 1992b; Davis and Browne, 1996b).

Figure 3.8 *The boundary between the Mississippian and Triassic rocks (here seen at Rainy Cove, Southern Bight of Minas Basin), known as an unconformity, represents over 100 million years of "deep time"*

Source: photo by Rob Fensome, 2004

Figure 3.9 *Over 390 million years ago, two small continental fragments collided and slid against one another to form much of the geological structure of what we know today as Nova Scotia: The boundary, known as the Cobequid–Chedabucto Fault (here seen near Port Greville, north of the Minas Channel) is analogous to today's San Andreas Fault in California and is a prominent feature of geological and topographic maps of the province*

Source: photo by Howard Donohoe, 2004

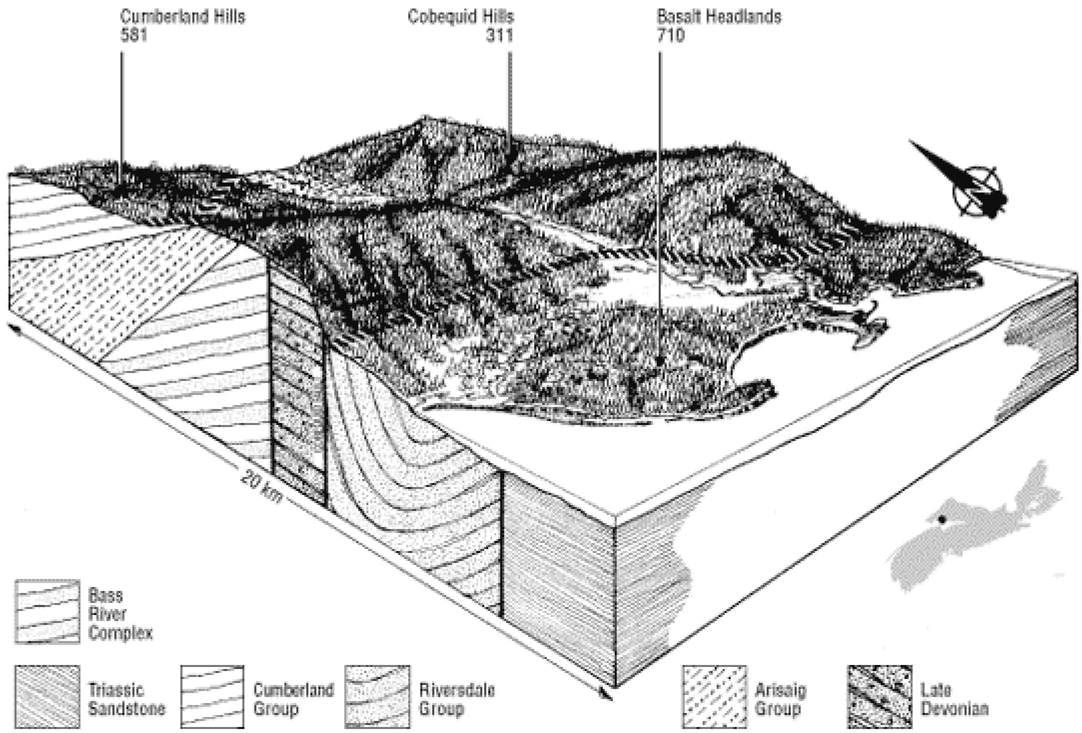


Figure 3.10 *The Cobequid Hills descend abruptly along the Cobequid Fault to the lowlands fringing the Minas Basin; to the north, in contrast, the Cobequids merge gradually into the Cumberland Hills*

Note: Headlands of basalt along the Minas Basin are distinguished from bays carved from the less-resistant Riversdale shales and Triassic sandstones of the Fundy Coast.

Source: Davis and Browne (1996b, p26)

As mentioned earlier, much of the Triassic Lowlands from Truro to the north side of Cobequid Bay (see Figure 1.2) are covered by glacial deposits (Hubert and Mertz, 1980, 1984; Mertz and Hubert, 1990; Wade and MacLean, 1990; Brown and Grantham, 1992). The Truro sub-basin is filled with outwash sands and gravels carried from the north and east, forming a platform elevated to 18 m above sea level (Davis and Browne, 1996b); the plain is now divided by streams. On the north side of Cobequid Bay, outwash deposits are evident in river terraces. At Glenholme, for example, on the north shore of Cobeuid Bay the underlying Triassic sandstone is exposed where the gravels have been washed away. As sea levels continue to rise, the soft coastal red beds along the Minas Basin are being eroded rapidly, contributing enormous volumes of sediment to the waters of the bay. This sediment is washed up and down the rivers with the tide, while some is deposited in the estuaries as sand bars (for example, in the Avon and Shubenacadie river estuaries; see section 5 on "Sedimentology") (Fader et al, 1977).

Figure 3.11 *Jurassic lavas associated with the opening of the Atlantic Ocean form dramatic cliffs and headlands around the Minas Basin: The vesicular or bubbly tops of some flows were ideal for the precipitation of mineral crystals, such as zeolites and agates*

Source: photo by Heinz Wiele (specimen courtesy of the Fundy Geological Museum), 2004

Throughout the Minas Basin, researchers have discovered fossilized plant fragments, fish scales and fin spines, worm burrows, arthropod trails, amphibian bones, and the marks of ancient raindrops and ripples (see Figure 3.3). Footprints, which proved to be the largest amphibian tracks ever seen in such ancient rocks, were found near the mouth of the Avon River in the Southern Bight. The Kennetcook River is noted for its marine fossils, including horn corals, stony bryozoa, brachiopods, pelecypods, cephalopods and trilobites. The north shore of the basin is also known for its varied fossilized plants, animals and amphibian trackways. However, it is undoubtedly the fossils of dinosaurs and their tracks that have attracted the most attention. The rocks of Cape Blomidon have revealed the tracks of a pheasant-sized bird-hipped dinosaur known as *Atrepius*, one of the oldest found in Canada. Prosoraupods and other dinosaur fossils and tracks are to be seen in the sandstone along the Parrsboro shore, north of the Central Minas Basin. Nearby Wasson's Bluff became known worldwide in 1986 with the discovery of an unusual mammal-like reptile, *Pachygenelus* (Thurston, 1994).

With most of the Triassic Lowlands submerged in water, the largest area still above sea level is the eastern part of the Annapolis–Cornwallis Valley, which – though undergoing rapid erosion – is protected somewhat by its resistant rock: the North Mountain basalt and the South Mountain granite that form Cape Blomidon and Cape Split (Grant, 1980; Scott and Greenberg, 1983; Stea and Mott, 1989; Forbes et al, 1991; Shaw et al, 1991; Davis and Browne, 1996b). According to Dalrymple (1977) and Colwell (1980), zeolites and amethyst are common in the basalt units (see Figure 3.11). Nevertheless, extensive erosion and the Triassic deposits that fringe the shoreline of the Minas Basin and Cobequid Bay continue to form low, rapidly retreating sea cliffs fronted by wide 100 m to 300 m wave-cut platforms, gravel beaches and mud flats.

4. GEOMORPHOLOGY

The topography of the Bay of Fundy is strongly controlled by its geomorphology, as well as its geology. The highest points in the area are located in the Cobequid Mounains, where elevations of over 300 m are found within 11 km of the Minas Basin shore (Dalrymple, 1977). South of the Cobequids and the Glooscap Fault, the land drops rapidly to the Triassic lowlands, which rarely exceed 60 m in elevation. The shores of the Minas Basin are almost everywhere bordered by cliffs that reach up to 30 m in height, cut into Triassic sediments. On Cape Blomidon, the North Mountain basalt forms a cuesta approximately 190 m high (Dalrymple, 1977). The surface underlain by Carboniferous sediments on the south shore rises much more gradually than do the Cobequid Mountains, and generally does not exceed 180 m in elevation within 10 km of the shore.

Known for its very large tidal range, which increases from 4 m near its mouth to an average of 12 m in its upper bays (where extreme values of 16 m have been recorded), the Inner Bay of Fundy is funnel shaped and structurally influenced (see Figure 1.1) (Daborn et al, 2004). The energy of the extreme tidal flows that occur in the area is dissipated in the actions of sediment transport, scour and coastline erosion. The Minas Basin – the focus of this report – is a large, triangular and shallow estuarine embayment located at the head of the Bay of Fundy, in the central region of Nova Scotia, and is generally considered an estuarine environment because of its changeable salinity, the vigorous movement of its tidal water and the close interation between its water and the surrounding land (Daborn et al, 2004) (see Figure 1.2). Its coastal zone is protected from the extreme climatic conditions of the Atlantic Coast by Cape Blomidon on the south coast and Economy Mountain on the north. Here, the Fundy Coast is best described as a climatic and vegetation transition zone dominated by basaltic rocks. Coastal sediments are locally abundant, forming small areas of salt marsh, gravel beaches and mud flats, and wide intertidal platforms have been eroded in both basaltic and sedimentary rocks, providing a diversity of coastal habitats (Davis and Browne, 1996b).

The geomorphology of the erosive sea cliffs of the Fundy Coast is characterized by volcanic faulting and subsequent glaciation. Approximately 200 million years ago, the Atlantic Ocean began to form as the continents drifted apart. The gently sloping, sandy arid plain between the Cobequid Hills and the South Mountain collapsed as the spreading continued (Dalrymple, 1977; Stevens, 1980; Wark and Clarke, 1980; Roland, 1982; Davis and Browne, 1996b; Daborn et al, 2004). Tensions created by this movement opened rifts in the plain from which basaltic lavas welled up to spread over the sands and gravels. Faulting continued after the lavas had cooled, causing fractures, tilting and offsets in the basalt (Stevens, 1980; Wark and Clarke, 1980; Roland, 1982; Davis and Browne, 1996b). Basalt occurred as far east as Portapique on the north shore of Cobequid Bay and is still present in four downfaulted blocks inland of Economy Point. From Gerrish Mountain west, on the north side of the Minas Basin, a series of faulted basalt blocks form headlands with vertical cliffs (see Figure 4.2). Inland, sandstone cliffs have been protected by the basalt caps (Davis and Browne, 1996b). These coastal Triassic sandstone cliffs contribute to the relatively coarse intertidal grain sizes found in the area, compared to Cobequid Bay, where the cliffs are siltstone and shale (BoFEP, 2001; Daborn et al, 2004). The distinctive red colour of the sediments is due to the presence of hematite, rich in iron and easily oxidized, and which explains the friable nature of the cliffs.

South of the Minas Channel, the basalt lava flows formed the continuous ridge of the North Mountain. High, continuous vertical cliffs are found on the outer side of this escarpment, on the coast from Cape Split to Cape Blomidon, and inland from Cape Blomidon to the Annapolis Basin (Davis and Browne, 1996b; BoFEP, 2001). Vertical or columnar jointing in the basalt of the Minas Basin cliffs makes them susceptible to erosion. Wide intertidal platforms, with widths of up to 2 km (Dalrymple, 1977; Amos, 1984), have been cut at the base of the basalt, and even wider platforms have been cut in the sandstone bays of the northern shore (Davis and Browne, 1996b; BoFEP, 2001).

During the Pleistocene, the Bay of Fundy was (at least) twice covered by continental ice sheets (Dalrymple, 1977; Grant, 1977; Scott and Medioli; 1980; Denton and Hughes, 1981; Grant and King, 1984; King and

Fader, 1986; Stea and Brown, 1989; Stea and Mott, 1989; Stea et al, 1992a, 1992b), deeply scoured and then thickly covered by glacial debris (silty till, with abundant pebbles and cobbles). During deglaciation, ice remained longest in the Cobequid Mountains, and large amounts of sandy and gravelly outwash are present along the north shore, although on the south side, outwash is uncommon (Dalrymple, 1977; Stea et al, 1992a, 1992b). Sea-level movements from deglaciation to the present are complicated due to the offsetting factors of sea-level rise and isostatic rebound. At some point 13,000 to 11,500 years ago, immediately following deglaciation, the sea invaded the Minas Basin, and much of the outwash along the north shore was deposited as marine deltas and raised beaches (see Figure 4.2) (Amos, 1984). As the ice load was removed between 12,000 and 6000 years ago, rebound then overtook sea-level rise and the sea withdrew, leaving the floor of the Bay of Fundy exposed (Grant, 1977; Denton and Hughes, 1981; Stea and Mott, 1989; Davis and Browne, 1996b; Daborn et al, 2004). During this period, the rivers flowing into the bay incised their valleys down to the new base level.

When the last inundation by the sea began 6000 years ago, the conditions for increased tidal amplitude were created by the shape of the bay. Subsidence of the land, as well as a slowly rising sea level worldwide have caused recently measured sea-level increases of 40 cm per century in the outer reaches of the Fundy Coast (Davis and Browne, 1996b). Rapid erosion of the crumbling rocks has been accelerated by this sea-level rise (BoFEP, 2001). Wide intertidal platforms, salt marshes, submerged forests and freshwater marshes have since formed, and large intertidal sand bodies have built up (Davis and Browne, 1996b).

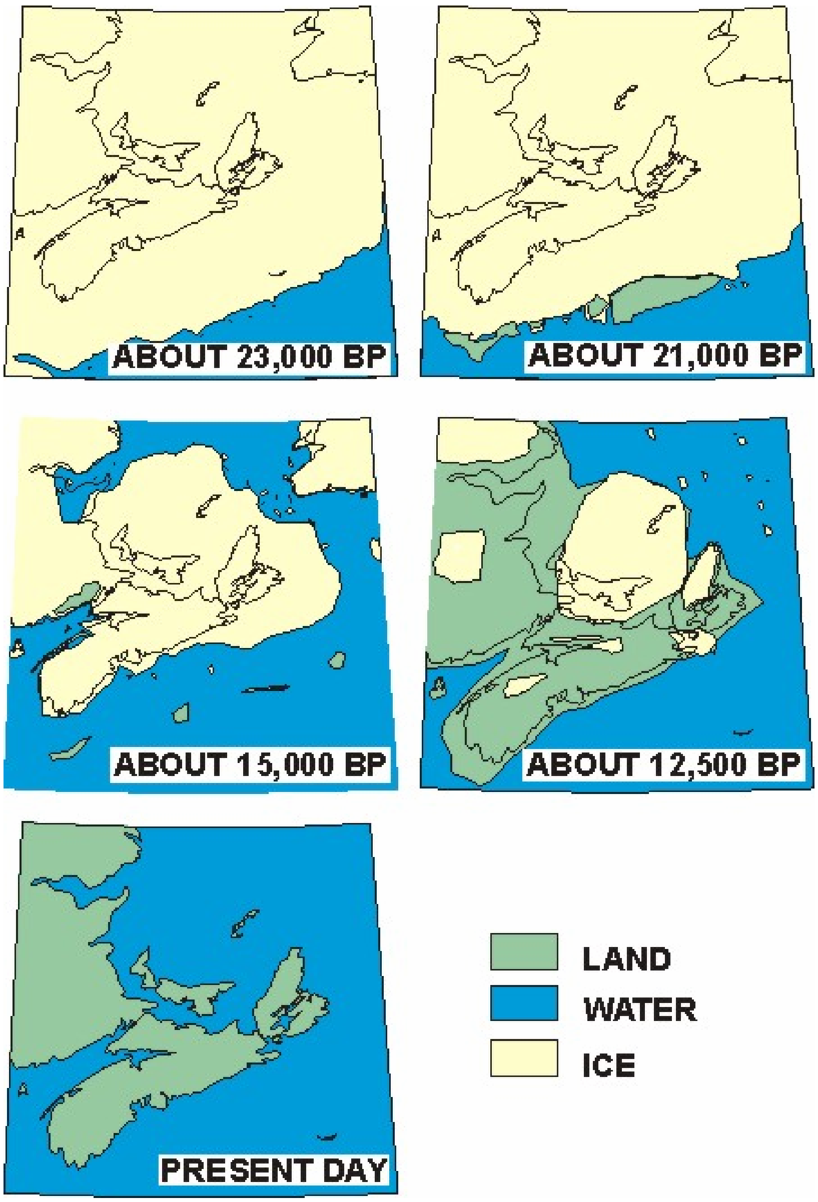


Figure 4.1 *Stages in the last retreat of glaciers from the Maritimes*

Source: AGS (2001)

4.1 Topography of Coastal Landscapes

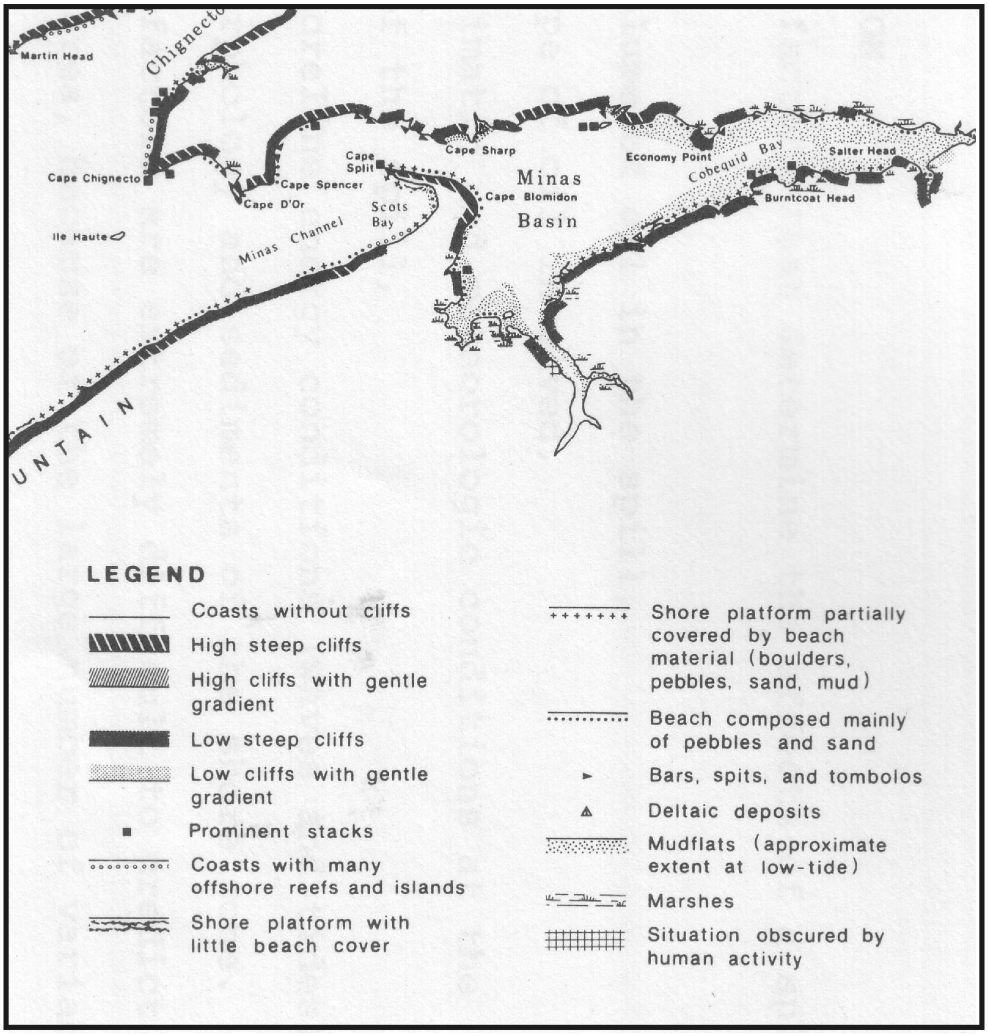


Figure 4.2 *General coastal morphology of the Minas Basin*

Source: adapted from Fisheries and Environment Canada (1977)

Two districts – the basalt headlands and the basalt ridge – comprise the coastal landscape of the Fundy Coast, and their topography reveals a number of contrasts.

Basalt Headlands

The Basalt Headlands extend from Economy to Cape Chignecto along the northern shore of the Minas Basin. Parrallel faults and juxtaposed resistant basalts, as well as eroding sandstones, create a varied landscape of hills and lowlands, bays, cliffs and headlands (see Figure 4.2) (Grant, 1980; Scott and Greenberg, 1983; Stea and Mott, 1989; Forbes et al, 1991; Shaw et al, 1991; Davis and Browne, 1996b). The area has been cut by three major faults into a series of "slices" that have minor faults within them. At the base of the Cobequids, the east–west trending Cobequid Fault (see Figures 3.9 and 3.10) forms the northern boundary of the district and sets the Carboniferous strata against the ridge of the Cobequid Hills (Grant, 1977; Grant and King, 1984; Davis and Browne, 1996b). Here they form a line of hills from Cape Spencer to the eastern border of the headlands and beyond. Cliffs have formed along Greville Bay, where the strata reach the coast. Further south, the Portapique Mountain Fault has brought younger erodable Triassic sandstone and resistant basalt in contact with Carboniferous deposits. Within this block, a smaller east–west fault, the Gerrish Mountain Fault, and other small crosscutting faults further divide the bedrock into small blocks. These have shifted vertically and, in some cases, have tilted (Dalrymple, 1977; Grant, 1977; Grant and King, 1984; Davis and Browne, 1996b).

From Economy to Partridge Island, the hilly landscape of the Basalt Headlands reflects the contrasting resistance to erosion of basalt and Triassic sandstones.While the sandstone is friable and normally forms lowlands, it may also form high steep-sided hills where it is capped with basalt – for example, at Portapique Mountain (150 m), Economy Mountain (245 m) and Spencers Island (150 m) (Dalrymple, 1977; Grant and King, 1984; Davis and Browne, 1996b). The high sandstone cliffs at Five Islands Park and on the islands themselves result from the protective effect of basalt. Some of the high basalt-capped blocks have cliffs with columnar jointing, such as at Partridge Island, Cape Sharp and Spencers Island (Davis and Browne, 1996b).

Exposed Triassic sandstone is easily eroded. At Lower Economy, a tidal platform more than 1 mile wide has been cut by wave action on the coastal exposures of these rocks. The low Triassic area immediately north of Cape D'Or will also probably be completely removed, leaving the basalt-capped sediments as stacks, similar to Five Islands and Isle Haute (Davis and Browne, 1996b). Large glacial outwash deposits and plains are common within this landscape (Hubert and Mertz, 1980, 1984; Mertz and Hubert, 1990; Wade and MacLean, 1990; Brown and Grantham, 1992). The harbour at Advocate, for example, is enclosed by a bar-and-cobble beach derived from gravels eroded from the outwash deposits. During the immediate post-glacial era, approximately 13,000 years ago, a higher sea level created beaches on the hillside north of Advocate. These raised beaches are very similar to those in today's Advocate harbour (Davis and Browne, 1996b). At Parrasboro and throughout the Basalt Headlands district, a nearly horizontal wave-cut surface can be seen on the glacial outwash gravels. This surface, eroded during the same time as the Advocate raised beach was being formed, gradually descends eastwards. This sloping nature of the former shoreline attests to the differential recovery of the coast's topography since the last glaciation and, therefore, to the differential crustal loading during glaciation (Dalrymple, 1977; Stea et al, 1992a, 1992b; Davis and Browne, 1996b).

Basalt Ridge

On the southern side of the Inner Bay of Fundy lies a steep-sided Basalt Ridge that rises to more than 225 m at its eastern end and slopes to near sea level in the west (Davis and Browne, 1996b). The ridge is composed of several Jurassic basaltic lava flows that dip northwest towards the Inner Bay at a shallow angle. They form the southern rim of a tilted spoon-shaped trough (or half-grabens) that underlies the bay (Dalrymple, 1977; Grant and King, 1984; King and Fader, 1986; Scott and Medioli, 1989; Davis and Browne, 1996b). The rounded up-tilted eastern side of the trough can be seen in the curve of Scots Bay. The basalt in the lower western part eventually disappears under the water beyond Brier Island.

The hightest elevations and most dramatic scenery are found on the North Mountain, particularly at Cape Blomidon, where Cape Split curves around into the Minas Basin. The steep southern escarpment ridge may represent a fault line; the shallower northern side is a dip slope (Stea et al, 1992a, 1992b; Davis and Browne, 1996b).

Figure 4.3 *The white gypsum cliffs at St. Croix, near Windsorin the Southern Bight of the Minas Basin: The gypsum, like the salt mined at Pugwash and the limestones along the banks of the Kennetcook River, represents sedimentary deposits of the tropical Windsor Sea that covered the Minas Basin during the Mississippian*

Note: *The Windsor Sea was home to teeming marine life, such as this horn coral (right) found in limestone cut by the nearby Kennetcook Rive, Southern Bightr.*

Source: photo by John Calder; inset by Heinz Wiele (specimen courtesy of Gordon Oakey), 2004

4.2 HYDROGRAPHY AND WATERSHEDS

Drainage patterns across Nova Scotia have developed almost entirely since the Tertiary and are closely tied to geology (Roland, 1982; Davis and Browne, 1996b). They are a result of water flowing down an inclined plain in response to the structure and composition of underlying rocks. Dendritic drainage patterns, for example, develop on unconsolidated sediments with an even slope and on evenly resistant rocks with moderate to high relief (Davis and Browne, 1996b), such as on the soft Triassic sediments around the Minas Basin. In general, water follows lines of weakness, such as soft strata, joints or faults, and forms a characteristic drainage pattern. This changes over time until the river develops a profile that is in equilibrium with the regional slope, precipitation and geology of its drainage basin (Davis and Browne, 1996b). Parallel drainage, for example, is characteristic of areas where streams cascade down a steep slope and do not branch substantially before entering the sea, such as the streams rising on North Mountain and flowing down to the Bay of Fundy. In Nova Scotia, drainage patterns diverge from their ideal form due to three influences: the Pleistocene glaciation, which scoured the surface of the province and then deposited unsorted rock debris upon it; fluctuations in sea level; and ancient river channels, which developed before the Tertiary and are now superimposed upon the terrain (Roland, 1982; Scott et al, 1987; Davis and Browne, 1996b).

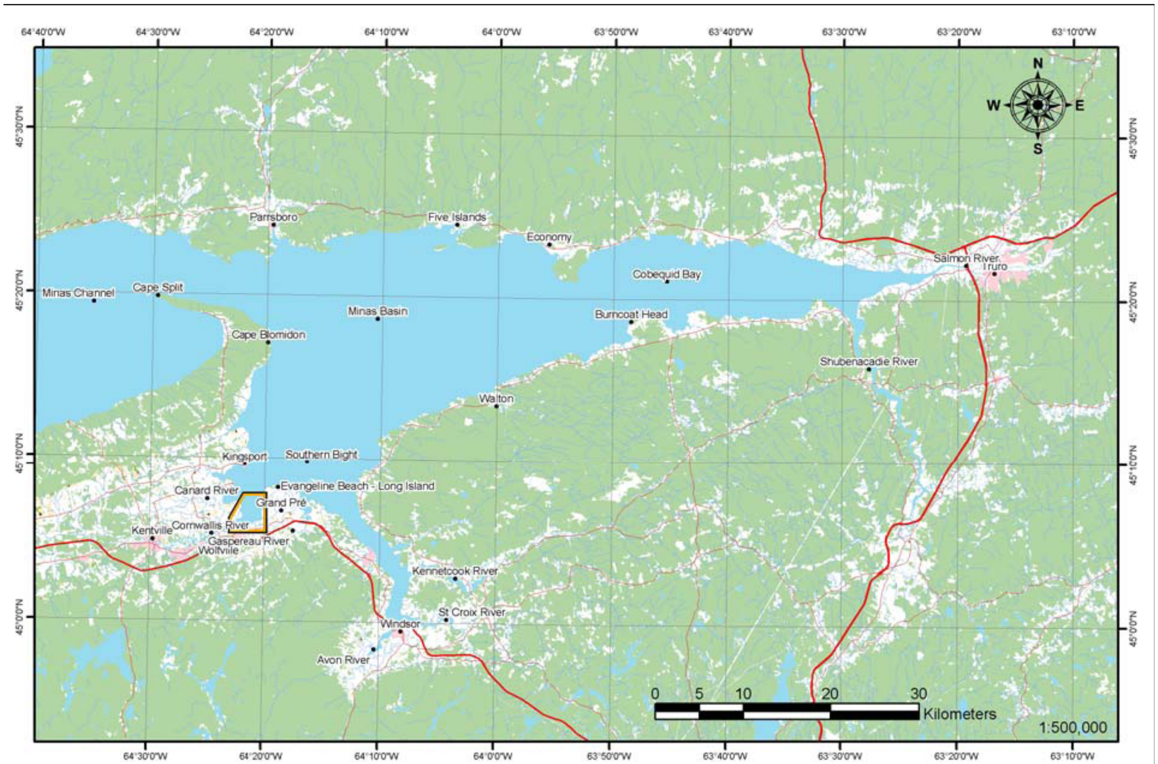


Figure 4.4 *The Minas Basin watershed, depicting its principal rivers: the Cornwallis, Avon, Shubenacadie and Salmon rivers*

Source: Natural Resources Canada NTDB 1:50,000 digital map series

The Minas Basin watershed (or drainage basin) is comprised of the Minas Basin and several major watersheds surrounding it, including the Cornwallis River watershed in Kings County, the Avon River watershed in Hants County, the Shubenacadie River watershed in Hants and Colchester counties, and the Salmon River watershed in Colchester County (Willcocks-Musselman, 2003). It also contains smaller watersheds in the North Shore of the Minas Basin, including the Parrsboro area, and the South Shore of the Minas Basin around Noel in Hants County. The topography of the whole area has been smoothed and rounded by glaciation and can be described as rolling (Dalrymple, 1977). The southern edge of the Cobequid Mountains is the most rugged terrain, and here streams and rivers have cut deep into canyons and descend to the lowlands through a series of waterfalls and rapids. Dalrymple (1977) states that stream gradients are on the order of 30 m/km in this section of their course, but flatten to about 3 m/km on the Triassic lowlands. Streams and rivers on the south shore also have low gradients of approximately 3 m/km or less and are smaller.

In all, 33 rivers enter the Minas Basin, as well as many more streams and creeks (Nova Scotia Salmon Association, undated). Its principal rivers include (in alphabetical order) the Cogmagun, Cornwallis, Debert, Economy, Five Island, Folly, Gaspereau, Habitant, Kennetcook, Moose, North, Parrsboro, Pereaux, Portapique, Herbert, Salmon, Shubenacadie, St. Croix, Tennycape and Walton rivers (Atlantic Salmon Federation, undated). Freshwater that enters the Minas Basin and Minas Channel supplies approximately

15% of the total mean annual flow into the Bay of Fundy (Bousfield and Leim, 1959). Many of these rivers are tidal, with tides reaching up to 30 km inland, as in the case of the Shubenacadie River (Fundy Shore Ecotour, undated). The entire watershed, including the Minas Basin, is approximately 10,700 km^2 in extent (Willcocks-Musselman, 2003) (see Figure 4.5).

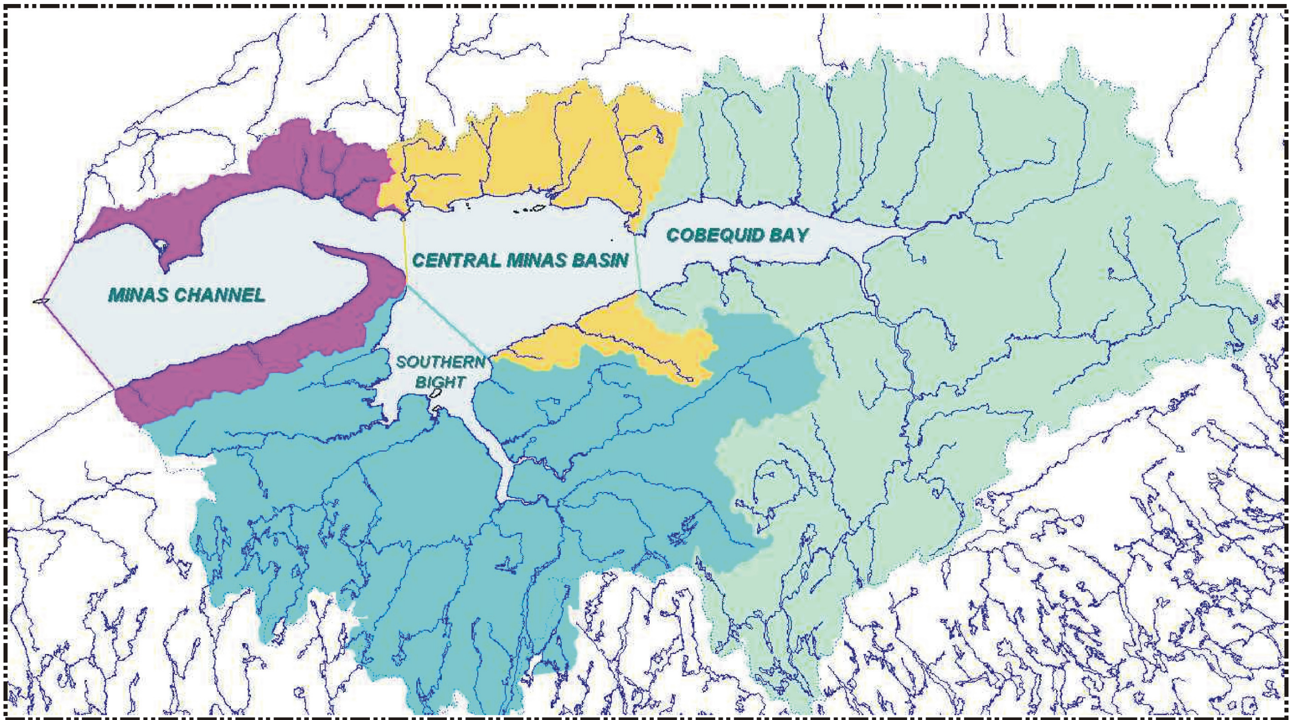


Figure 4.5: *Watershed boundaries of the primary subwatersheds of the Minas Basin.*

It is the semi-diurnal aspect of the Inner Bay of Fundy's tidal cycle that is by far the dominant component of the area's hydrography, with the bay's shallow-water origin and its astronomical influence (see Figures 4.6 and 4.7) the key elements (Godin, 1968). The average semi-diurnal tidal range in the Minas Basin comprises 11.5 m, ranging up to 15 m to 16 m in Cobequid Bay. The surface of the Minas Channel and the Minas Basin covers approximately 1630 km^2, and the volume of water necessary to raise the level by about 9.15 m equals 14.9 x 10^9 m^3, so that around 15 km^3 of water enters the area twice a day (Godin, 1968). The extreme tidal range and shallow bathymetric gradients also produce an extensive intertidal zone that averages 1 km to 2 km in width (though the waterline can recede as much as 5 km seaward). Approximately 15,400 km^2 of intertidal zone (sand and mud flats, as well as salt marsh), or approximately one third of the water-covered area, is exposed at low tide in the Minas Basin (Percy, 2001) (see Figure 1.3). Major flood-and-ebb currents trend east–west, respectively, with minor variations due to the occurrence of bedrock or local sediment accumulations. Current velocities vary from 1 m/s to 1.5 m/s in channels, to 0.5 m/s to 1.0 m/s over bars, and decrease shoreward (Knight, 1972; Dalrymple et al, 1975; Dalrymple, 1977; Knight and Dalrymple, 1976; Yeo and Risk, 1981). These currents resuspend large quantities of fine sediment.

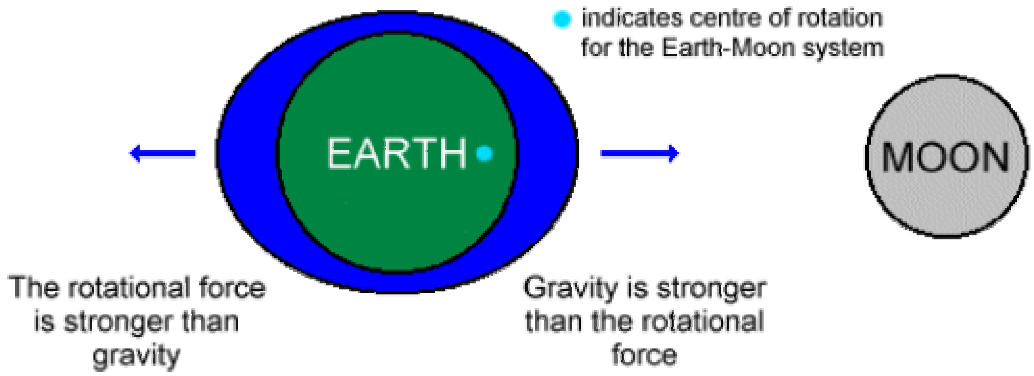


Figure 4.6 *The tidal cycle within the Bay of Fundy is caused by the effects of gravity in the earth–moon system: The rise and fall in sea level is induced by the earth rotating on its axis underneath the two 'bulges' of water that cover the earth (one towards the moon and the other towards the other side)*

Source: Natural Energy Research Council, 2005

The main rivers of the Minas Basin watershed, the Cornwallis, Avon, Shubenacadie and Salmon, bring in a small amount of freshwater compared with the volume of tidal water; nevertheless, this is sufficient to lower the salinity of the Minas Basin to 26% to 30%, compared to a salinity of 35% found in the ocean (Amos, 1976; Daborn et al, 2004).

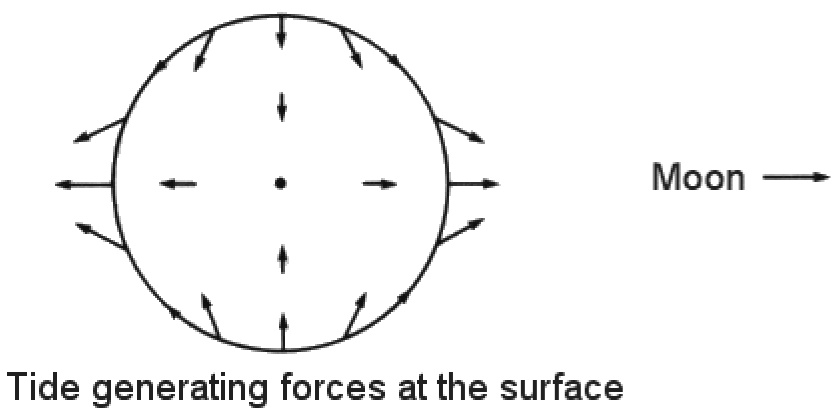


Figure 4.7 *The tide-generating force within the Bay of Fundy is the difference between the force of gravity towards the moon and the rotational force away from the moon (both of which act in perfect balance)*

Note: *On the surface of the earth nearest the moon, gravity is greater than the rotational force; therefore, there is a net force towards the moon, causing a bulge (in water) towards the moon. On the opposite side of earth, gravity is less as it is further from the moon – in the case, the rotational force is dominant. As a result, there is a net force away from the moon. It is this that creates the second bulge away from the moon. On the surface of the earth, the horizontal tide-generating forces are more important than the vertical forces in creating the tidal bulges*

Source: Natural Energy Research Council, 2005

4.3 BATHYMETRY AND SEASCAPES

In general, the bathymetry of the Minas Basin, which is dominated by large accumulations of sand, is considered relatively simple, except in Cobequid Bay, where tidal currents have shaped the bottom into an elongated series of sand bars and channels, large parts of which are exposed at low tide (Dalrymple et al, 1975; Dalrymple, 1977; Amos et al, 1991). Amos and Long (1980) subdivided the Minas Basin system into three physiographic regions in order to detail the bathymetry:

1. The Minas Basin proper is an enclosed basin that comprises most of the system. It includes Windsor Bay and the Avon, Cornwallis and Gaspereau river estuaries. It is surrounded by steep eroding cliffs of variable composition that have regressed up to 7 km, featuring a marginal, smooth wave-cut platform. Most of this platform is visible in the intertidal zone during periods of low tide, when the platform is seen as being overlain by shifting features, such as migrating sand wave fields, gravel and cobble storm beaches, occasional pocket beaches, and transgressing mudflats and salt marshes (Grant, 1970). In contrast, the subtidal region is hummocky and irregular (see Table 4.3 for the basic dimension of the system).

2. Cobequid Bay lies east of the Minas Basin and is separated from it by a "narrow" to the south of Economy Point. It includes the Salmon and Shubenacadie river estuaries. During periods of low tide, two-thirds of the bay is exposed, revealing a wide stretch of sand bars (Dalrymple et al, 1975; Amos and Joice, 1977) and salt marshes, partly enclosed within reclaimed marshlands and sections of low eroding cliffs (see Table 4.1).

3. The Minas Passage connects the Minas Basin system to the Bay of Fundy. It is 11 km long and 4 km wide and is the conduit for the flooding and ebbing tidal waters of the Minas Basin. It is scoured of sediment by turbulent currents that attain 5 m/s, generated by the passage of the tidal prism (the volume of which reaches 15.3 km^3). The passage is contained between a fault scarp along its northern margin and a promontory to the south, known as Cape Split (see Table 4.1) (Amos and Long, 1980).

Table 4.1 *Summary of the general physiography and bathymetry of the Minas Basin system*

Length (maximum)	77 km	
Width (maximum)	31 km	
Depth (average)	15 m	(below lowest low water)
Perimeter	320 km	
Surface area:		
Minas Basin	805 km^3	(intertidal: 172 km^3; subtidal: 633 km^3)
Cobequid Bay	306 km^3	(intertidal: 186 km^3; subtidal: 120 km^3)
Intertidal	358 km^3	
Subtidal	753 km^3	
Saltings	107 km^3	
Volume:		
Minas Basin	22.8 km^3	(intertidal: 13.3 km^3; subtidal: 9.5 km^3)
Cobequid Bay	3.2 km^3	(intertidal: 2.0 km^3; subtidal: 1.2 km^3)
Intertidal	15.3 km^3 (max)	
Subtidal	10.7 km^3 (min)	
Cross-section area:		
Minas Passage	3.4×10^5 m^2	(below mean sea level)
Economy Point/Cape Tenny	1.5×10^5 m^2	(below mean sea level)

Source: adapted from Amos and Long (1980)

Much of the Minas Basin is relatively shallow, with water depths in the range of 15 m to 20 m below the lowest low-water level (Canadian Hydrographic Service Chart D7-4010). Depths increase rapidly as the Minas Passage is approached (Dalrymple et al 1975; Dalrymple, 1977; Amos and Long, 1980). Here, with tidal currents of up to 5 m/s, concentrated flow has scoured to depths of almost 120 m. According to Dalrymple (1977), another smaller scour is present south of Economy Point, which defines the outer limit of the eastern portion of the Minas Basin (Cobequid Bay). Pleistocene deposits, combined with the current hydraulic regime, have smoothed out most of the irregularities. The seaward boundary of the Southern Bight of the Minas Basin is defined roughly by a line from Cape Blomidon to the vicinity of Cambridge (Hants County).

Knight (1980) provides a detailed description of bathymetry, linear sand bar development and tidal current flow in Cobequid Bay (see Figure 4.8). The bay is renowned for its large semi-diurnal tides, which are the result of the tide's lunar component being amplified (Garrett, 1972) as it moves across the continental shelf southwest of Nova Scotia and into the Bay of Fundy. Grant (1970) states that the amplitude of the tide developed largely within the last 6000 years as the Bay of Fundy system reached "resonant dimensions" through eustatic sea-level rise, sinking of the land as a result of isostatic rebound, and erosion of the shoreline and seabed.

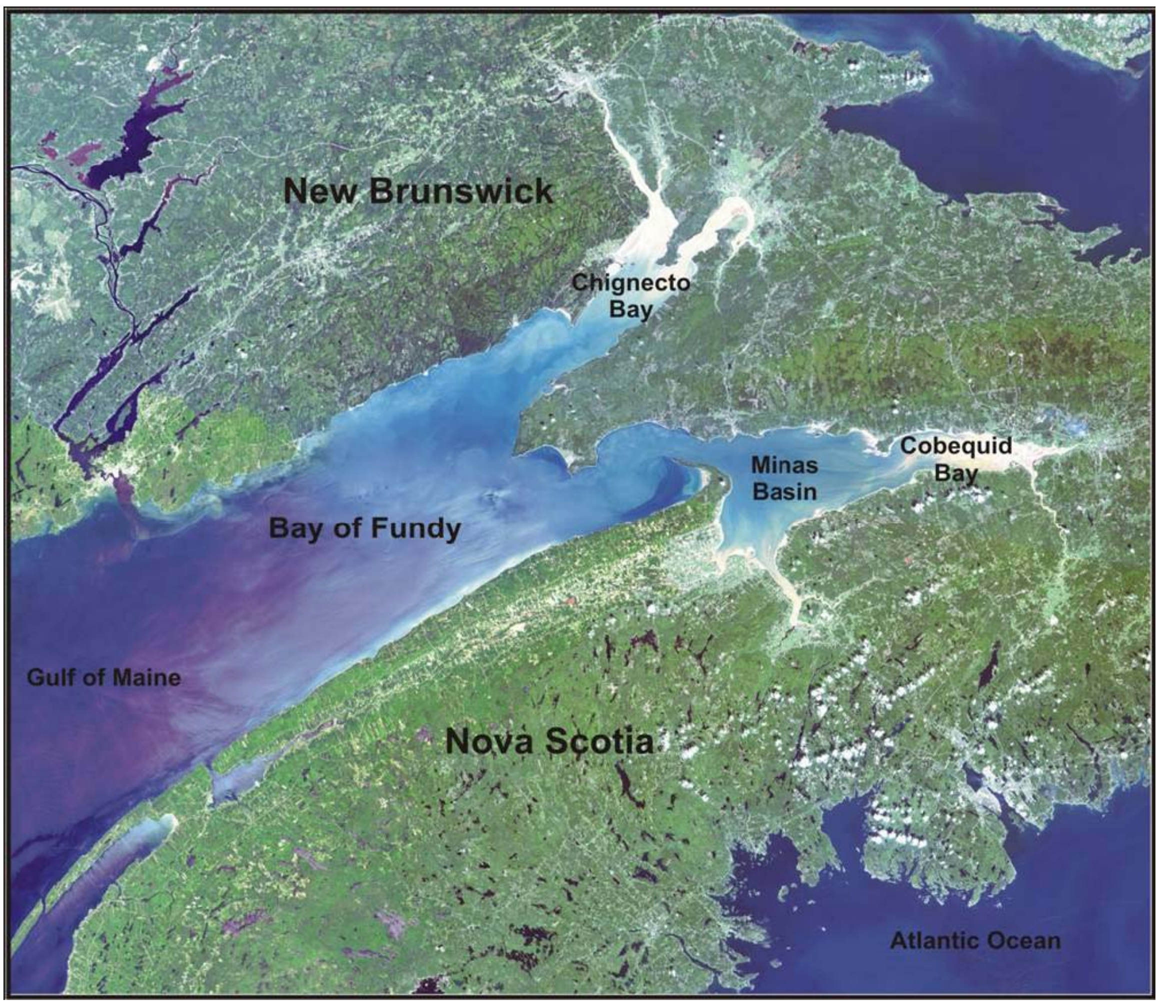


Figure 4.8 *Landsat Enhanced Thematic Mapper (EPM +) at 30 m resolution of the Inner Bay of Fundy, used for tidal research study for the Bay of Fundy Tidal Barriers GIS Database*

Source: van Proosdij and Dobek (2005)

The amount of suspended sediment in Cobequid Bay is much higher than sediment found in the rivers above any tidal influence. Knight (1977) found that concentrations range up to 2700mg/l, but are generally approximately 20 mg/l to 200 mg/l. The large amount of suspended sediment in the water is probably related to the resuspension of mud from intertidal mudflats through wave and current activity. Knight (1980) describes this sediment as mostly silt- and clay-sized particles, not sand-sized sediments. It is interesting to note that in 1875, Hind (1875) recorded several sedimentation processes as well as changing expanses of mudflats within Cobequid Bay. He watched a large patch of "grass-covered turfy soil, resting on a sandy substratum, and recently detached from the main land, slowly sliding over the smooth surface of tidal mud" near the mouth of Bass River in the Central Minas Basin. It was a "patch" of some 45 m length and 7.5 m in width. When he last saw it, it was about 4 m "below the surface of the formerly spruce-covered level track form which it had been disengaged en masse." Hind (1875) also noted the "evil" effects of silting near the mouth of the Shubenacadie River, stating that in as little as 30 years prior (1845), vessels up to 150 tonnes would sail almost daily up to a short distance below Truro. By 1875 no boats would proceed past Yuills Island, some 10 km further out in the bay near Old Barns.

The complex sandbars and channels within Cobequid Bay that Dalrymple (1977) describes vary considerably in size, geometry and morphological complexity. Knight's (1980) research provides the following information. The dimensions of the emerging parts of the sandbars range from 1 km to 10 km in length, and 0.2 to 4.2 km in width. At high tide, the bars are covered by 5 m to more than 20 m of water, depending upon their location in the bay. The surface elevation of the sand body and the individual sandbars increases towards the head of Cobequid Bay. The surfaces of the sandbars are covered with a variety of bedforms, including ripples, megaripples and sand waves. The bedforms form as a result of the movement of bed material by traction and occasional suspension close to the bed. Knight (1980) and Dalrymple et al (1978) state that at low tide, the bedforms are either ebb-oriented or ebb-modified flood features with their crestlines generally oriented at an oblique angle to the longtitudinal axis of the sandbars.

Figure 4.9 *Minas Basin seascape, viewed from the north shore near Parrsboro , Central Minas Basin*

Source: Barker and Westhead (2006)

5. SEDIMENTOLOGY

5.1 NATURE AND CHARACTERIZATION OF SURFACE SEDIMENTS

The Bay of Fundy is a large macrotidal embayment situated on the east coast of Canada between the provinces of New Brunswick and Nova Scotia (see Figure 4.8). Two main branches extend off the Central Bay: Minas Basin to the east, which is dominated by large accumulations of sand, and Chignecto Bay to the northwest, which is characterized by large accumulations of silt. The Bay of Fundy is located in the Appalachian region (Amos et al, 1991), an area of deformed sedimentary and volcanic rocks. Amos (1984) describes the bedrock geology within the region as exhibiting Triassic half-graben basinal development that "overprinted" earlier Ordovician to Carboniferous tectonic events, which began 430 million years ago. The half-graben basin is composed of Triassic sandstones and volcanic rocks that underlie much of the region (King and Maclean, 1976). Bedrock "flexuring" during earth movements upthrusted and folded much of the material currently comprising the erosive cliffs surrounding the Bay of Fundy (Amos and Long, 1980; Amos, 1984; Amos et al, 1991; Davis and Browne, 1996a). Amos (1984) describes the "basement" structure of the bay as taking 100 to 200 million years to evolve between the Ordovician and the Triassic periods.

There is great variability in local relief due to the effects of glacial and fluvial erosion on rock outcrops that yield differing resistance. These glacially derived sediments comprise much of the seabed of the bay and show significant differences, especially between the Minas Basin and Chignecto Bay (Amos and Long, 1980; Amos, 1984). Essentially, Chignecto Bay is a glacially excavated, elongated macro-tidal estuary (Amos et al, 1991) with blankets of silty, glacial and post-glacial unconsolidated sediments in its upper reaches. The Minas Basin is a large triangular basin at the head of the Bay of Fundy. Towards its eastern end, a promontory called Economy Point defines the outer limit of the eastern portion known as Cobequid Bay (see Figure 4.8). The seaward boundary of the Southern Bight of the Minas Basin is defined roughly by a line from Cape Blomidon to the vicinity of Cambridge in Hants County. The Minas Basin is typically a sandy estuary, with wide expanses of sand flats and sand bars. Despite its silty waters, however, Amos (1984) states that the proportion of silt- and clay-rich depositional environments (mudflats and salt marshes) is low – these environments are restricted to shelted embayments.

The abundance of sand in the Minas Basin is the result of wave erosion of the Triassic sandstone cliffs that surround the shoreline, supplemented by the input of glacial outwash sand (Thomas, 1976; Stea, 2003). As a result, light penetration and phytoplankton production are both very limited. Minimum Secchi disk values at Kingsport reported by Huntsman (1952) are as low as 1.25 m. Bousfield and Leim (1959), however, noted that in some areas of the Minas Basin, when a hand was immersed wrist deep, the fingertips were not visible. In general, suspended sediment concentrations are higher in Cobequid Bay than all other areas (Dalrymple, 1977; Yeo, 1977). Turbidity values along the edge of the tide, furthermore, can be as high as 1000 mg/l in the first several centimetres of the incoming flood tide (Swift et al, 1971). Overall, suspended sediment concentrations range from minimum of 0 to a maximum of 1157 mg/l. Most measurements fall in range of 50 mg/l to 200 mg/l (Swift et al, 1971).

Amos (1984) provides the following data: a total of 3×10^6 m^3 of sand is introduced to the system annually from erosion of the cliffs, which varies from 0.55 m per year to 1.5 m per year (see Figure 5.1). The finer-grained silt and clay, derived largely from a reworking of seabed sediments, is limited because of an ice-rafted gravel lag that overlies it (Amos and Long, 1980; Greenberg and Amos, 1983; Amos, 1984; Amos et al, 1991) and protects it from the force of strong tidal currents within the Bay of Fundy – this input from the sea amounts to 1.6×10^6 m^3. A further substantial amount of sediments is derived from rivers (see Table 5.1). In contrast, Chignecto Bay is surrounded by erosive cliffs of Paleozoic siltstones and shales (Dalrymple, 1977). The bay also has greater exposure to ocean swell and is therefore subject to greater wave attack – this causes silt-sized material from the seabed to be released through cliff erosion (Greenberg and Amos, 1983; Amos, 1984). The resulting sediment is principally transported in suspension. The cliffs erode at rates of up to 1 m per annum, supplying 1 x 10^6 m^3 per annum of fine-grained sediment – while a further source of fine-grained material is from seabed erosion (Amos and Long, 1980; Amos, 1984; Amos et al, 1991).

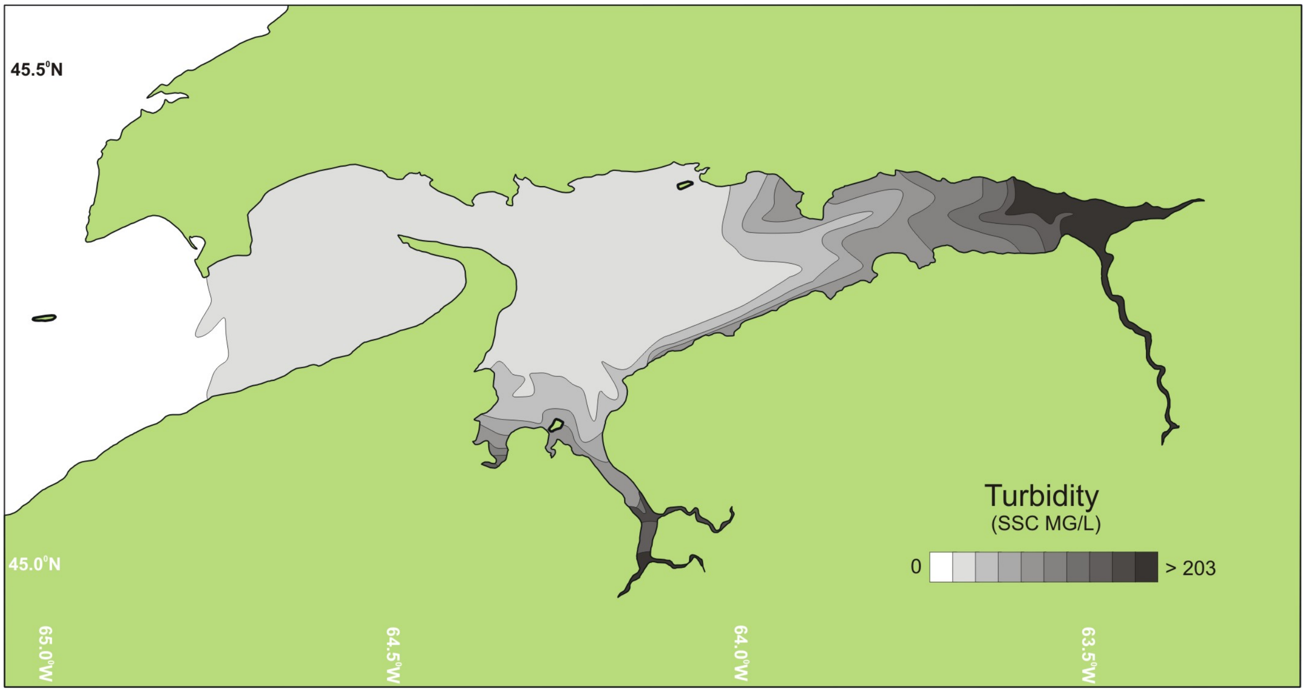


Figure 5.1 *Suspended sediment concentrations in the Bay of Fundy from Landsat data acquired in 1974*

Source: map by Lesley Carter, from Greenberg and Amos (1983)

Table 5.1 *Summary of sediment input and removal in the Minas Basin system, Inner Bay of Fundy*

	Input (m^3 per year)	Removal (m^3 per year)	Dominant sediment type
Rivers	5.9 x 10^4	not available	Silty/clay
Cliffs	3.1 x 10^6	not available	Sand
Open sea	1.6 x 10^6 (max)	0.0	Clay/silt/sand
Total	4.8 x 10^6	0.0	

Source: Amos and Joice (1977)

Fader et al (1977) describe the open environment of the Bay of Fundy as being dominated by storm waves and tidal currents, its seabed covered with glacial and post-glacial deposits. Over the past 6000 years, these deposits have been (and continue to be) re-worked through storms tidal currents associated with tidal amplification. The ensuing sediment patterns are the product of complex and dramatic sea-level changes in the region since glacial times. The below low-water sediments show a complicated patterns of sediment types that reflects both relict and modern environments (Amos, 1984). In general, the sequence shows morainic material overlain with glaciomarine outwash and fine-grained lagoonal sediments. Amos (1984) describes these sediments as having been deposited 6000 to 9000 years BP, now overlain by laminated silt and sand that, in turn, grades upwards into coarse sand or "winnowed lag" – this constitutes the current surface. Clearly, this complicated stratigraphy represents a shift in environmental conditions, from continental glaciation to stiller lagoon conditions, and finally to tidally active conditions influenced by storm waves and winter ice rafting (Amos, 1984).

In general, the intertidal zone is characterized by a wave-cut rock terrace or by a sequence of intertidal deposits. Yeo and Risk (1981) identified seven distinct physical–biological facies that describe the intertidal zone: salt marsh; beach; upper and lower mud flat; mixed mud flat; sand flat; channel lag; and sand bar – each with its own unique sedimentary structures and biological communities (see Figure 5.2).

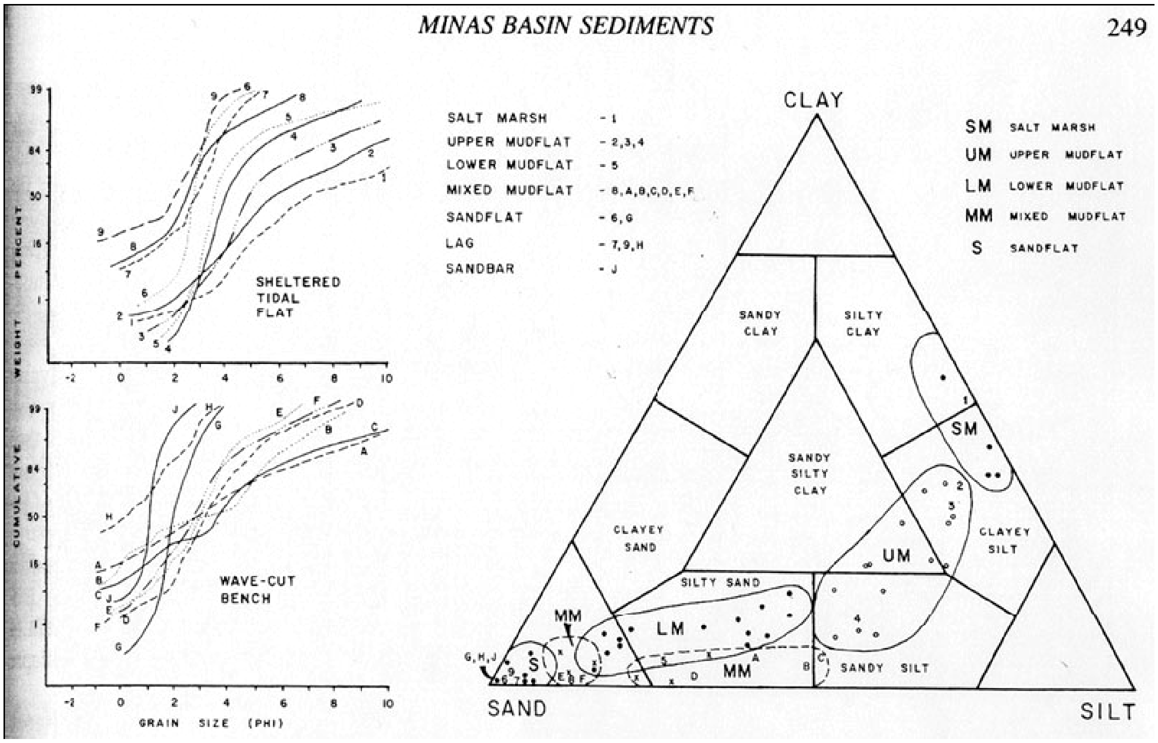


Figure 5.2 *Grain size of the seven distinct physical–biological facies that characterize the intertidal zone of the Minas Basin, Inner Bay of Fundy*

Source: Yeo and Risk (1981)

A building-block template devised by Amos and Joice (1977) provides a description of the relationsip between time, process and result in the sedimentary budget of the Minas Basin:

Wave currents + tidal forces + climate + sea-level rise (the processes) of the past and present – Erosion + Deposition (the result) = Sedimentary budget of the present and the future (time dependent).

From this template and from data provided in current research, Amos and Joice (1977) inferred future trends in the sediment budget of the Minas Basin (see Table 5.2).

Table 5.2 *Calculated future volumetric evolution of the Minas Basin based on a comparison between present input of sediment to the system and assumed mean sea-level rise*

Minas Basin		Cobequid Bay	
Sediment balance	+ 5.0 x 10^6 m^3/year	Change in volume 1858–1976:	
Inferred sea-level rise	0.003 m/year	Volume eroded	5.3 x 10^6 m^3/year
Area of Minas Basin system	1111 km2 = 1.111 x 10^9 m^2	Volume deposited	6.9 x 10^6 m^3/year
Increased volume due to sea-level rise	3.3 x 10^6 m^3/year	Net	+ 1.6 x 10^6 m^3/year
Increased volume due to cliff retreat	1.3 x 10^5 m^3/year		

Increased volume of Minas Basin	3.4 x 10^6 m^3/year		
The Minas Basin is diminishing in volume by 1.6 x 10^6 m^3 per year		32% of the material infilling in the Minas Basin system is deposited in Cobequid Bay	

Source: Amos and Joice (1977)

5.1.1 Distribution

Bottom sediments

Amos and Long (1980) studied the distribution of surface sediments from 281 Van Veen grab samples collected in the Minas Basin and 198 samples from Cobequid Bay. The data analysed supplemented earlier analysis by Forgeron (1962), Huntec (1966), McMullen and Swift (1967), Swift et al (1966, 1967), Swift and McMullen (1968), Pelletier and McMullen (1972), Dalrymple (1977), Klein (1970), Middleton (1972), Pelletier (1974) and Middleton et al (1976).

Within the northern Minas Basin, linear sand bars are found parallel to the shore (Amos and Long, 1980; Daborn, 1989). The associated tidal channels are comprised of gravelly sand, sand and gravel, and gravels. South of Five Islands to a depth of 5 m there is a north–south oriented delta that grades seawards into gravels, cobbles and pebbles, and sand and gravels. The percentage of sand also decreases south of Economy Point (Amos and Long, 1980). Bordering the south shore of Minas Basin is more sand (a large part of the intertidal wave-cut platform is covered with a thin, 30 cm to 50 cm, layer of sand). Most of Windsor Bay is underlain by an intricate ebb delta that contains sand-sized sediment derived locally. This delta is described by Amos and Long (1980) and Daborn (1989) as being modified by freshwater discharges from the Cornwallis and Avon river estuaries. The main flood and ebb channels, furthermore, are lined with sandy gravel. Near the entrance to the Cornwallis River estuary, the sediments become finer with the deposition of silt-sized material in the intertidal region. Channel bottoms in the region are lined with sand.

The southern Minas Basin sand complex moves eastward, and the sand bars are aligned east–west parallel to the shore; they are created by an ebb-dominant current, flowing east–west from Cobequid Bay along the south shore. In the subtidal region, the sand bars are aligned northwest–south east, parallel to the lines of separation of the ebb current (which deflects offshore towards the Minas Passage) (Amos and Long, 1980; Daborn, 1989).

The Minas Channel, which contains the Minas Passage, shows evidence of substantial scouring (Dalrymple, 1977; Amos and Long, 1980). At Cape Split (see Figure 5.3), the tidal channel is scoured through bedrock to depths of 120 m. While the entire channel bottom is lined with bedrock, the northern and southern margins of the channel are covered with locally derived gravel and cobbles. Farther westward, where the Minas Passage is wider, two regions of sandy substrate are found, resulting from the complex currents of the region and from the sheltering effects of features such as Scots Bay (Dalrymple et al, 1975; Amos and Long, 1980; Greenberg and Amos, 1983). Here the bottom sediments grade towards the shore in a progression from gravels and cobbles to silts and clay (Amos and Long, 1980).

Figure 5.3 *Cape Split in the Minas Channel: Here the tidal channel is scoured through bedrock to depths of 120 m*

Source: Davis and Browne (1996a)

In Cobequid Bay, the distribution of bottom sediments follows two regions. The western section, west of Noel Head, shares many of the same characteristics observed in Minas Basin: the central region is scoured; the main tidal channel is lined with gravels and cobbles in its deepest parts; shoreward, to both north and south, the progression is from gravelly sand to sandy gravel to sand. In contrast to the Minas Basin, however, the north shore of western Cobequid Bay has much more sand than the south shore (Amos and Long, 1980; Greenberg and Amos, 1983). East of Noel Head, the distribution of bottom sediments contrasts substantially. Here, the main gravel- and cobble-lined tidal channels occur close to the north and south shores, respectively, and are separated by a wide intertidal stretch of sand (see Dalrymple, 1977; Knight, 1977, 1980; Middleton, 1977).

Suspended sediments

The distribution of suspended sediments in the tidal regions of the Minas Basin varies considerably with the stage of the tide (Dalrymple et al, 1975; Amos and Long, 1980; Daborn, 1989). Large-scale turbulence and strong tidal currents cause frequent fluctuations of suspended sediment concentrations. Amos and Long

(1980) state that a single sediment particle may be moved 40 km in one tidal cycle. Landsat radiometric data, therefore, was used by Amos and Long (1980) to interpret suspended sediment concentrations and suspended particulate matter. Results indicate that there is a consistent increase in suspended sediment concentration from the Minas Passage into Cobequid Bay and Windsor Bay, and concentration is generally higher along the south shore of the Minas Basin. Amos and Long (1980) further calibrated the temporal and vertical distribution of suspended sediments. Within the nearshore subtidal regions of the Minas Basin, suspended particulate matter is well mixed throughout the water column and suspended sediment concentrations are usually constant with depth at all stages of the tide. Suspended sediment concentration, furthermore, is highest at low water levels and decreases in high water. Amos and Long (1980) and Greenberg and Amos (1983) explain that sediment concentration at any site within the Minas Basin, as well as sediment settling, resuspension and entrainment, appear to be controlled by such processes as wave stirring, turbulence and biological activity on the intertidal zone, rather than from any other phenomena.

Modelling of the sedimentation character of fine-grained sediments in the Bay of Fundy was conducted by Amos and Mosher (1985), who found that resistance to erosion of intertidal sediments is largely controlled by degree of exposure and resulting dehydration and compaction. Indeed, the resistance of intertidal mud to erosion may be 80 times greater than sub-tidal counterparts (Amos and Mosher, 1985) – with consequent implications for tidal barrage proposals. Amos and Mosher (1985), for instance, state that sedimentation on the intertidal zone in areas influenced by tidal barrages has been underpredicted in other studies, and that depletion of suspended matter due to this increased intertidal deposition results in less deposition in the subtidal zone. The end result is a generally clearer water mass.

Further research on the distribution of Minas Basin sediments has centred on a wide range of aspects. Dalrymple (1977), Knight (1977), Middleton and Davies (1979) and Lambiase (1980) have evaluated specific sand bars in the basin, their superimposed bedforms and the transport of sand under tidal flow, putting forward fundamental concepts of sediment response to high-energy tidal flow. Working on the Avon Estuary in the Minas Basin, Lambiase (1980) showed that there is an inverse relationship between mean grain size and current speed, and that textural parameters do not directly reflect hydraulic conditions. This finding is important in interpreting sediments, where a direct relationship between grain size and current speed is inferred. Collins (1984) examined the theory of intermittent suspension by water sampling immediately above the seabed over a sand bar in Cobequid Bay. He suggested that this phenomenon does occur, but only during periods of wave stirring. It appears that relatively small waves superimposed on strong tidal currents can have a significant effect on seabed stability, sediment mobility and sediment distribution. More recently, Russell et al (2007) have mapped selected areas of the sea floor of the Bay of Fundy using multibeam sonar (a technique that has been practised since 1992). Large sediment bedforms were discovered in the Minas Channel. Russell et al (2007) detail how the demand for small-scale (large area) mapping of sediments, local geology, biology and oceanography within the Bay of Fundy has culminated in the launch of a new three-year regional sea survey to map the Bay of Fundy sea floor from the approaches in the southwest to the Inner Bay in the northeast. The resulting 1:50,000 scale maps will be released as part of the new National Research Canada national marine map series and will include sheets of sea floor topography, backscatter strength, and surficial geology.

5.1.2 Biogeochemistry: The Ecological Role of Sediments

The extreme tidal range in the Inner Bay of Fundy is renowned for exposing intertidal mud and sand flats of up to 4 km wide. These flats support large populations of invertebrates whose zonation is profoundly influenced by sediment type (Featherstone and Risk, 1977; Wilson, 1988). The Minas Basin, in particular, which is distinguished from the open bay at last partly due to the presence of resistant Triassic basalts in the Cape Split–Cape Blomidon area (Swift et al, 1968), is characterized by large numbers of deposit-feeding polychaete worms (see Figure 5.4), both sedentary and transitory (Fager, 1964; Featherstone and Risk, 1977). The redbeds that surround the Minas Basin, and which erode especially rapidly, give a reddish colour to the water of the Minas Basin, which is known to have surface temperatures in excess of 15˚C and shore salinities of less than 30.5%, lake-like wave action and no surf, extremely turbid water, and high tides (Bousfield and

Leim, 1959). Nevertheless, in spite of reduced phytoplankton productivity as a result of a restricted "photic zone" and high levels of sedimentation, the Minas Basin is a highly productive marine environment (Featherstone and Risk, 1977). Large populations of benthic invertebrates are found year round in the sediments, as well as passing organisms such as shrimps and predatory fish. Resident benthic invertebrates are dominated by deposit-feeders and these are strongly controlled and affected by the substrate (Fager, 1964; Risk and Craig, 1976; Featherstone and Risk, 1977). Featherstone and Risk (1977) detail the zonation of these invertebrates. Mudflats are dominated by the deposit feeders *Macoma balthica* and *Corophium volutator*, with occasional occurrences of the suspension-feeder *Mya arenaria* (softshell clam). Flats of fine sand and silt, however, feature the tubicolous polychaete worms *Clymenella torquata* (an upside-down deposit feeding maldanid) and *Spiophanes wigleyi* (a deposit-feeding spionid), both of which have a pronounced effect on the surrounding sediment of the basin.

Clymenella torquata reach maximum population densities of 500/m^2 in the medium sands of the lower intertidal (Featherstone and Risk, 1977). Sediment incorporated within their tubes is coarser and lower in heavy minerals than the substrate. When population densities are high, the formation of ripple marks is prevented. *Spiophanes wigleyi* reach maximum densities of 98,000/m^2 in the silts and sands of the lower energy, upper intertidal zone. Featherstone and Risk (1977) state that up to 50% of the sediment in the upper 5 cm may be incorporated within their tubes, which are identical in mean grain size and sorting to the substrate within the basin. Again, heavy minerals are avoided in tube building, and large populations prevent the formation of ripple marks in the sediment and lower the level of the anoxic zone. Both polychaete species reach their highest recorded population densities in the Bay of Fundy, probably due to the exclusion of filterfeeding organisms because of the water's high suspended sediment content. Featherstone and Risk (1977) explain the geological significance of these worms in relation to sediments. In high population densities, *Clymenella torquata* stabilize the sediment, inhibiting ripple formation. Their feeding activities create locally spongy terrain through an increase in porosity, and result in transport of "fines" through the sediment. Tidal currents then move the fines out of the area. *Spiophanes wigleyi* live in finer sediment and in lower energy conditions. Large numbers of tubes have a stabilizing effect on sediment; however, since tubes degrade quickly once worms die, sediment modification can only occur with living *Spiophanes*.

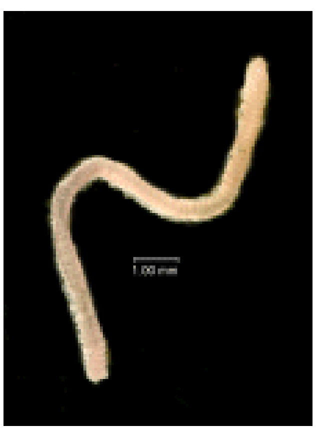


Figure 5.5 *Polychaete worms in the Minas Basin, Inner Bay of Fundy*

Source: Volkaert (1987)

Wilson (1988) also studied zonation of benthic communities within the sedimentary beds of the Bay of Fundy (see Figure 5.5 for a review of the different regions within the Bay of Fundy, including the Inner and Outer Bay, for this and other sediment studies). While acknowledging the following paradigm – that for rocky intertidal communities, the upper limits of organisms' distributions are determined by physiological constraints, while lower limits are determined by biological interactions – Wilson's research (1988) suggests that soft-sediment intertidal communities frequently fail to fit this model and that there are distinct shifts in zones. Unlike the sloping rock face of a rocky shore habitat, Wilson notes that the substrate of soft-sediment habitats changes along the tidal gradients, with finer sediments generally found in the intertidal zone. As a result, habitat selection, linked to sediment characteristics, may play an important role in determining the zonation patterns in soft-bottom communities. In general, Wilson (1988), Gratto (1978), Gratto et al (1983) and Bromley (1979) noted that the upper intertidal zone of the Upper Bay of Fundy was populated by *Heteromastus*, *Tharyx*, *Streblospio*, *Pygospio* and *Eteone*, while most of the intertidal zone below the upper zone was dominated by the amphipod *Corophium valuator*, with dense aggregations of the eastern mud snail (*Ilyanassa obsolete*) (see Figure 5.6) occurring throughout the upper intertidal zone. However, due to the greater mobility of deposit feeders and the reduced stability of the substrate, Wilson (1988) states that in the Upper Bay of Fundy, the boundary between zones is more dynamic in soft-sediment communities, and populations of *Corophium* frequently shift between zones. Indeed, Wilson (1988) and Hicklin et al (1980) state that there is no basis for claiming that any benthos are restricted to a particular tidal level by physical constraints or biological interactions. While on rocky shores the dominant organisms (such as barnacles, mussels and microalgae) tend to be stationary, since no movement is possible after settlement, infaunal organisms – in contrast – are rarely sessile (though they may be sedentary). As a result, movement of benthic communities up or down the intertidal gradient can occur after settlement (Dauer and Simon, 1976; Myers, 1977; Dauer et al, 1982; Dauer, 1984; Wilson, 1988). This dispersal of the invertebrates of soft-sediment organisms within the Inner Bay of Fundy thus contributes to the blurring of patterns of intertidal zonation.

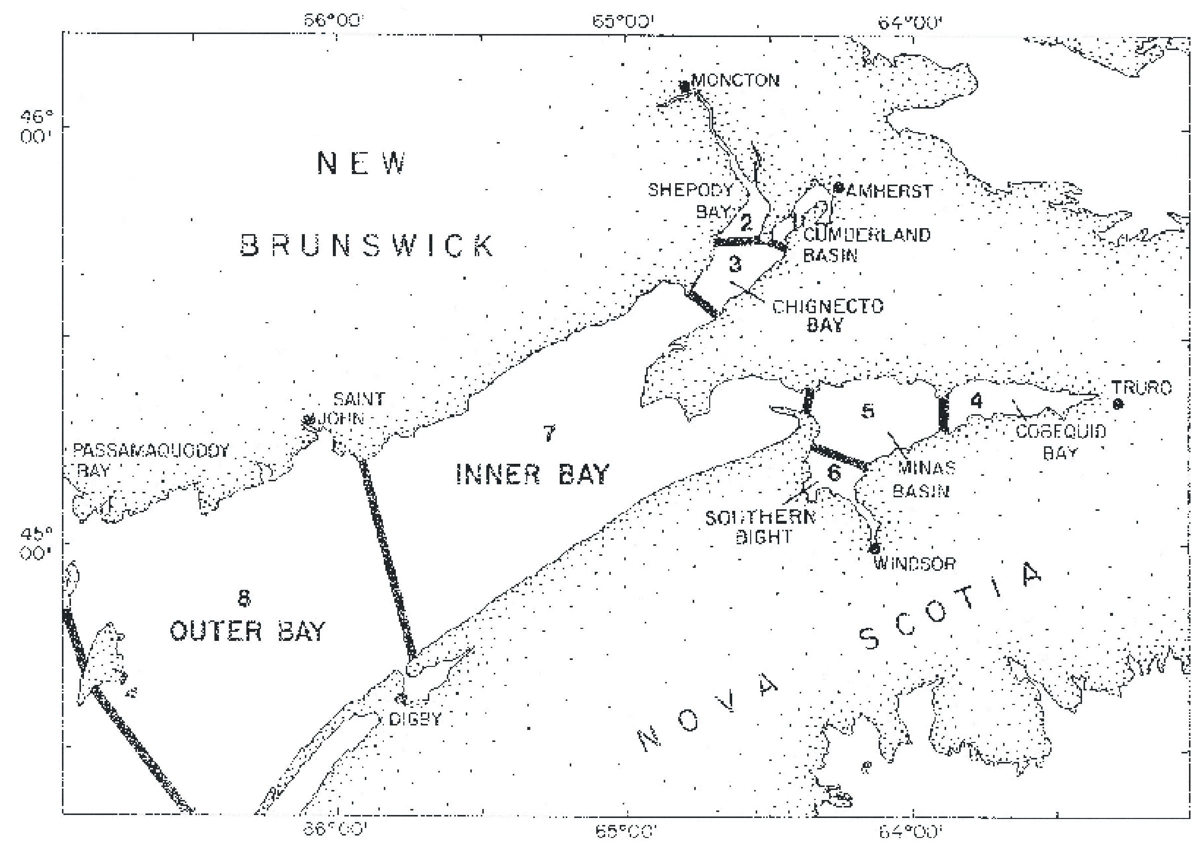


Figure 5.5 *Bay of Fundy indicating different regions, including Inner and Outer Bay, in relation to benthic community–sediment habitat studies*

Source: Peer (1984)

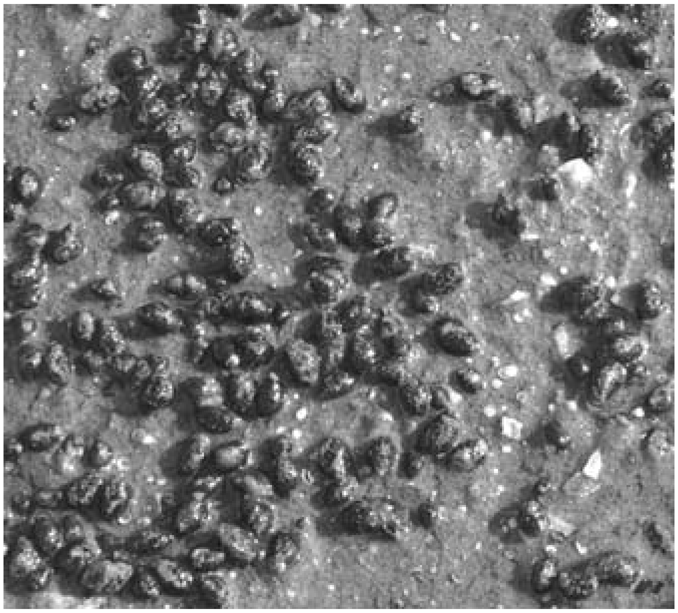


Figure 5.6 *The eastern mud snail (*Ilyanassa obsolete*) on exposed upper intertidal zone in the Inner Bay of Fundy, Nova Scotia*

Source: Davis and Browne (1996a)

Since Whiteaves (1901) summarized early work in the 19th century on benthic fauna and benthic communities within the Bay of Fundy, there were few relevant studies within the bay until 1966; since then, a number of key studies have been published. Inventories, densities and spatial organization of benthic communities in relation to the ecological role of sediments in the Bay of Fundy have been provided and assessed by Caddy (1970: faunal assemblages from dredge hauls in the Bay of Fundy); Peer (1970: the polychaete *Pectinaria hyperborea* in St. Margaret's Bay); Gratto (1978: flora and fauna of the western Minas Basin and the Minas Channel); Yeo (1978: animal–sediment relationships in the Minas Basin); Bromley (1979: a preliminary checklist of marine fauna in the Minas Basin); Hicklin et al (1980: distribution and abundance of *Corophium volutator* and *Heteromastus filiformis* in the Bay of Fundy); Gratto et al (1983: growth and production of the intertidal amphipod *Corophium volutator* in the Inner and Outer Bay of Fundy); Wildish and Peer (1983: tidal current speed and production of benthic macrofauna in the Lower Bay of Fundy); Caddy and Carter (1984: macro-epifauna in the Lower Bay of Fundy); Wildish (1984: a review of sub-littoral benthic communities in the Bay of Fundy); Gordon (1986: a review of primary production in the Bay of Fundy); Murdoch et al (1986: population dynamics and nutrition of *Corophium volutator* in the Cumberland Basin); Peer et al (1986: the life history and reproductive biology of *Corophium volutator* in Chignecto Bay); Volkaert (1987: polychaetes in St. Margaret's Bay); Wilson (1991: epibenthic predation and ice disturbance in Bay of Fundy mudflats); and Kenchington (1999: benthic faunal species associated with scallop grounds in the Bay of Fundy).

Table 5.3 provides an interesting synopsis of Caddy's (1970) 196 dredge hauls that were retrieved from depths of 55 m to 128 m in the Bay of Fundy. Caddy (1970) describes the substrate as composed of rock, gravel, sand and mud; 130 invertebrate species were found, forming five faunal assemblages – three of these assemblages were correlatd with substrate type (Table 5.3). Due to the dredge hauls extending over large areas (up to 1.5 km long), it is likely that the collection incorporated more than one community; therefore, Caddy described faunal assemblages rather than communities. The 130 invertebrate species came from nine taxa (see Table 5.4), with molluscs contributing the greatest species number (36: 18 bivalves and 14 gastropods), followed by poriferans (21), echinoderms (18), polychaetes (17), bryozoans (16) and crustacean (12). The remaining groups contributed approximately 7% of the total species number.

Table 5.3 *Constituent species of the benthic assemblages and related substrate type from Bay of Fundy sediment sampling during 1966–1967*

Assemblage	Constituent species		Substrate
Coastal sand assemblage	*Eucratea loricata* *Polymastia* spp *Spisula* spp	*Asterias vulgaris* *Colus stimpsoni* *Polydora* sp	Sand
Upper Bay assemblage	*Boltenia ovifera* *Chlamys islandicus* *Henricia* spp Hydroids *Modiolus modiolus* *Pteraster militaris*	*Balanus balanus* *Buccinum undatum* *Hiatella arctica* *Hyas coarctatus* *Pagurus* spp *Weberella bursa*	Not correlated
Scallop ground assemblage	*Crossaster papposus* *Neptunea decemcostata* *Placopecten magellanicus* *Solaster endeca*	*Anomia* spp *Balanus balanus* *Clione vastificia* *Thelepus cincinnatus*	Gravel (suspected)
Deep water mud assemblage	*Gorgonocephalus arcticus* *Terebratulina septentrionalis*		Mud
Deep water offshore assemblage	*Balanus hameri* *Hippasteria phryginia* *Terabratulina septentrionalis* *Urticina* sp	*Placopecten magellanicus* *Thelepus cincinnatus* Yellow papillate sponge	Not correlated

Source: Caddy (1970)

Table 5.4 *Distribution of 130 invertebrate species by phyla/class from Bay of Fundy sediment sampling during 1966–1967*

Taxon	Number of species
Mollusca	
Bivalvia	18
Gastropoda	14
Scaphapoda, Polyplacophora, Cephalapoda	4
Polychaeta	17
Crustacea	12
Echinodermata	18
Brachipoda	1
Bryozoa	16
Coelenterata	7
Porifera	21
Tunicata	2

Source: Caddy (1970)

From these and other studies of benthic community–sediment habitat relationships, it is clear that sediments provide two fundamental requirements for benthic fauna: space and food. Sediment substrates are frequently described as either sand and gravel bottoms or mud bottoms. Sand is usually a mobile bottom and generally provides a smooth, if undulating, and rippled terrain. In areas of intense currents, such as within the Minas Basin, a sandy bottom can create a hard pavement (Davis and Browne, 1996a), with small invertebrate populations. Gravel and sand waves can have different benthic communities within the crests and troughs as a result of varying grades of sediment. Small particles do not provide a habitat for epifauna, although small stones and shells of dead molluscs may be colonized by forms typical of rock and boulder bottoms. On sand bottoms, infauna predominate – but many species of hyperbenthos (fauna that live at the surface or in the lower water column) also commonly occur. Davis (1976) and Davis and Browne (1996a) list species typically occurring on subtidal sandy substrate: cumaceans (*Diastylis quadrispinosa* and *D. sculpta*); amphipods (e.g. *Unciola irrorata*, *Ampelisca macrocephala* and *Psammonyx nobilis*); small polychaete worms living between sand grains and tube-building species, as well as the sand dollar (*Echinaracnius parma*) and the tanaidaceans (see Figure 5.9). Ocean quahogs (*Arctica islandica*), sea scallops (*Placopecten magellanicus*) and Stimpson's surf clam (*Mactromeris polynyma*) commonly occur on the sandy/gravelly bottom on the Inner Shelf and offshore banks of the Bay of Fundy. The surf clam (*Spisula solidissima*) occurs on sand bars and banks in shallow waters (Davis and Browne, 1996a). In contrast, a mud bottom usually contains varying proportions of silt and clay, as well as other components. Clay is finer and accumulates in relatively still conditions in basins and smaller depressions, providing a flat terrain. Subtidal areas near river mouths usually have high proportions of silt. Infaunal species predominate on silt/clay bottoms and the majority feed on particulate organic matter sorted from the sediment or filtered from the water (Davis, 1976; Tremblay and Chapman, 1980; Davis and Browne, 1996a). These, in turn, support a variety of epifaunal carnivores and bottom-feeding fish. It is important to note that species diversity and abundance are generally reduced as the sediment grades into fine and compacted clay deposits, although occasional stones and shells are colonized by epifauna similar to those associated with rock and boulder bottoms. Mud-bottom infauna include burrowing sea anemones; sea pens (in deeper waters); polychaete worms; bivalve mollusks; tusk shells; Dentalium spp; the gastropod Aporrhais occidentalis; sea cucumbers; brittlestars and starfish. The burrowing shrimp Axius serratus has been noted building burrows several metres into the muddy bottom of Chedabucto Bay (Davis and Browne, 1996a). Epifauna comprise hermit crabs, crabs, shrimp, sea spiders and bottom-feeding fish.

Davis and Browne (1996a) note that the diversity and abundance of polychaete worms, crustaceans, molluscs and echinoderms is often enhanced as the proportion of mud in the sediment increases due to the mechanical and nutritional advantages of a sandy/mud habitat. Burrowing fauna on mud bottoms include sea anemones (*Cerianthus* spp); polychaetes (*Onuphis conchylega*, *Pectinaria* spp. And the tube-building maldanid polychaetes); echinoderms, including brittle stars (*Ophiura sarsi*) and particularly the mud star (*Ctenodiscuscrispatus*); polychaete worms, including the seamouse (*Aphrodite* spp) and scaleworm (*Laetmonice filicornis*); bivalve molluscs (*Cyclocardia boreali* and *Astarte* spp); and the large predatory moon snail (*Lunatia heros*) (see Figure 5.7). Several kinds of starfish (Asteroidea), brittlestars (Ophiuroidea), sea urchins and sand dollars (Echinoidea) occur on sandy/muddy bottom (Davis, 1976; Wagner, 1979; Tremblay and Chapman, 1980). The distinctive heart-urchin (*Schizaster fragilis*) occurs on sandy mud in basins of the continental shelf. Snow crab and the northern pink shrimp prefer muddy bottoms, and the deep-sea red crab (*Geryon quinquedens*) occurs on muddy bottom along the edge of the continental shelf. Eel grass beds on muddy bottoms in Bay of Fundy shallow water provide habitat for benthic fauna, which typically require warm summer temperatures for reproduction and growth, such as the American oyster (*Crassostrea virginica*); snails (*Acteocina canaliculata, Bittium alternatum, Mitrella lunata* and *Turbonilla interrupta*); the bivalves *Macoma balthica, Gemma gemma* and *Mysella planulata*; the crab *Neopanopeus sayi*; the amphipods *Corophium insidiosum, Gammarus mucronatus* adn *Ampithoe longimana;* the isopods *Jaera marina, Idotea balthica and I. phosphorea;* the polychaetes *Capitella capitata* and *Scoloplos armiger*; and the oyster borer *Polydora cornuta* (Davis, 1976; Davis and Browne, 1996a).

Figure 5.7 *The large predatory moon snail (*Lunatia heros*), which feeds on other mollusks by drilling through the shells of its prey with its radula, leaving a small beveled hole*

Source: Barnes (1980)

In brief, sediments supply the necessary three-dimensional space for colonization and reproduction, as well as the key food source for dependent benthic fauna. Several authors have suggested that the organic content of sedimentary deposits increases logarithmically with decreasing particle size through an organic film on particle surfaces by bacteria and/or diatoms (for a review, see Newell, 1970). Rodfield and Deevy (1952), Peer (1984) and Daborn (1984) noted that bacteria develop in a matter of hours, with algae and diatoms maturing in four to seven days. In addition, dissolved organic particles are adsorbed on sediment particle surfaces (Zobell, 1946; Bader, 1960); as a result, microbial extracellular metabolytes and micro-organisms such as bacteria and fungi will develop on sedimentary particles exposed to the marine environment in a relatively short period of time.

Studies have shown that the bacterial populations found in sedimentary deposits tend to increase directly with the total surface area of the particles that make up that deposit (Newell, 1970; Tserhoglou, 1971). Some deposit feeders (mainly polychaetes and bivalves) directly ingest sediment grains, strip off the organic film, then excrete the grains, thereby allowing a new organic film to be developed (Craig, 1976), which can be redeveloped in a matter of hours.

Temperature, salinity, water turbulence (a result of strong tidal currents), current speed, water turbidity (availability of light) and nutrient limitation are all accepted by recent research as elements that affect the life population history of benthic communities (Cammen, 1984; Daborn, 1984; Peer, 1984; Wildish, 1984). However, there is general agreement that substrate is the most important local factor in determining the viability of benthic inhabitants (Saunders, 1958; Nicol, 1960; Rhoads, 1970; Cammen, 1984; Daborn, 1984; Wildish, 1984). In particular, substrate influences the following:

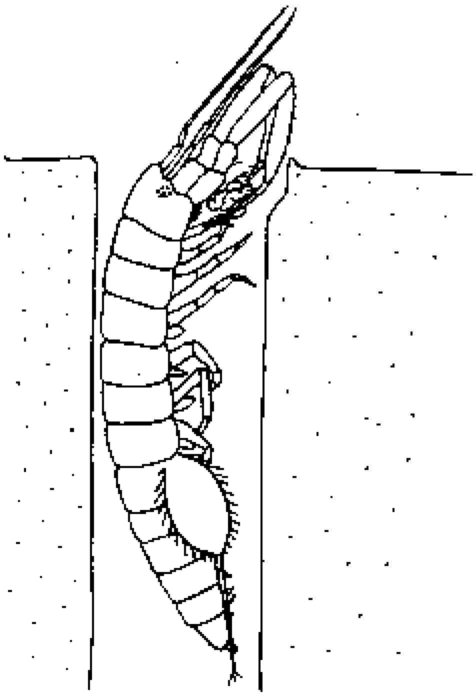
1. *Larval ecology.* Some invertebrate larvae show preferences for organic and other sedimentological properties (for a review see Webb, 1958).

2. *Burrowing behaviour.* Some fauna are limited by the type of sediment in which they can successfully burrow (i.e. *Arenicola marina*; see Chapman, 1947).

3. *Burial response.* The ability of fauna to recover from burial, especially relevant in areas of migrating megaripples in Cobequid Bay, is integral to habitat zonation. Only mobile organisms are found in these areas (Craig, 1976).

4. *Feeding behaviour.* Filter-feeders rely on suspended particulate matter in areas with relatively strong currents that keep water circulating. In general, higher current velocities result in coarser sediments. Therefore, filter-feeders typically predominate in coarser sediments (Craig, 1976). Deposit-feeders ingest sediment directly, removing bacteria and other organic matter, thereby favouring sediments with high organic content. Grain size has been shown to be related to organic content (Buchanan, 1968; Newell, 1970; Tserhoglou, 1971), with finer sediments allowing for more organic film to develop than coarse sediments (Dale, 1974; De Flaun, 1983; Peters, 1989; Fleituch, 2001). These sediments are typically found in sheltered areas with low current velocities.

Low quantities of phytoplankton, high concentrations of suspended sediment, large amounts of detritus (both in suspension and on tidal flats), and biological films on sediment particles provide an intertidal environment best suited for deposit-feeders (Craig, 1976). Exceptionally large populations of these deposit-feeders can be found in many areas (e.g. *Corophium* spp and spionid worms), interspersed with local occurrences of filter-feeders (e.g. *Mytilus* spp).



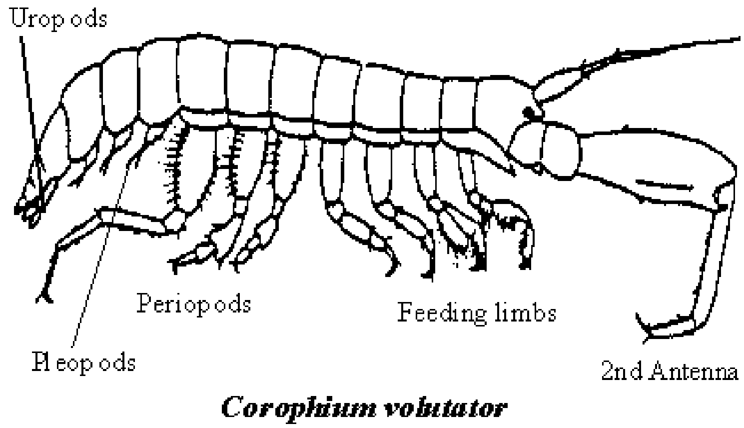


Figure 5.8 Corophium volutator*, a keystone species in the Bay of Fundy, is deliberate in choosing its burrow in mudflats: Upon alighting upon the substrate, this deposit-feeder carefully manipulates particles of sediment to assess their texture and chemical properties*

Source: Percy (1999) after Meadows and Reid (1966)

This inter-relationship between benthic communities and substrate is well illustrated by the life history of *Corophium volutator*, a keystone species within the Bay of Fundy (see Figure 5.8). Deliberate in choosing where it burrows, *Corophium* swim at random, occasionally alighting to examine the surface of the substrate. Upon landing, they crawl about and carefully manipulate particles of sediment, assessing their texture and chemical characteristics (Meadows and Reid, 1966; Peer et al, 1986; Wells, 1998). Responding to properties of the surface layer of the substrate when deciding whether or not to burrow, *Corophium* are chiefly concerned with the size and nature of the sediment so that the mud has the right consistency for digging burrows: if the sediment is too fine and watery, burrows cannot be built (Wells, 1998; Percy, 1999) or soon collapse; if it is too coarse, less organic film is present on the surfaces of the large particles. Sediment particles, furthermore, must be small and well coated with such organic matter if they are to be acceptable as food. These "biofilms" typically consist of bacteria, microscopic algae, fungi, protozoans and their secretions, as well as other organic compounds that stick to the particle surface (Peer et al, 1986; Wells, 1998). In addition, the depth of the sediment layer must be at least 0.5 cm, with larger animals requiring an even deeper layer in which to burrow. The composition of the mud in different parts of a mudflat can vary greatly. Current or wave action may wash out fine particles in some areas, while elsewhere small depressions or channels may trap fine sediments and organic material. Mudflats thus tend to be a patchwork, and it is not surprising that the distribution and abundance of *Corophium* in the Bay of Fundy is also patchy (Murdoch et al, 1986; Peer et al, 1986; Wilson, 1988).

Given their tiny size, *Corophium* have a surprising influence on the ability of mudflats to withstand the erosion of currents and waves (Peer et al, 1986; Wilson, 1988; Wells, 1998; Percy, 1999). Diatoms, bacteria and other micro-organisms in the surface layers of mud secrete sticky, organic substances (muccopolysaccharides), which ensures that sediment particles stick together and which reduces the likelihood of their being swept away by tidal currents. *Corophium* consume large numbers of these organisms, with the end result that sediment particles are more easily washed away (Peer et al, 1986). This has been demonstrated by spraying an area of mudflat with insecticide to kill off *Corophium* (Murdoch et al, 1986). Diatoms and bacteria flourished so that the sediment's ability to resist erosion increased significantly. Flocks of hungry shorebirds eating large numbers of *Corophium* can have a similar stabilizing effect on mudflats. Murdoch et al (1986) term this an "ecological cascade", with shorebirds influencing *Corophium* abundance, which, in turn, influences diatom abundance, which, in its turn, influences the stability of mudflat sediments. Nevertheless, *Corophium* may also have a positive effect on sediment stability. When it builds its burrows, it not only compacts the intervening sediment, but also cements together the particles lining the walls, creating a "forest of erosion-resistant chimneys in the mud" (Percy, 1999). The manner in which these opposing effects of *Corophium* on mud stability interact together is complex and requires further research.

5.2 SEDIMENT SOURCES

The total sediment input into the Minas Basin, as estimated by Amos (1976) is between 4.26 x 10^6 m^3 per year and 5.11 x 10^6 m^3 per year. Sediments in the Minas Basin are derived from four major sources: the eroding cliffs bordering the system; the rivers draining into the system; the Bay of Fundy, via the Minas Passage; and reworking of the seabed. Amos and Long (1980) state that the first three sources physically contribute material to the system and are therefore active components of the sediment budget of the Minas Basin. Reworking of the seabed, on the other hand, redistributes material already within the system and is therefore considered under section 5.3 on "Sediment transport". Descriptions of the three primary sediment sources for the Minas Basin are as follows.

Eroding cliffs (66% to 80% of total sediment contribution)

The cliffs surrounding the Minas Basin have been known to be eroding at rates of up to 2 m per year and are therefore supplying large quantities of sediment to the system (Churchill, 1924; Amos, 1976; Amos and Long, 1980). Cliff-derived sediments have been identified by Klein (1963, 1970) and Middleton and Davis (1979). Of the 320 km perimeter, 79% is comprised of eroding, unstable cliffs of Triassic sandstone, glacial till and outwash, Cretaceaous basalt or Paleozoic sedimentary rocks (Amos and Long, 1980). Based on aerial survey photos between 1939 and 1964 at 105 sites within the Minas Basin, Amos (1976) and Amos and Long (1980) found that average cliff retreat was 0.55 m per year, although this rate varies considerably around the basin. Rates are highest at Five Islands (1.5 m per year) and along the north shore of Cobequid Bay (1.6 m per year). These regions have cliffs composed of Triassic sandstone and glacial material, respectively. Along the south shore, recession rates are lower: at Burntcoat Head, no significant erosion was measured, whereas the remainder of the south shore showed a mean regression rate of 0.5 m per year (Amos and Long, 1980).

Amos and Long (1980) note that cliff recession is a function of three elements:

1. the degree of exposure to wave attack during high tide inundation of the cliff foot;
2. composition of the cliff (Triassic sandstone and glacial material erode faster than Paleozoic rock); and
3. the depth of cliff foot inundation.

Along the north shore of the Minas Basin, for example, recession rates are high because of exposure to the dominant southwest winds, because of the friable nature of the cliffs, and because cliff foot inundation is 2 m during spring tides (Amos and Long, 1980).

The volume of material put into the system from regressing cliffs, on the other hand, is a function of cliff height. The volume of sediment derived from cliff erosion during the time period of the study's 26 years was estimated to be 3.9 x 10^6 m^3 per year (Amos, 1976; Amos and Long, 1980). Of this total, 12% is derived from Cobequid Bay and the Central Minas Basin; the remaining 88% is derived from the Five Islands and Cape Blomidon areas, which are predominantly composed of Triassic sandstone.

Rivers (1.91% of total sediment contribution)

Amos (1976) roughly estimates the amount of sediment flowing into the Minas Basin from rivers to be 1.3 x 10^4 m^3 per year of suspended particulate matter. Of this total volume, 60% is thought to be contributed during 20 days of high runoff during the spring freshet. Analysis of the Herbert River fluvial load (adjacent to the Minas Basin watershed) showed that it was primarily composed of organic detritus and silt/clay grade material, with a mean discharge of 5 m^3 per second, or an annual discharge of 680 m^3 (Amos and Long, 1980). The Salmon River, one of the larger rivers within the Minas Basin watershed, has a mean sediment discharge of 21.6 tonnes per day (based on a mean daily discharge of 8.8 m^3 per second), derived from a catchment of 363 km^2 in extent. Amos (1976) therefore suggests that it's fluvial particulate matter contributing to the suspension load of the Minas Basin system.

Table 5.5 *Summary of the postglacial annual sediment budget (m^3 per year) within the Minas Basin system*

Sediment	Location	Postglacial to 6300 years BP (m^3 per year)	6300 years BP to near present (m^3 per year)	Present (m^3 per year)
Silt/clay	Intertidal[1]	–	–	–
	Subtidal[2]	0.5 x 10^6	–	–
	Marginal[3]	– (?)	0.1 x 10^6	1.7 x 10^6
Sand	Intertidal	–	2.8 x 10^6	2.8 x 10^6
	Subtidal	–	–	–
	Marginal	– (?)	– (?)	–
Granules, pebbles or cobbles	Intertidal	–	0.6 x 10^5	0.3 x 10^6
	Subtidal	–	–	–
	Marginal	– (?)	– (?)	–
Total (sediment budget)		0.5 x 10^6	3.0 x 10^6	4.8 x 10^6
Maximum tide range		0–2 m	2–16 m	> 16 m

Notes: 1 = between high- and low-water levels; 2 = below low water; 3 = at or outward of the high tide line.

Source: Amos and Long (1980)

Open sea (20% to 33% of total sediment contribution)

Based on a study of 11 tidal cycles by Amos and Long (1980) that estimated suspended sediment movement in the Minas Channel, the total influx of sediment to the Minas Basin system was calculated to be 4.8 x 10^6 m^3 per year. Sand comprised 58% of this volume, silt and clay 35% and coarser material only 7% (see Table 5.5). The relative difference between basin infill due to sedimentation and basin enlargement due to sea-level rise is used to determine evolutionary trend in basin size (Amos, 1976; Amos and Long, 1980). Using a figure of 15 cm per century for mean sea-level rise, Amos and Long (1980) deduced that the volume increase of the Minas Basin resulting from sea-level rise and from enlargement due to erosion amounts to 3.4 x 10^6 m^3 per year. Since the annual sediment influx is 4.8 x 10^6 m^3 per year, the Minas Basin system must be diminishing in volume at a rate 1.4 x 10^6 m^3 per year (Amos and Long, 1980).

5.3 SEDIMENT TRANSPORT

Bed material, transport and deposition

Amos and Long (1980) state that in the Minas Basin, with the exception of Windsor Bay, the distribution of bottom sediments shows that bed material is transported principally in the intertidal zone. Wide expanses of sands and megaripples are visible during low tide, covering a substantial area of the marginal wave-cut platform. These features have been used to infer the direction of bedload transport (Middleton, 1972; Dalrymple, 1977; Knight, 1977; Lambiase, 1977, Amos and Long, 1980). In the subtidal region, the surface material is predominantly comprised of gravels, pebbles and cobbles in a layer that is approximately 0.5 m thick (Amos, 1976). Under this lies a thin sand layer 10 cm to 30 cm thick, and still below this are 4 m to 5 m of wet marine mud with thin sand laminations. This mud layer rests on a layer of consolidated material that is estimated to be Pleistocene in nature (1.5 million to 11,000 years old).

Most sand in the sand bars of the Minas Basin is derived from a limited number of sites along the local eroding cliffs (Amos and Long, 1980). Along the western shore of the Minas Basin, Amos and Long (1980) calculate that up to 0.49 x 10^6 m^3 of sand is transported annually into Windsor Bay. Some of this sediment accumulates on the Avon Estuary ebb delta and in the Avon River estuary itself. The remainder is thought to pass through this region and move eastward to supply sediment to Hogsback and Walton Bar. Amos and Long (1980) sugges that sediment is prevented from moving farther by the ebb residual to the east.

The sand found along the north shore of Minas Basin and Cobequid Bay is largely derived from the Five Islands region. The general distribution of this sand indicates an eastward transport (Amos, 1976; Dalrymble, 1977; Amos and Long, 1980). From the volume of sediment input from the cliffs, an approximate sediment transport rate of 0.85 x 10^6 m^3 per year under steady state conditions can be derived (Amos and Long, 1980).

Within the western part of Cobequid Bay, sand moves from the west to east along the northern intertidal margin (Dalrymple, 1977; Amos and Long, 1980). However, farther east the transport of material is more complicated, though it is generally redistributed westwards along the centre of the bay (Middleton, 1977). This redistribution has resulted in the complex sandbar that extends throughout eastern Cobequid Bay.

Long-term changes in the transport of material in the Minas Basin are manifested by changes in the bathymetry and in the distribution of the various bottom sediment and morphological types. Amos and Long (1980) show that erosion patterns in Cobequid Bay between 1858 and 1976 have resulted in a central tidal channel south of Economy Point, that has been scoured in places to 5 m. Each year, 5.3 x 10^6 m^3 of sediment is eroded in Cobequid Bay, mostly from tidal channels, and 6.0 x 10^6 m^3 of sediment is deposited (Amos and Long, 1980). A net amount of 0.7 x 10^6 m^3 per year is therefore deposited – equivalent to almost the entire supply of sediment derived from the north shore of the Minas Basin by cliff erosion.

Suspended sediment transport and deposition

Amos (1976) and Amos and Long (1980) show that there is a residual transport of suspended material eastward into Cobequid Bay (0.1 to 3.5 x 10^6 grams per metre per tide) and southward into Windsor Bay (0.1 to 0.4 x 10^6 grams per metre per tide). Amos and Long (1980) state that in most cases, there is a positive correlation between residual sediment transport and residual current ($r = 0.90$) and only a poor relationship between suspended sediment composition and current speed ($r = 0.31$). In the greater part of the Minas Basin, suspended sediments behave as a "wash load" (Amos and Long, 1980). Settling rates, established from settling experiments in seawater, are no higher than 6.7 cm per minute. Amos and Long (1980) explain that material is deposited only under still conditions. These conditions are created artificially by earth-filled causeways across tidal estuaries, and accumulations of fine-grained sediment are dramatic seaward of such structures. This has implications for sediment deposition, habitat change and the viability of benthic fauna as a result of the construction of causeways (Daborn et al, 2003). Dalrymple (1977), for example, explains that, in general, there is significant inequality between ebb and flood currents. Sediment transport is ebb dominated, meaning that, overall, sediment is transported out of the Minas Basin. This is not the case for the localized area of the Avon River estuary, however, which is flood tide dominated as a result of the causeway – here, there is substantial build-up of sediment on the seaward side of the causeway (Daborn et al, 2003; Perry-Giraud, 2005).

6. Geological System Information Gaps

Geological system information gaps within the Minas Basin watershed relate primarily to how sedimentation patterns affect marine biota, and how the distribution and dispersal of bottom and surface sediments respond to basin bathymetry and to human disturbance, especially in relation to tidal flow. Settling conditions created artificially by earth-filled causeways across tidal estuaries, for example, result in accumulations of fine-grained sediment seaward of such structures. This has significant implications for sediment deposition, habitat change and the viability of benthic communities. Amos (1985), for example, states that sedimentation on the intertidal zone in areas influenced by tidal barrages has been under-predicted in research studies, and that depletion of suspended matter due to this increased intertidal deposition results in less deposition in the subtidal zone. The end result is a generally clearer water mass.

Kosters et al (2007) emphasize the importance of research into sediment pathways and sedimentation patterns within the Minas Basin given the need for detailed knowledge on seabed substrates in relation to keystone species within the basin, renewed interest in tidal power generation, changing views on coastal zone management, and climate change. Kosters et al (2007) propose the following research agenda as being crucial for the future management of critical habitats and keystone species within the Minas Basin:

1. Map the entire Bay of Fundy floor using multibeam bathymetry, with special attention to mussel reefs and sand bedforms.
2. Establish a sediment budget: focus on the different contributions of bedload, suspended sediment load, and organic and inorganic matter to the Bay of Fundy system.
3. Improve understanding of sea-level rise over the last 10,000 years.
4. Establish the proportions of organic and non-organic material in the sediment column, both spatially and temporally.
5. Establish the timing of origin of the large sand waves on the bottom of the bay.
6. Address bottom fishing and its effects on benthic communities and sediment erosion.
7. Establish a sediment monitoring system in the Upper Bay of Fundy before the Petitcodiac Causeway is removed.
8. Quantify the role of winter ice as a source of sediment and of new vegetation.
9. Quantify the effects of increased wave activity on exposed marsh cliffs.
10. Compile detailed high-resolution LIDAR surveys of marshes and mudflats.
11. Integrate modern and historical bathymetric data with historical aerial photography and high-resolution satellite imagery.
12. Expand monitoring of dredge spoil disposal sites to other locations.

Russell et al (2007) also detail how the demand for small-scale (large area) mapping of sediments, local geology, biology and oceanography within the Bay of Fundy is crucial to addressing gaps in knowledge of the interactions between biotic and abiotic elements within the Bay of Fundy – particularly interactions between biological communities and marine substrates. Such gaps in knowledge have culminated in the launch of a new three-year regional sea survey to map the Bay of Fundy sea floor from the approaches in the southwest to the Inner Bay in the northeast. The resulting 1:50,000 scale maps will be released as part of the new National Research Canada national marine map series and will include sheets of sea floor topography, backscatter strength, and surficial geology. In selected coastal regions around the bay, the linking of airborne topographic and bathymetric survey data with ship-borne data will provide a "seamless digital elevation model across the intertidal zone"; these maps of the Bay of Fundy will provide a crucial scientific underpinning for integrated ocean management.

Tidal barriers exist on at least 25 of the 44 major rivers around the Bay of Fundy (Wells, 1999), and research has suggested that their implications for Bay of Fundy rivers and estuaries include reduced lengths of tidal rivers; altered current and tidal movements; reduced water quality; changed freshwater discharges; reduced movement of saltwater upstream; altered hydrodynamics; sedimentation (often severe); reduced open salt marsh; reduced nutrient transfer to the Bay of Fundy; and interference with the movement of fish and invertebrates (Wells, 1999). Nevertheless, the full scope of environmental impacts is still not well understood and reliable quantitative documentation on the effects of tidal barriers on ecological processes and components is scarce or unavailable. Indeed, except for a few rivers and their estuaries, data are largely anecdotal (Wells, 1999). Federal agencies, provincial departments and other groups and interested parties must address gaps in knowledge regarding suspended sediment loads in rivers and streams, the effects that tidal barriers have, and concerns over the gradual, cumulative and potentially far-reaching impacts of barriers. Data on tidal barriers must be strengthened; river flow information must be updated; changes and cumulative effects in relation to sedimentation patterns and tidal barriers must be modelled; and the effects of rehabilitation or remediation efforts on selected river barriers must be considered (see below).

The land in most watersheds around the Minas Basin has been extensively transformed through agriculture, forestry and urbanization since European settlement. Agriculture exists in many Minas Basin watersheds, especially those of the Salmon and Cornwallis rivers, with consequent inputs of nutrients and pesticide residues into estuaries and embayments. Changes in land use affect water run-off volumes and patterns, soil retention, bank erosion rates, water quality and sediment loads, and are cumulative in nature, with significant effects for aquatic health. These must be addressed across a broad scale. Recent reports on river water quality and loadings (fluxes of metals, and dissolved and particulate trace elements to the Bay of Fundy) provided by Pol (1996), Windom (1996) and Dalziel et al (1998) have filled in many gaps in knowledge; however, full interpretation and modelling in the context of specific watersheds and their influence on the Minas Basin are still lacking and must be supplied if sedimentation is to be prioritized as a management issue.

Wells (1999) details a number of actions that should be considered by the appropriate federal and provincial natural resource, transportation/highway and energy agencies, as well as all interested parties and stakeholders, in addressing geological and sedimentation knowledge gaps for the Minas Basin:

1. *Data and information base:* improve upon the data and information base on change in rivers related to barriers, especially by ground-truthing the presence and extent of barriers on all Bay of Fundy rivers and streams (major and minor) and their estuaries, and by measuring features such as the area and condition of remaining open salt marshes.
2. *River flow characteristics:* determine total annual flows into the Bay of Fundy from the rivers and the level of change in volumes or changes in other flow characteristics due to barriers, as well as the influence that this might have or have had on estuaries and the broader Bay of Fundy.
3. *Modelling changes and cumulative effects:* build a simulation model of the changes that occur to rivers and streams as a result of tidal barrages in order to test the hypothesis of gradual cumulative effects (positive or negative) on biological and ecological processes in important geographic parts of the Minas Basin.
4. *Effects of rehabilitation and remediation:* run the simulation model as a way of testing the effects of local and area-wide rehabilitation efforts, and as a way of setting priorities for remediation initiatives for tidal rivers.
5. *Pilot projects on selected rivers and keystone species within the Minas Basin:* given the number of habitats and species across all rivers and estuaries in the Bay of Fundy, and the need to simplify an approach to quantifying the impacts and effects of remediation, one project could be "to explore the usefulness of an index river–species approach to identifying the impacts of barriers on the living resources of the Bay of Fundy and the means of mitigation" (Wells, 1999).

Recent research by the Applied Geomatics Research Group (AGRG) of the Centre of Geographic Sciences (COGS) in Lawrencetown, Nova Scotia, in conjunction with the Canadian Space Agency (CSA), the

Canadian Hydrographic Service and the Canada Centre for Remote Sensing during 2002–2003 has applied grey-level threshold methods to model coastline positions, sea-level height, sedimentation patterns and topographic data for the Minas Basin (Dupont et al, 2003; Milne, 2003). Such research has been a step towards addressing knowledge gaps in the following fields:

1. flood and storm risks (incorporating terrain and riparian data for landslide and soil erosion modelling along the Minas Basin);
2. knowledge of surficial material (utilizing terrain and landcover information for the mapping of groundwater reserves, aggregate and clay deposits onshore and offshore);
3. geophysical data on bedrock material (correlating the surface topography/bathymetry of the Minas Basin with subsurface sedimentary characteristics);
4. marine habitat analysis and characterization (offshore habitats mapped through the use of multi-beam bathymetry)
5. coastal erosion analysis (datasets used as a baseline for future high-resolution surveys to monitor global change and local coastal erosion rates).

Fader et al (2003) explain that traditional geological seabed mapping has focused on defining surficial sediment units or formations, which are basic map units that can be traced over large areas. These early regional geological maps relied on statistical sample grids spaced at a variety of distances, from hundreds of metres to kilometres. The advent of sidescan sonar presented geologists with imagery of the seabed similar to aerial photography of land. As a result, sample methodologies began to focus on providing ground truth for the sediment acoustic characteristics and features interpreted from this data. This significantly reduced the requirement for a large number of samples and allowed accurate correlation between samples.

Over the past ten years, major developments in seabed mapping technology have occurred that meet many of the requirements of the marine biological community, and which have been instrumental in addressing geological system information gaps within the Minas Basin. These include high-resolution sidescan sonars, multibeam bathymetric mapping systems, precise navigation, precision sampling and photographic systems, and advances in digital data processing and scientific visualization techniques. Adequate attention to marine habitat is considered by some to be the most fundamental of ecological concepts, often missing from ocean fisheries management (Willison and Butler, 1998). To address this issue, closer cooperation between marine biologists and marine geologists is essential. Fader et al (2003) provide a list of critical geological seabed attributes considered to be of ecological importance based on initial and ongoing discussions between cooperative bodies, such as the BoFEP. These attributes are frequently characterized by insufficient data and must be the subject of ongoing research if the general knowledge base of the Minas Basin is to be expanded upon:

micro-relief of the Minas Basin: centimetres to decimetres (roughness);
macro-relief of the Minas Basin: metres to hundreds of metres (topography, morphology, slope);
sediment grain size (gravel, sand, silt and clay) – lithology (rock composition);
topographic patchiness within the Minas Basin (local variability, shape and spatial patterns);
sediment distribution;
sediment sorting;
porosity (pore spaces and packing);
grain shape (roundness and sphericity);
stratigraphy (layering – centimetres to decimetres);
marine dynamics/processes (relict to modern and combinations);
bedforms (all scales, centimetres to tens of kilometres);
sediment transport pathways (net and varying directions);
sediment thickness (centimetres to metres);
regional setting (e.g. sandbank, moraine, beach ridge and basin);
anthropogenic features (shipwrecks, anchor marks, cables and debris).

Fader et al (2003) explain that some of these attributes, such as sediment grain size and lithology, are more easily determined than other attributes, provided that valid seabed samples can be collected. This is not a simple matter in coarse gravely sediment. Other characteristics, such as porosity and high-resolution stratigraphy, are more difficult to determine since the process of sampling frequently destroys the fabric of the seabed material, particularly in coarse-grained sediments. For these areas, reliance is placed on remote sensing by acoustic means and *in situ* geotechnical methods for assessment. The measurement of many of these attributes remains an area of continued study.

It is clear from such research that viewing and exploring data at varying scales can open up new avenues of enquiry and potentially identify patterns not immediately visible at the local scale. For example, modelling data can reveal spatial patterns of sedimentation and erosion, or the sequence of tidal barriers needed to be modified or removed along a river course in order to permit fish passage, or rates of coastal erosion in relation to local bathymetry and topography. Furthermore, restoration and remediation activities can be used to mitigate some of the long-term impacts of climate change, such as the restoration of salt marsh habitat. Nevertheless, as van Proosdij and Dobek (2006) point out, the long-term ecosystem and geomorphic impacts of restoring or enhancing tidal flow in a macrotidal environment such as the Bay of Fundy is not clear, nor is it possible, yet, to predict if the system will return to its original pre-existing state – with consequent impacts for marine species–habitat inter-relationships. Furthermore, models and restoration practices developed and adopted by jurisdictions in other geographic areas cannot simply be extrapolated to the Minas Basin with its extremely high tides, large suspended sediment concentrations, dynamic intertidal conditions and ice (van Proosdij and Dobek, 2006). Numerous knowledge information gaps regarding the Minas Basin system still exist, and it is only by having a solid understanding of current hydrological, bathymetric, geomorphologic and sedimentation conditions within the Minas Basin that scientists and conservation managers can begin to explore the questions of "why", "how much" and what will happen in the future.

PART B – OCEANOGRAPHIC SYSTEM

7. ATMOSPHERE/OCEAN EXCHANGE

7.1 SEASONAL CLIMATIC PATTERNS

There are five climate stations around the Minas Basin that have climate norm reports: Kentville, Avon, Falmouth, Debert and Parrsboro. However, only the station at Parrsboro meets the World Meteorological Organization's standard to calculate 30-year norms of temperature and precipitation. Within the Minas Basin, June tends to be the driest moth, while July and August are the warmest. Relative humidity remains generally high throughout the year. The rainy season, marked by the highest monthly precipitation, occurs through the fall and early winter. Maximum snowfall is consistent during the month of January, when the coldest average temperature occurs, although, on average, little more than 25 cm is ever on the ground at the month's end in the coastal communities reporting measures (Environment Canada, 2007b). Kentville is reported to have 42% of the total possible sunshine (Davis and Browne, 1996).

7.1.1 Regional Patterns

The Minas Basin and Bay of Fundy are considered part of the larger Gulf of Maine ecosystem. In this region, the average winter temperature has increased by 2.4˚C over the last 100 years, with the greatest change occurring during the past 30 years (1970–2000, based on data comparing Boston to Halifax, and Philadelphia to Boston). Annual precipitation has increased 2% globally, but as much as 12% in the Gulf of Main region. Other regional climatic changes include a general decrease in snowfall since 1970; a decrease in the length of time that snow is on the ground; earlier spring runoff; earlier ice thaws; and a rise in sea level of approximately 30 cm during the past 100 years (Pohle et al, 2007).

The prevailing westerly winds of the region bring Nova Scotia and the Minas Basin a continental type of climate (Davis and Browne, 1996a), along with airborne pollutants from larger North American centres to the west of the province. At a provincial scale, the Minas Basin is somewhat an intersection of two of Nova Scotia's climatic regions. In the Southern Bight, warm air masses from the sheltered Annapolis Valley move down the Cornwallis and neighbouring river valleys towards the basin. The Annapolis Valley has the warmest temperatures and least precipitation in the province (Davis and Browne, 1996a). These influences can be seen in the long-term rain and temperature data for the town of Kentville that lies on the banks of the Cornwallis River (see Table 7.1). At the same time, a Bay of Fundy influence moves in through the Minas Channel toward the Central Basin. The coastal influence from the cool bay waters brings considerably lower air temperatures and moderate fog and precipitation (Davis and Browne, 1996b) into the basin.

Extremes do occur in the Minas Basin, as they do in all locations. In 1975, Hurricane Beulah ran up the Bay of Fundy and into the Minas Basin, where it purportedly removed the top 20 cm of tidal mudflats, killing some 90% of the organisms living in the mud (Thurston, 1990). Other large storms that have hit the Minas Basin include the "tidal wave" reported in November of 1759, and the Saxby Storm of October 1869 (Hind, 1875).

7.1.2 Air Temperature

Using data from 1971 to 2000, the average winter temperature across the Minas Basin is approximately –5˚C, with the coldest month being January (–4˚C to –8˚C). The average summer temperature is around 16˚C, and July garners honours as the warmest month, with a range of 17˚C to 19.4˚C (Environment Canada, 2007b). Current temperature data appear to show an increase over the past 30 years: Dalrymple (1977) reported the average summer temperature to be only 12˚C using observations from between 1968 and 1972. However, lack of statistical analysis means that such an observation may be misleading. Relative humidity is generally high throughout the year (Board, 1977).

The mean annual temperature (1913–2006) at the Kentville meteorological station was 6.8˚C (van Proosdij et al, 2006). Kentville has the warmest average daily temperature location of those within the Minas Basin for which longer data sets exist (Environment Canada, 2007b).

Table 7.1 *Climatology data for various weather stations around the Minas Basin: Parrsboro is the only station on the Minas Basin that meets the World Meteorological Organization's standards to prepare 30-year normals*

Sub-watershed	Community	Annual precipitation	Annual rainfall	Annual snowfall	Average daily temperature
Southern Bight	Kentville 1971–1996*	1211 mm	948 mm	266 mm	6.9˚C
Central Minas Channel	Parrsboro 1971–2000*+	1281 mm	1068 mm	213 mm	5.9˚C
Southern Bight	Avon 1961–1990*	1412 mm	1172 mm	237 mm	NA
Cobequid Bay	Debert 1982–2000*	1169 mm	1014 mm	155 mm	6.1˚C

Notes:
* Years of record reported, but may not include data from all years.
+ Meets the World Meteorological Organization's standard for 30 year normals.
NA = not available.

Source: Environment Canada (2007b)

7.1.3 Precipitation

June is the driest month of the year, with an average of between 77.5 mm to 99.1 mm of precipitation being reported from the various Minas Basin climate stations (Environment Canada, 2007b). The highest precipitation corresponds with the rainy season and tends to occur in November (111.9 mm to 158.8 mm). There is, however, a reasonably balanced level of precipitation over the three-month period of November to January. Maximum snowfall is consistent during the month of January (36 cm in Debert to 70.9 cm at Kentville).

Total precipitation in the Minas watershed area averages approximately 1200 mm/yearto 1300 mm/year, with slightly more falling on the north shore than the south (Board, 1977). Total annual rainfall ranges between 750 mm/year to 1000 mm/year, with July being the driest month (Board, 1977); the mean monthly precipitation (1913–2006) at the Kentville meteorological station also reveals June and July to be the driest months (van Proosdij et al, 2006). An average of approximately 40 mm fell during a dry July in 1945–1946 at seven stations located around the watershed (Huntsman and Rice, 1946), although 80 mm to 90 mm tends to be the norm (Environment Canada, 2007b).

Fog is very common in the area, usually caused by warm air from the south cooling as it passes over the cold water. During the winter fog may exist for two days, but in the summer it can occur for as many as 10 to 14 days (Board, 1977).

7.1.4 Prevailing Winds and Storms

As with most of Nova Scotia, prevailing winds within the Minas Basin are from the west, with a southerly component in the summer. The prevailing winds result from the Coriolis effect, an inertial force resulting from the Earth's rotation (Davis and Browne, 1996a), which also brings incoming tidal currents and fish along the southern boundary into the bay toward the mouth of the Minas Basin. Storm winds also blow most commonly from the west, directly parallel to the long axis of the Minas Basin, but can also come from the south–southwest (Dalrymple, 1977). Seasonally, the lighter southeasterly winds are dominant in the summer months, while the stronger west and southwest winds are prevalent in the winter months.

7.2 AIR QUALITY

Across Canada, monitoring of sulphur dioxide, carbon monoxide and suspended particulate matter have shown decreasing concentrations since the 1970s. Primarily due to changes in gasoline composition, lead has decreased dramatically from a high in 1974 to extremely low levels in 1990, where concentrations have remained level since. Nitrogen dioxide has also dropped since the late 1970s, though only slightly. Ground-level ozone levels have shown the opposite trend, increasing steadily since 1980. Nova Scotia and New Brunswick are below the national average concentrations for particulate matter, benzene, and benzo(a)pyrene (Environment Canada, 2007c). Many of these airborne pollutants that affect Nova Scotia are derived from human activity to the west of the province, and are carried with the prevailing winds to areas such as the Annapolis Valley and Minas Basin.

Various human activities can affect air quality because of the potential for adverse effects on species and environments. Air quality indexes (AQIs) have been developed to assess the potential for impact. AQIs are composed of a series of relevant air quality parameters that are measured at more than 20 sites in Atlantic Canada by the Atlantic Region Ozone Monitoring Network (Environment Canada, 2007d). This network is a provincial/federal partnership between Environment Canada and the New Brunswick Department of Environment and Local Government, the Nova Scotia Department of Environment and Labour, the Prince Edward Island Department of Fisheries, Aquaculture and Environment, and the Department of Environment of Newfoundland and Labrador. There is one AQI monitoring station in the Minas Basin watershed at Kentville.

The AQI is an indicator of air quality, based on hourly pollutant measurements of some or all of six common air pollutants: sulphur dioxide (SO_2); ground-level ozone (O_3); nitrogen dioxide (NO_2); total reduced sulphur (TRS); carbon monoxide (CO); and fine particulate matter (PM2.5) (Environment Canada, 2007d). Values for the AQI fall into four categories (see Table 7.2). Daily AQI results for Kentville are based solely on ground-level ozone. For the first 11 months of 2006 (the most current data available), the Kentville AQI station reported predominantly within the "good" air quality category. Only six of the daily readings were

Table 7.2 *Air quality index interpretation*

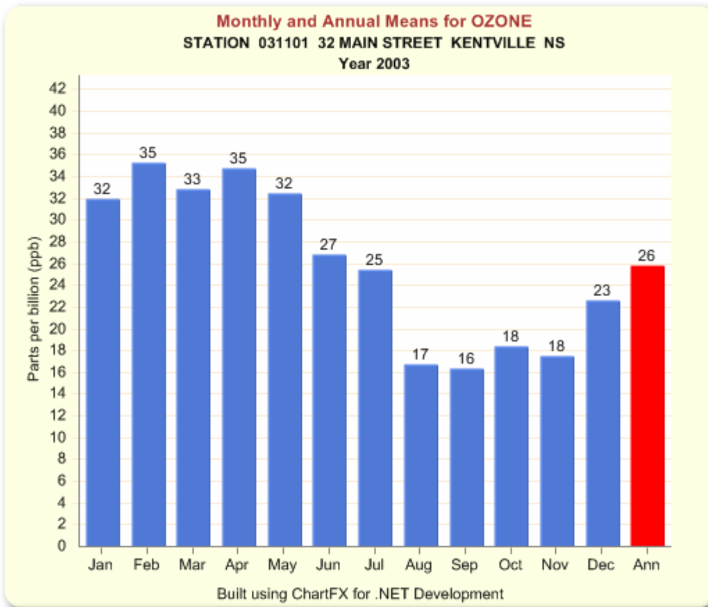
Air quality index value	Category/interpretation
≤ 25	Good
26–50	Fair: there may be some adverse effects on very sensitive people
51–100	Poor: may have some short-term adverse effects on human or animal populations, or may cause significant damage to vegetation and property
> 100	Very poor: may cause adverse effects on a large proportion of those exposed

Source: Environment Canada (2007d)

"fair", all occurring between April and July 2006 and with an AQI ranging between 27 and 31. No "poor" readings were recorded during 2006. In general, air quality appears to degrade within the Minas Basin during the summer months, as reflected by increasing AQI scores (Environment Canada, 2007d).

Ground-level ozone is also monitored within the province by the National Air Pollution Surveillance (NAPS) network. The annual ozone mean for Kentville was 26 parts per billion (ppb) for 2003, 24 ppb in 2004, and 23 ppb in 2005. The monthly means for 2003 show the January to May period as being times of higher ozone concentration, while lowest concentrations are observed between August to November (see Figure 7.1). These results are consistent with the AQI. The Kentville station reported over 120 exceedences of the National Air Quality Objective for desirable level of average ozone concentration over a one-hour period in 2003 (Environment Canada, 2007c).

Figure 7.1 *Monthly and annual ozone means at Kentville in the Southern Bight of the Minas Basin watershed*



Source: Environment Canada (2007c)

7.3 Heat Exchange Budgets

Although there is nowhere within the exisiting literature reviewed discussion, detailed measurement or modelling of heat exchange and transfer budgets between the marine waters of the Minas Basin and the surrounding atmosphere or ocean floor, several authors have noted a significant transfer from the intertidal flats of Cobequid Bay and the Southern Bight. Such an exchange may not be considered geothermal in its purest sense, but a significant measureable heat transfer does occur. The flats act as a sink in the winter and a heat source in the summer.

During the winter months, temperatures of –1.5 C have been recorded (Pennachetti, 1978) and ice is common. Due to the relatively large surface area of the intertidal mudflats, the waters of the Minas Basin tend to be warmer in the summer and colder in the winter than in the Bay of Fundy proper (Craig, 1976). Daborn and Pennachetti (1979) also noted that the diel temperature change was more significant than the tidal, as the large mudflats of the Southern Bight would warm with the day's sun, transferring heat to the incoming tidal waters. Waters that came in over the flats in the night or early morning hours would be notably cooler than late afternoon flood tide waters.

8. Physical Oceanography

The Minas Basin's physical oceanographic character is that of a well-mixed macro-tidal movement. There is little stratification or sharp horizontal gradients in the chemical pattern of its waters, and relatively weak freshwater input. However, the somewhat significant chemical signature of the basin may be derived, in part, from the freshwater contributions. The highly turbid water limits primary productivity in the Southern Bight and Cobequid Bay areas of the marine watershed; as a result, large expanses of intertidal salt marshes in these bays play a significant role in the production of the overall Minas Basin ecosystem.

The Bay of Fundy is known the world over for having the highest tides on the planet. Cobequid Bay within the Minas Basin is the location for which that world record exists. Tides of 11 m- to 16 m-change in elevation means that a large volume of water moves into or out of the basin within a very short period: approximately six hours. Estimates of water exchange ratios (flushing) between the Minas Basin and the Bay of Fundy have ranged from 0.39 to 0.60/tidal cycle (Ketchum and Keen, 1953, cited in Bradford and Iles, 1993). The strong tidal forcing and relatively shallow bathymetry of the Minas Basin (average mean of 20 m) facilitate this exchange.

The relatively short fetch of the Minas Basin and its sheltered nature from prevailing winds means that wave actions are relatively unimportant. However, ice block formation can be significant, particularly in the Southern Bight and Cobequid Bay. On the intertidal flats and salt marshes of these sub-watersheds, ice has long had a significant role in plant colonization, tidal channel formation and many sediment processes.

8.1 Freshwater Inputs

The freshwater input into the Minas Basin, particularly from rivers on the south side of the watershed, is significant. The rivers of the watershed provide approximately 15% of the total mean annual flow into the entire Bay of Fundy. The total land area of the Minas Basin watershed is estimated to be in the range of 8547 km^2 (Watson, 1936) to 8700 km^2 (Willcocks-Musselman, 2003).

There are five major rivers that flow into the basin and that provide the greatest influence to the Cobequid Bay and Southern Bight sub-watersheds. The Salmon and Shubenacadie rivers flow into the head of Cobequid Bay. The Kennetcook, St. Croix and Avon rivers flow into the Southern Bight area. In the northwest portion of the Southern Bight are three smaller systems: the Gaspereau, Cornwallis and Pereau rivers. In total, these rivers and the smaller systems in between drain nearly 20% of the total Nova Scotia mainland towards the Minas Basin.

The average yearly mean discharge rate for all Minas Basin rivers is 239 m^3 per second (Bousfield, 1959). A peak discharge of 587 m^3 per second occurs in April during the spring freshet, resulting from moderate rains and snowmelt. Discharge is typically bimodal, with another peak in November that corresponds with the peak rainfall period in the watershed (Environment Canada, 2007b). A minimum total watershed discharge of 93 m^3 per second occurs in August (Watson, 1936). Between July and September an average of approximately 99 m^3 per second is discharged into the Minas Basin, and more than half of this volume flows from the Avon and Shubenacadie sub-watersheds (Bousfield, 1959).

The Salmon River and Shubenacadie River are two of the largest freshwater systems within the Minas Basin watershed. The Salmon River sub-watershed covers some 690 km^2 (Hennigar, 1968), or approximately 8% of the Minas Basin watershed land mass. ATPEMC (1969) and Peters (1974) have shown that the mean discharge from the Salmon River varied between 8.8 m^3 per second and 13.9 m^3 per second between 1968 and 1972. Amirault et al (1989) reported a maximum monthly mean of 31.5 m^3 per second as occurring in March 1979 for the ten-year period of 1977 to 1987. Maximum daily discharges exceeding 55 m^3 per second were observed during the months of March and April of the same period. In the Shubenacadie River system a similar monthly maximum of 33.3 m^3 per second was reported for the month of April over the years 1974 to

1987. The annual low monthly discharge for both rivers occurs in August or September when approximately 3 m^3 per second flows from each of these two rivers (Amirault et al, 1989).

Freshwater systems and analysis of their chemistry is not a focus for this report. However, Yeats (Yeats and Westhead, 2007) has analysed metals from many of the rivers that enter the Minas Basin as part of his chemical evaluation of the marine waters. Both dissolved and particulate metals were analysed from samples collected from 17 rivers from all sides of the Minas Basin watershed. The results of this seasonal analysis are categorized based on rivers coming from the Cobequid Highlands area to the north of the Minas Basin and those rivers that flow from geological areas on the south side of the basin (see Table 8.1). Geographic differences appear to exist for such parameters as suspended particulate matter (SPM) and particulate copper. Low pH, which affects many Nova Scotian rivers as a result of acid precipitation, has not had a significant impact on rivers entering the Minas Basin, and most have maintained a pH of above 6.0 (Amirault et al, 1989).

Table 8.1 *Sampled metal concentrations from 17 rivers entering the Minas Basin collected in 2003: Mean and standard deviation (bracketed) are given for each measure*

Dissolved or Particulate Metal	**North Shore Minas Basin**		**South Shore Minas Basin**		**Canadian Water Quality Guidelines for the Protection of Aquatic Life***
	May (n = 10)	October (n = 10)	May (n= 7)	October (n = 10)	
SPM (mg/l)	0.74 (0.42)	1.59 (1.45)	6.78 (4.62)	37.4 (42.6)	–
Cd_d (µg/l)	0.016 (0.005)	0.016 (0.010)	0.018 (0.008)	0.011 (0.005)	0.017
Cu_d (µg/l)	0.39 (0.07)	0.33 (0.10)	0.56 (0.24)	0.41 (0.18)	2–4
Fe_d (µg/l)	44 (19)	120 (52)	158 (60)	170 (52)	300
Pb_d (µg/l)	0.07 (0.01)	0.13 (0.05)	0.11 (0.04)	0.18 (0.07)	1–7
Mn_d (µg/l)	7.4 (8.1)	10.1 (8.3)	50.8 (21.5)	80.1 (51.5)	–
Ni_d (µg/l)	0.31 (0.21)	0.32 (0.21)	0.49 (0.29)	0.41 (0.25)	25–150
Zn_d (µg/l)	1.6 (0.5)	2.9 (0.8)	2.2 (0.7)	4.3 (2.6)	30
As_p (mg/kg)	18 (9)	15 (10)	14 (6)	19 (14)	–
Cd_p (mg/kg)	0.82 (0.63)	0.73 (0.40)	0.34 (0.20)	0.27 (0.28)	–
Cu_p (mg/kg)	61 (17)	63 (17)	30 (11)	30 (7)	–
Pb_p (mg/kg)	54 (19)	49 (20)	31 (12)	30 (7)	–
Mn_p (mg/kg)	1780 (788)	2580 (1250)	764 (323)	1660 (980)	–
Mo_p (mg/kg)	2.4 (1.4)	2.5 (1.0)	1.4 (0.7)	0.9 (0.4)	–
Ni_p (mg/kg)	33 (12)	20 (9)	26 (15)	26 (11)	–
Zn_p (mg/kg)	449 (335)	177 (43)	405 (312)	134 (48)	–

Notes:
XX_d = dissolved; XX_p = particulate.
* Source is CCME (2002)

Source: Yeats and Westhead (2007)

Fifty-five sites on seven freshwater systems that enter the Minas Basin have been part of a recent temperature study conducted in Nova Scotia (MacMillan et al, 2005). Of those sites, 21 were considered to be cool water sites based on the results of temperature data logging over the warm summer months. Such sites are likely have additional value as summer refuge and rearing areas for temperature-sensitive freshwater fish species such as Brook trout (*Salvelinus fontinalis*). In total, 86% of the Nine Mile River sites and 75% of the Salmon River sites, both of which flow to the Cobequid Bay, were cool water sites with a mean summer temperature of less than 16.5˚C. This is well above the 30.5% of total cool water sites observed for the province of Nova Scotia (MacMillan et al, 2005).

8.2 SEA LEVEL AND TIDES

The Minas Basin was uncovered 10,000 to 14,000 years ago with retreat of ice from the Wisconsinan glaciation. However, it is estimated that the basin did not become macrotidal (tide greater than 4 m) until 4000 to 6000 years ago (Grant, 1970).

The Minas Basin is characterized by a semi-diurnal tidal regime (two high and two low tides approximately every 24 hours) (Dalrymple, 1977). The tides and the resulting tidal currents have been amplifying over the last 6000 years (Amos, 1984). An estimated 3 billion cubic metres of water are carried into (and out of) the Minas Basin with each tide (Atlantic Tidal Power Programming Board, 1969). The incoming tide moves at speeds of up to 14 km per hour (8 knots) past Cape Split in the Minas Channel (BoFEP, 2001).

Due to the funnel shape of the basin, the tidal range increases towards the inland portion of Cobequid Bay (Yeo, 1977). Although the average tide is 11.5 m (McCurdy, 1979), the maximum spring tide range is near 17 m, measured at Burntcoat Head (Knight, 1972). The world record tidal amplitude has been documented at Burntcoat Head, which lies on the southern shore of the Cobequid Bay portion of the Minas Basin watershed. There, high tides are further enhanced by the rotation of the Earth (known as the Coriolis force) to the record amplitude of 16.27 m (BoFEP, 2001). The tidal influence of seawater can even be seen as far as 40 km inland from the mouth of the Shubenacadie River (Dalrymple, 1977).

Although the sea-level variability is dominated by the tide most of us think of as the M2 tide (see Figure 8.1), which creates the over 6 m of amplitude (12 m tides) we see at the head of Minas Basin, other tidal constituents exist as well. Referred to as the N2 and S2 tidal constituents, these smaller movements have not insignificant amplitudes of over 1 m. Other semi-diurnals constituents have amplitudes of order 0.1 m (Dupont et al, 2003). Furthermore, there are extra high tides resulting every 1.5 months, and other significant tidal increases on as much as an 18-year cycle (Desplanque, Mossman, 2000).

The tides move in and out of the Minas Basin with such force that frictional energy losses to the sea bed from the moving water through the Minas Channel have been measured at 50 W/m^2 to 60 W/m^2 (Dupont et al, 2003) It is in this area where currents are the strongest in the whole Minas Basin. Generally, shallower areas experience less energy loss, with the exception of a shallow bar area in Cobequid Bay (see Figure 8.2).

As long ago as 1875, Hind (1875) noted that there was “really no objection to the view that the tides may be locally rising higher than formerly” in the Inner Bay of Fundy. Hind felt that the cause was due to changes in the cross-sectional area of channels entering the upper basins, and did not suggest a general sea-level rise. Global sea level was rising rapidly between the last glacial recession and roughly 6000 years ago. Since then, sea level has been rising at a much slower rate due to the rebound of the land surface in response to the removal of weight from the melted glaciers. The ice covering Nova Scotia decreased in thickness from north to south, so there has been a similar pattern of recoil (Davis and Browne, 1996a). Based on historical data, it is suggested that tides in the Minas Basin have increased about 0.1 m to 0.2 m per century (Desplanque and Mossman, 2000).

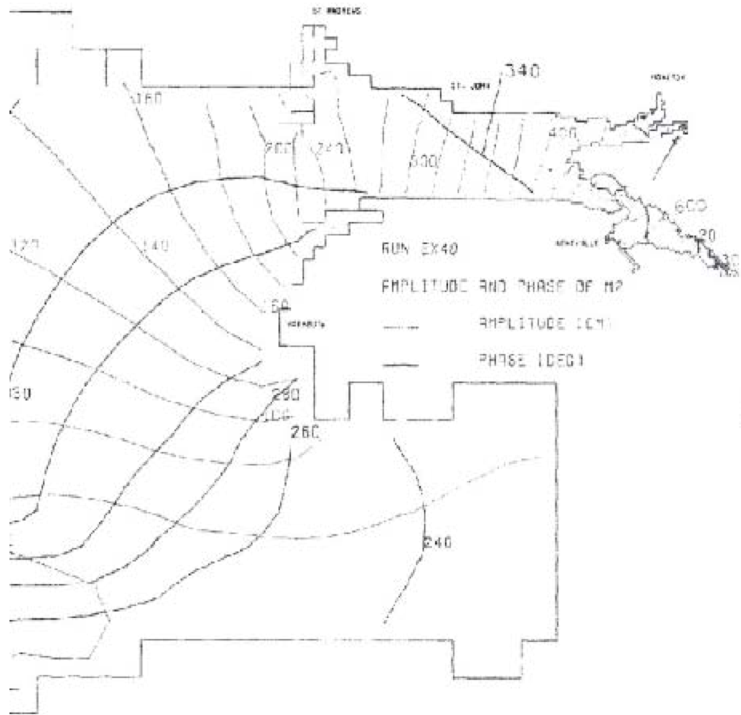


Figure 8.1 *The M2 tidal current from Greenberg (1979): Phases are relative to the time zone +4; the M2 tide can be considered the mean timed in the Bay of Fundy and the Gulf of Maine. The Minas Basin is to the right of the image.*

Source: Greenberg (1984)

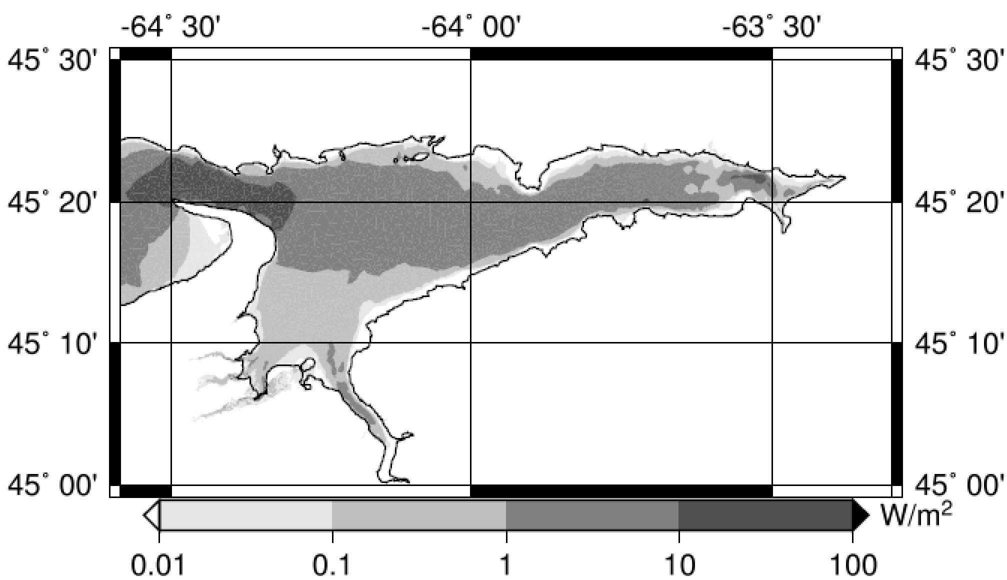


Figure 8.2 *Frictional dissipation, or energy loss due to bottom friction, in the Minas Basin is highest through the Minas Channel, where the tidal currents are strongest*

Source: Dupont et al (2003)

One of the most feasible ways of understanding a physical system is through modelling based on a number of field-verified measurements (see Figure 8.3). A high-resolution model of the Upper Bay of Fundy has been developed to simulate the tides and sea level. This model includes the wetting and drying (inundation) of the extensive tidal flats in Minas Basin, reproducing the dominant M2 tidal harmonic, as well as the total water level in the Minas Basin (Dupont et al, 2003). Overall, the system is capable of simulating the land–water interface with a sea-level error of 8% to 11% in the basin.

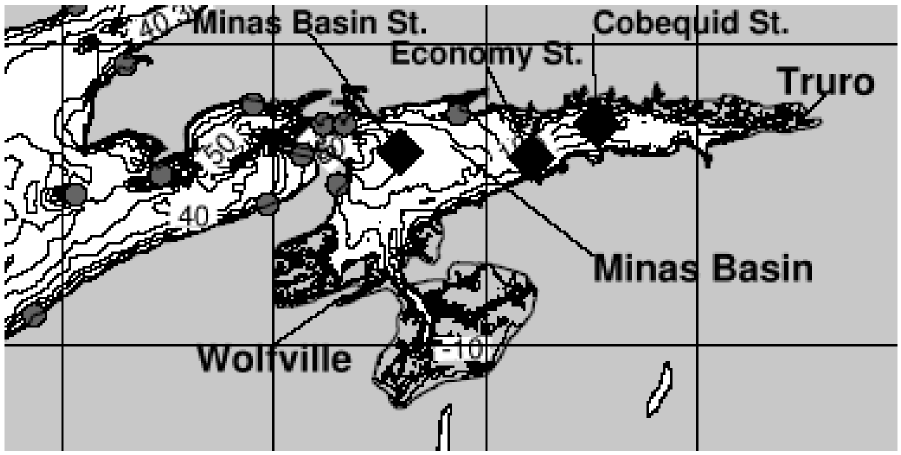


Figure 8.3 *Several tide gauge stations (grey circles) and the time series stations (black diamonds) exist in the Minas Basin: Areas below mean sea level are white and areas above mean sea level, predominantly in the Southern Bight, are grey*

Source: Dupont et al (2003)

In the fall of 1999 and the summer of 2000, another project was initiated during which a wide range of digital remote sensing data were collected for the Minas Basin in order to facilitate modelling within the basin. Polarimetric SAR, Radarsat, Lidar, CASI, Ikonos and Landsat 7 data were all collected and ground referenced. As data modelling is developed, it is expected that the digital database of terrain and cover type information will be used for a variety of future scientific applications, including flood-risk mapping both from storm surge and global sea-level rise; coastal and soil erosion analysis utilizing the terrain slopes and land cover conditions; geological mapping of surficial and bedrock resources onshore and offshore; and habitat analysis of sensitive coastal zone areas utilizing terrain and imaging data (Webster, 2002).

8.3 WATER MASSES AND CURRENTS

Tidal currents in the Minas Channel (see Figures 8.4 and 8.5) are extremely variable and difficult to gage accurately, primarily for the following reason: currents are closely related to tidal elevation (which are themselves unpredictable and highly changeable), but also vary with basin configuration and topography. Nevertheless, Greenberg (1984) provides some general observations. Currents are in the order of 1 m/second around southwest Nova Scotia and over George's Bank. The rest of the Bay of Fundy has lower tidal currents (about 0.5 m/second), and these are even lower in the western corner of the Gulf of Maine. Tidal currents increase from 0.75 m/second to 1 m/second from the mouth of the Bay of Fundy to Cape Chignecto, and continue fairly uniformly at this level in Chignecto Bay. The entrance to the Minas Channel has tidal currents of 1 m/second to 1.5, increasing to as high as 4 m/second in the narrows by Cape Split, then decreasing to 1.5 m/second in the Minas Basin. Depending upon the information source, other top speeds near Cape Split have been reported as 4 m/second by Greenberg (1984), over 4 m per second by DeWolfe (1981) and 6 m/second by Percy (1997).

Within the basin proper, the current weakens to an average strength of 1.5 m/second (Greenberg, 1984). In the open waters of the Minas Basin, no tidal current in excess of 2.6 m/second has been observed (Bay of Fundy Tidal Power Review Board, 1977). Maximum speeds for both ebb and flood range from 0.7 m/second to 1.8 m/second (Dalrymple, 1977), which is enough to keep the waters of the basin vertically mixed year round (Greenberg, 1984). Tidal currents are strongest in the northern half of the Minas Channel, reaching speeds of over 4 m/second (DeWolfe, 1981).

Greenberg (1984) reports that numerical model studies have indicated that the residual circulation at the head of the Bay of Fundy is largely driven by tides (see Godin, 1968; Tee, 1976, 1977; Greenberg, 1983). Strong residuals and four gyres (see Figure 8.4) have been identified around Cape Split and Cape Blomidon. Around Cape Chegnecto, Cape D'Or and Chignecto Bay, model results demonstrate mean current patterns – but Greenberg (1984) states that there are insufficient observations to verify them. Some observations suggest that in parts of Chignecto Bay, the mean current varies in magnitude and direction with depth. In the main part of the Bay of Fundy, some of the currents appear to be tidally generated, while others, such as the principal counter-clockwise gyre in the Lower Bay of Fundy, are driven "baroclinically", largely from the freshwater input of the Saint John River. In Cobequid Bay, Pelletier and McMullen (1972) and Swift and McMullen (1968) suggested a counter-clockwise circulation of water and sediment. Conversely, Dalrymple (1977) suggested clockwise sediment circulation. A weak clockwise eddy was suggested by Tee (1976, 1977) at the tip of Economy Point. Greenberg (1984) states that the models do not adequately respond to the rapid changes in topography at the mouth of the Bay of Fundy, so that their irregular pattern should only be seen as evidence that tides generate strong mean currents in the area. Seasonal wind stress does not appear to play a major role in determining mean circulation patterns.

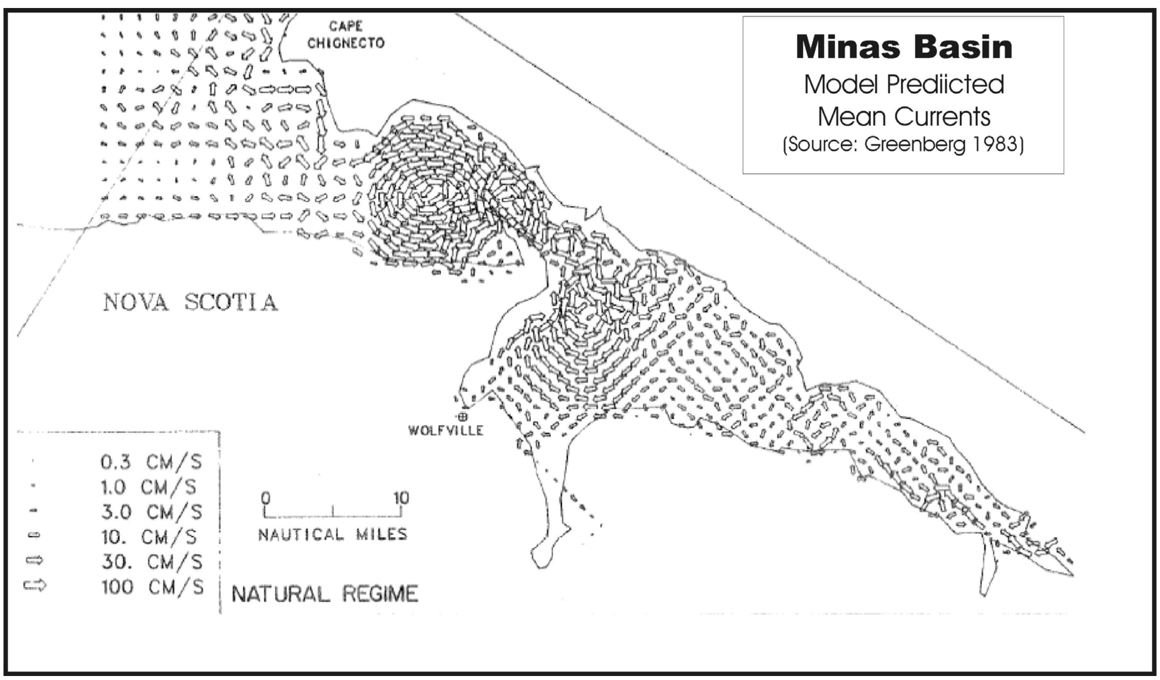


Figure 8.4 *Gyres around Cape Blomidon and Cape Split, and residual currents as modelled by Greenberg (1984)*

Source: Greenberg (1983) cited in Greenberg (1984)

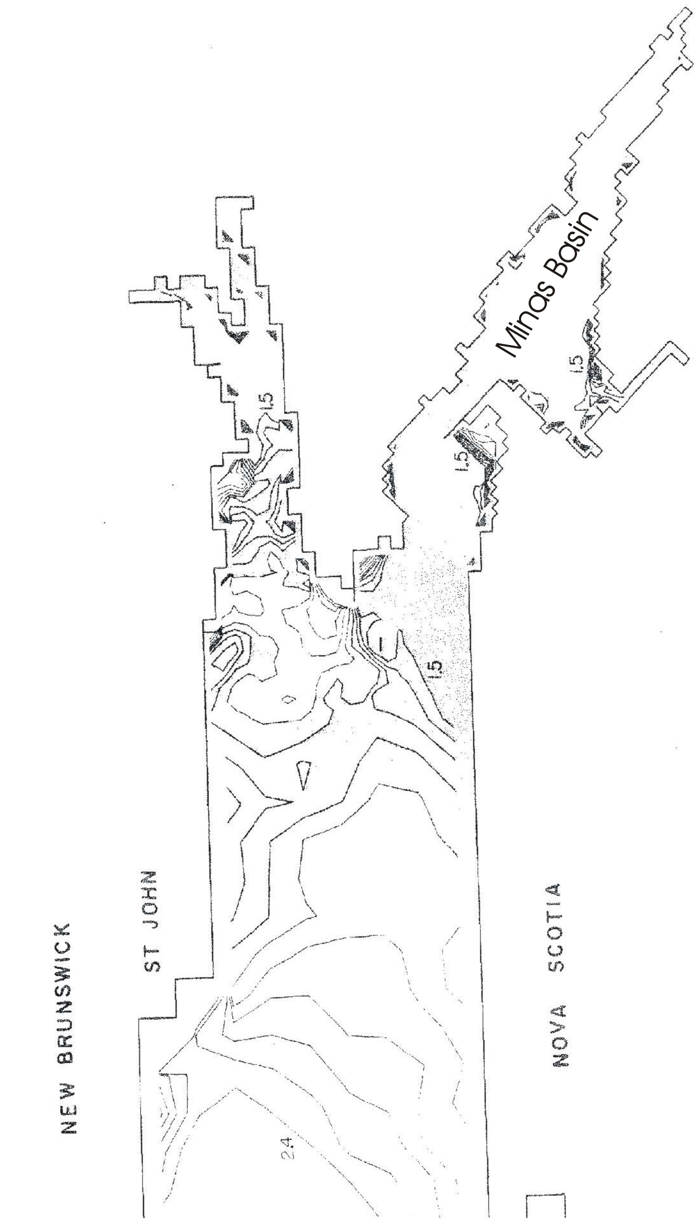
8.4 Stratification, Mixing and Upwelling

Green (1984) explains that although some studies of horizontal mixing within the Bay of Fundy have been conducted, there is still much scope to identify the important mixing, stratification and upwelling processes within the bay, and to quantify the exchange of water. Ketchum and Keen (1953) analysed hydrographic data for the Bay of Fundy and concluded that during times of heavy runoff in the St. John River, flushing time was approximately 76 days. When runoff is less important, flushing is longer. Holloway (1981) analysed salinity and runoff data and found eddy diffusion within the Minas Basin to be related to the tidal friction along the basin. Estimates were in the order of 200 m/second, which is a value that is expected to be found in a typical open coastal area.

Tidal currents cause vertical mixing in the Bay of Fundy. Garrett et al (1978) found that for the summer months below a critical value of the ratio of depth to tidal dissipation, the water is vertically well mixed; above this value, water is frequently stratified. Most of the Bay of Fundy northeast of Saint John is well mixed, as are areas around Grand Manan Island, Brier Island and southwest Nova Scotia (Greenberg, 1984). When summer heating is reduced and meteorological forcing increases during the late fall, winter and early spring, stratification is reduced through the bay (Bailley, 1954; Greenberg, 1984). It is apparent, then, that the tides within the Bay of Fundy are very effective at vertically mixing the bay; but the horizontal exchanges are comparatively low, even with the existing large tidal excursions (Craig, 1976; Greenberg, 1983, 1984). An example of this low horizontal mixing is provided by the locally known “cedar swamp”, a miniature Sargasso Sea, which occurs in the Minas Channel. Although water is carried back and forth by tidal action, the water on the south side of the channel, to the west of Scots Bay, remains relatively stationary. Here, seaweed, wreckage and other debris collect and drifts back and forth until they become waterlogged and sink. Local fishermen tell of a small wrecked vessel that drifted in the area for months (Bousfield and Leim, 1959). This oceanographic phenomenon may have important ecological implications: wastes dumped into the basin may not be flushed out as quickly as one might expect. It may also be critical for some marine species with “planktonic” larval stages that occur in the Minas Basin but not in the Bay of Fundy. Sufficient larvae, for instance, may be kept in the basin long enough to settle to the bottom and maintain the population. Other than this localization, however, no separate water masses exist due to the high currents and resultant mixing.

Within the limits of the Minas Channel and the Minas Basin, the tidal cycle is a fairly simple back-and-forth flow. During ebb tide, water at the mouth of Cobequid Bay (at Economy Point) moves to the mouth of the basin (near Parrsboro). Ketchum and Keen (1953) have estimated a 0.6 exchange ratio at this point (intertidal: high tide volume), which means that 60% of the water mixes with the next seaward segment and does not return on the flood. In Cobequid Bay, the estimated exchange ratio is much higher (76% to 94%), while in the Minas Channel it is much lower (23% to 39%). However, Bousfield and Leim (1959) believed that virtually all of the same water moved on the ebb tide returned each tidal cycle, and that the small amount of freshwater resulted in a limited net seaward flow from the Minas Basin and Minas Channel into the Bay of Fundy proper. This would allow for particular endemic populations in the Southern Bight and Cobequid Bay to maintain substantial populations by allowing developing larvae to remain in the Minas Basin until they complete their planktonic development (Bousfield and Leim, 1959). Today, it is still not known exactly how much water is exchanged per tide or what volume of water leaves and enters the basin per tide, and figures vary widely. Drift bottles dropped outside the mouth of the Bay of Fundy reach the Minas Channel in 106 days (Jermolajev, 1958). ATPEMC estimated the amount of water entering and leaving the Minas Basin every half tidal cycle to be 2.94×10^9 m^3, greatly reducing Godin’s (1968) earlier estimate of 8.81×10^9 m^3.

Figure 8.5 *Contours of the mixing parameter log_{10} (depth/dissipation) for the Bay of Fundy, including the Minas Basin*
Source: Greenberg (1984)



8.5 Waves and Turbulence

Wave height and wave period is increased with duration, fetch and wind strength (Hasselmann et al, 1973). Fetch is the unobstructed distance over which wind may blow and therefore relates to the size and frequency of waves that are formed. Wave fetch is typically less than 50 km in the very sheltered Minas Basin, although areas of the outer Minas Channel that are exposed to the Bay of Fundy can have fetch of up to 100 km (Fisheries and Environment Canada, 1977) and are prone to larger wave formation.

Amos and Joice (1977) showed that lower wave energy levels are found in the Minas Basin than in the Outer Bay of Fundy, even though prevailing south-westerly winds align with the long axis of the basin. This is likely due to the barrier effect of the Cape Blomidon–Cape Split peninsula (Dalrymple, 1977). Studies by the

Atlantic Tidal Power Engineering and Management Committee (ATPEMC) (1969) indicated that wave energy is concentrated at the tip of Economy Point and Cape Tenny (which align south-westerly with the Minas Channel and the opening of the Minas Basin to the Bay of Fundy), leaving the waters of Cobequid Bay and the Southern Bight relatively calm, with little wave energy.

In the Minas Basin, significant wave heights exceeded 0.6 m only 10% of the time (Dalrymple, 1977). The same study showed that the larger waves in the Minas Basin have a 4- to 5-second period (time between successive wave crests). This short wavelength suggests locally formed waves over a short fetch. In contrast, the Groundhog Day storm of 1976 produced a 16-second wave period.

In the intertidal zone of the Minas Basin, wave activity on the tidal flats is very important in creating turbid conditions that characterize the Cobequid Bay and Southern Bight. In this zone, which is periodically exposed and covered by tidal waters, waves are critical in resuspending the bottom material and providing vertical fluctuations so that sediments are maintained in suspension (Perry-Giraud, 2005). The suspension of sediments affects the nutrient and chemical character, and significantly affects light penetration into the water column. All of these characteristics, in turn, influence the biological community that is present in the intertidal zone.

8.6 Ice Cover

Ice formation in the Minas Basin serves many functions, particularly in the development and colonization of the vast intertidal mud flats of the Southern Bight and Cobequid Bay. Although there has been some recent study of ice processes in the basin (Dalrymple, 1977; van Proosdij, 2005), evaluation of winter ice by Hind (1875) some 125 years ago gave a perspective that has not significantly changed.

As early as 1875, Hind noted how the large ice blocks in the estuaries influenced the changing structure of the mudflats (Hind, 1875). Hind described how blocks of ice 3 m^2 and 2m thick would freeze to the mudflat during low tide, and after becoming covered by the incoming tide suddenly "spring" from the bottom through the surface waters, ripping sand and mud from the flat. He estimated that 4 kg to 7 kg of tidal mud per cubic metre of ice was being moved. He further noted that in the Avon Estuary of the Southern Bight, when the coldest winter temperatures set in, some blocks of ice reach dimensions of 7 m in length, 7 m in width and over 5 m in thickness, accumulating upwards of 560 m^3 of alternate films of ice and tidal mud. He noted that in some cases the large blocks of ice could freeze together into a larger mass if rained upon during a low tide. This could, in turn, create ice jams in some of the estuaries. He documented that jam duration was in the order of days in the Cornwallis Basin, surviving several tidal cycles. Hind (1875) also wrote of how the jams from the town of Windsor could extend all the way northward out to the village of Hantsport more than 10 km away. He estimated that the amount of tidal mud that could be carried within this ice jam was 93,750 tonnes, obviously having significant influence on the movement and deposition of sediment within the Southern Bight. He suggested that such large jams would, on occasion, influence major river channel changes across the mudflats on the ebbing tide as waters tried to force their way under the ice, scouring new channels.

Since Hind's (1875) observations, we have quantified and categorized some of his findings in a more current scientific manner. Other current measures allow us the opportunity to compare and contrast the dimension of ice block formation in the basin. Ice begins to form in Cobequid Bay in December and grows until the end of February, but can be found as late as April (Yeo, 1977; Davis and Browne). During February, up to 90% of the water surface can be covered by a loose mass of ice blocks and cakes (ATPEMC, 1969).

Dalrymple (1977) categorized three types of ice of mid-winter ice covering intertidal sediments of the Minas Basin:

1. *Ice foot:* this forms a shoreline rampart along high water. The seaward edge is a near vertical wall that varies in height from 1.5 m to 9 m, and a width that varies from 5 m to 30 m (usually inversely

proportional to height). The upper surface, building up to spring tide high-water level, tends to be a chaotic mass of drift ice blocks. Also known as shore-fast ice, it occurs primarily in protected coves in Cobequid Bay.

2. *Drift ice:* these are blocks of ice kept in constant motion by the tides, preventing the formation of one continuous ice sheet (except in localized areas of several daylong onshore winds; Knight and Dalrymple, 1976). Drift ice is often stranded in intertidal areas during low tide, only to be picked up again on the flood tide, as well as any sediment that has attached to the base. Some blocks may be frozen in place for several tidal cycles before breaking loose. Drift ice can significantly dampen wave energy.

3. *Ice crust:* this crust consists of alternate ice and sediment layers (first described by Knight and Dalrymple, 1976). Crusts vary in thickness from 5 cm to 50 cm and can cover hundreds of square metres uninterrupted. Surface sediments trapped underneath are completely immobilized.

More recently, van Proosdij (2005) noted four types of ice on the marsh and flats at the Avon River Causeway in the Southern Bight of the watershed:

1. drift ice – in the lower reaches of the low marsh;
2. shorefast ice – at the spring/neap limit;
3. frozen crust – the surface of intertidal sediments and the low marsh;
4. sheet ice – found in the upper marsh.

The ice block formation in the Minas Basin has been noted to still carry out several of the functions that Hind observed in 1875. Ice blocks, driven by wind and water, are typically several feet thick (Craig, 1976) and their weight excavates channels in the mudflats several metres long and several centimetres deep. These ice blocks often carry sediment (from mud to gravel) and organisms within them, and deposit their contents wherever they lay during thawing temperatures.

In some cases, these ice blocks are refloated at subsequent tides; however, those at the highest elevations usually start to become attached to the marsh vegetation and surface. With milder temperatures observed until mid February, many of these blocks often become fused as their surface layers melt during the day and refreeze during the night. These blocks then accumulate in the highest portions of the marsh or upper reaches of the creek channels, where they, in turn, trap additional ice floes on subsequent tides, creating a form of feedback condition (van Proosdij, 2005).

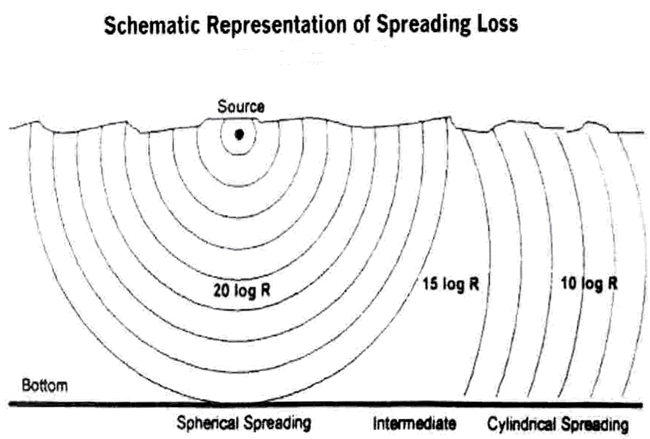
After mid February, mean temperatures have been observed to drop significantly, freezing ice blocks to the marsh and mudflat surface. Large ice blocks in 2005 were measured at 1.5 m in height and 2 m in diameter (van Proosdij, 2005). These were approximately half the size of those measured in the same area by Hind in 1875. Regardless of the size comparison, spring tides with any wave action would still provide the ice blocks the potential to rip out marsh vegetation and their roots (van Proosdij, 2005), and facilitate colonization of new areas.

8.7 UNDERWATER SOUND: SOURCES AND PROPAGATION

There has been no apparent study of sound sources or impacts of noise pollution within the Minas Basin. A few potential sources of noise pollution exist since there are industrial operations within the watershed. Most sources of noise pollution come from vessels. Commercial fishing and some localized shipping traffic are the most probable sources of sound that affect the aquatic species of the Minas Basin. No research has been conducted locally to determine whether any impact exists. However, a review of scientific information on seismic sound impacts indicates that there is no significant or long-term impact to fish or invertebrates from this source, and the impacts to marine mammals are few (DFO, 2004). Given that seismic sounds are likely stronger than anything currently found within the basin, and given the infrequent presence of most marine mammals through much of the watershed, ecological impacts associated with sound disturbances that may currently exist are expected to be minimal. However, new sources of noise pollution and cumulative impacts of noise sources ought to be considered since sound is known to sometimes alter animal behaviour.

Sound from all sources diminishes (attenuates) with distance. Attenuation in water is fairly rapid close to the source, but is more gradual at longer distances because sound levels diminish as a function of the logarithm of the distance from the source. As the distance from the source increases, the amplitude of the sound diminishes and the frequency spectrum broadens. Most of the loss in pressure is the result of spreading in the water. Spreading downwards in the water column is described as spherical spreading, whereas horizontal sound propagation occurs through cylindrical spreading (LGL, 2001, cited in TEC, 2005). As shown in Figure 8.6, for spherical spreading in seawater, the sound loss is 20 log R decibels (dB), where R is the distance from the source in metres. This means that the transmission loss is 6 dB with each doubling of the distance (i.e. pressure decreases by one half with each doubling). For cylindrical spreading, which occurs to the sides, after some amount of spherical and intermediate spreading, the sound attenuation is 10 log R dB, or a loss of 3 dB with each doubling of the distance. In general, spherical spreading occurs out to a distance approximately equal to the water depth. Thus, in deeper marine waters, the spreading loss is spherical, whereas in shallow waters (such as those that exist in the Minas Basin – typically only 25 m at high tide; Bousfield and Leim, 1959, cited in Dyer et al, 2005) spreading loss typically becomes cylindrical more quickly and sound attenuates more slowly. The implication is that loud sounds will not likely dissipate as quickly within the Minas Basin.

Figure 8.6 *Sound attenuation in marine waters as presented by LGL Ltd*



Source: TEC (2005)

Sound speed in the ocean is variable and depends upon the parameters of temperature, salinity and pressure (depth). The speed at which sound will travel through the water increases an average of 4 m/second per C rise in temperature, 1.5 m/second per psu rise in salinity, and 0.0018 m/second per 1 m increase in depth (Jones, 1990). Given that temperature and salinity do not vary significantly with depth in the well-mixed Minas Basin waters, temperature would be expected to be the dominant factor influencing sound speed in the basin where the large exposed mudflats of a sunny afternoon can act as a significant heat source to incoming tidal waters. Surface water temperatures may rise 5 C to 7 C between the Minas Channel and the Southern Bight (Bousfield, 1975). This means that based on water temperature alone, a loud noise would have the potential to spread through the waters of the inner Minas Basin at some 100km/hour faster than in the cooler waters of the Minas Channel. The implications for fish avoidance could be important.

With regard to boat propulsion, it is estimated that 85% of vessel noise results from propeller cavitation. This sound is the result of wasted energy from the perspective of moving a boat through the water (Barlow and Gentry, 2004). The energy of this noise is determined primarily by such propeller characteristics as number of blades, diameter and, most importantly, the propeller tip speed. The ship size and tonnage does not necessarily affect the level of noise other than that larger ships may have more and larger propellers (Leggat et al, 1981). Sound frequency, sound energy and speed of propagation are all variable factors that could influence response of marine biota to introduced noise sources in the aquatic environment.

Table 8.2 *Predicted noise impacts under ideal conditions of transmission vertically in water column or laterally from source*

Distance from source	Shipping dB levels	Fish response
4 m	190	Transient stunning zone for fish and panic reaction
8 m	184	Behavioural change zone avoidance and significant behavioural changes
16 m	172	
32 m	166	
64 m	160	

Source: adapted from TEC (2005)

Ship transport of gypsum through the Minas Basin and the Southern Bight is likely the greatest potential source of noise to the marine environment, although it does not appear to have been quantified or assessed. In the Gulf of St. Lawrence, it was estimated that ship noise may reach up to 190 dB (TEC, 2005), and other studies have estimated large ship noise to produce broadband levels up to 178 dB and discrete tones up to 201 dB (Leggat et al, 1981). This level of sound is high enough to affect behaviour of marine animals (see Table 8.3), but will typically dissipate at approximately 70 m from the source to a level below which there are significant impacts.

Table 8.3 *The effect of noise on fish and marine mammals based on air gun testing as would be used for seismic assessment*

Noise Intensity (dB re 1 uPa)	Effect on fish
160	Behavioural change
192	Transient stunning
220	Internal injuries
220	Egg/larval damage
230–240+	Fish mortality

Source: adapted from Turnpenny and Nedwell (1994)

Herring, which has long inhabited the Minas Basin waters, are known to be more sensitive to (and inclined to avoid) noise than other species (DFO, 1997b). Schwarz and Greer (1984) studied the responses of penned herring to various sounds and noted three kinds of responses, including a startle response and avoidance. 25% of the fish groups habituated to the sound of a large vessel and 75% of the responsive fish groups habituated to the sound of a small boat. These are the two most likely sources of sound pollution in the Minas Basin at this time. Chapman and Hawkins (1969) also noted that fish adjust rapidly to high sound levels in the open sea; fish that are to the side of a boat will avoid the sound of a moving boat by swimming away from it or trying to outrun it. Most schools of fish will not show avoidance if they are not in the path of the vessel. When the vessel passes over fish, some species, in some cases, show sudden escape responses that include lateral avoidance and/or downward movement of the school. Avoidance reactions are quite variable and depend upon species, life history stage, behaviour, time of day, whether the fish have fed recently, and the sound propagation characteristics of the water (Misund, 1997).

Within the Minas Basin, sound levels might be expected to be somewhat different than those shown in Table 8.2 because of the less saline waters than those for which the example has been developed. Certainly, it could be expected that the speed of propagation is likely higher in the Minas Basin relative to open marine waters given the shallow depth and the warmer water temperatures, although this would be slightly offset by the lower salinities in the basin. The shallow nature of the Minas Basin, 20 m to 25 m, would affect sound attenuation as spreading quickly changes from spherical to cylindrical once sound waves meet the basin floor. Therefore, sound effects from shipping traffic or any activity that occurs in the shallower waters of the Minas Basin may be more significant than those experienced in more open marine waters.

9. Chemical Oceanography

9.1 Temperature

The large tides and small freshwater inputs into the Minas Basin result in extensive vertical mixing of the waters, resulting in little difference between surface and bottom water temperatures. Within the Southern Bight, the vertical temperature profile rarely varies by > 1.5˚C from top to bottom of the water column (Daborn and Pennachetti, 1979). The sheltered nature of the basin allows water to warm to over 15 C and occasionally over 20 C in some areas during the summer (Bousfield, 1975). Surface water is warmed during rising tides by absorbing heat from the mud flats exposed to the sun. As seen in Figure 9.1, surface temperatures increase from a low of 12 C in the Minas Channel as one moves south into the Bight (to 22 C) and west into Cobequid Bay (to 20 C).

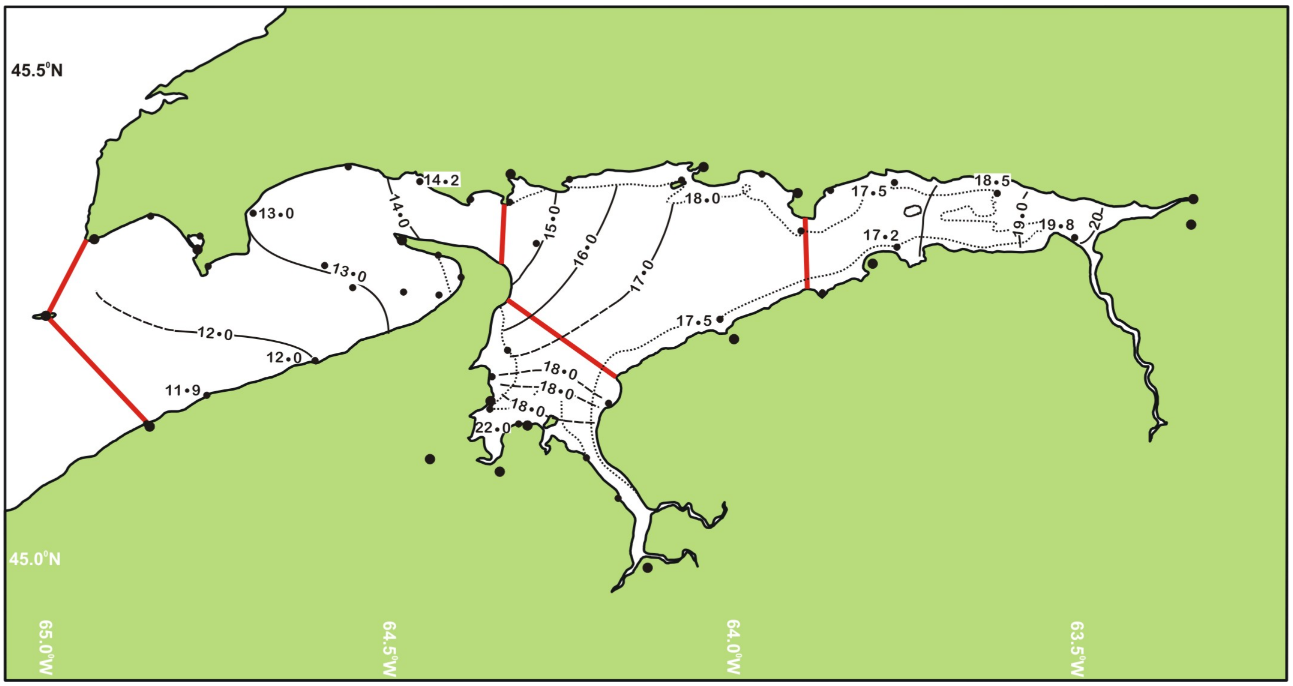


Figure 9.1 *Summer surface temperatures (C) in the Minas Basin at low water from 25 June to 2 August 1958*

Source: map by Lesley Carter in Bousfield and Leim (1959)

Fall temperatures have been measured between 6 C to 12 C, with warmest temperatures observed inshore for much of the year (Simon and Campana, 1987). However, during the winter months, water temperatures of –1.5 C have been recorded (Pennachetti, 1978) and ice is common. Craig (1976) reports that due to the relatively large surface area of the intertidal mudflats, the waters of the Minas Basin tend to be warmer during the summer and colder during the winter than in the Bay of Fundy proper. Daborn and Pennachetti (1979) also noted that the diel temperature change was more significant than the tidal change since the large mudflats of the Southern Bight would warm with the day's sun, transferring heat to the incoming tidal waters. Waters that came in over the flats during the night or early morning hours would be notably cooler than late afternoon flood tide waters.

9.2 Salinity

As a result of the shallow depths, high tidal currents and resulting turbulence, the Minas Basin has very well-mixed waters. An average freshwater input for all Minas Basin rivers of 239 m^3/second (Bousfield and Leim,

1959) is well mixed with an estimated 3 billion cubic metres of water that is carried into (and out of) the Minas Basin with each tide (Atlantic Tidal Power Programming Board, 1969). Therefore, freshwater runoff through several major rivers, primarily the Salmon, Shubenacadie and Avon, results in only a slightly lower salinity than the open ocean as far inland as the head of the Cobequid Bay and the Southern Bight. A slightly stronger salinity gradient can be seen from the head of these bays landward towards river mouths. Salinity generally decreases from 31 parts per thousand (ppt) in the Minas Channel to 24 ppt in Cobequid Bay as one moves eastwards through the Central Minas Basin (see Figure 9.2) (Huntsman and Rice, 1946; Dalrymple, 1977), and < 25 ppt into the Southern Bight (Daborn and Pennachetti, 1979). The Central Basin averages 30 ppt (Dalrymple, 1977; Daborn and Pennachetti, 1979). During the winter when there is less freshwater runoff, salinities tend to be slightly higher and more uniform (Greenberg, 1984).

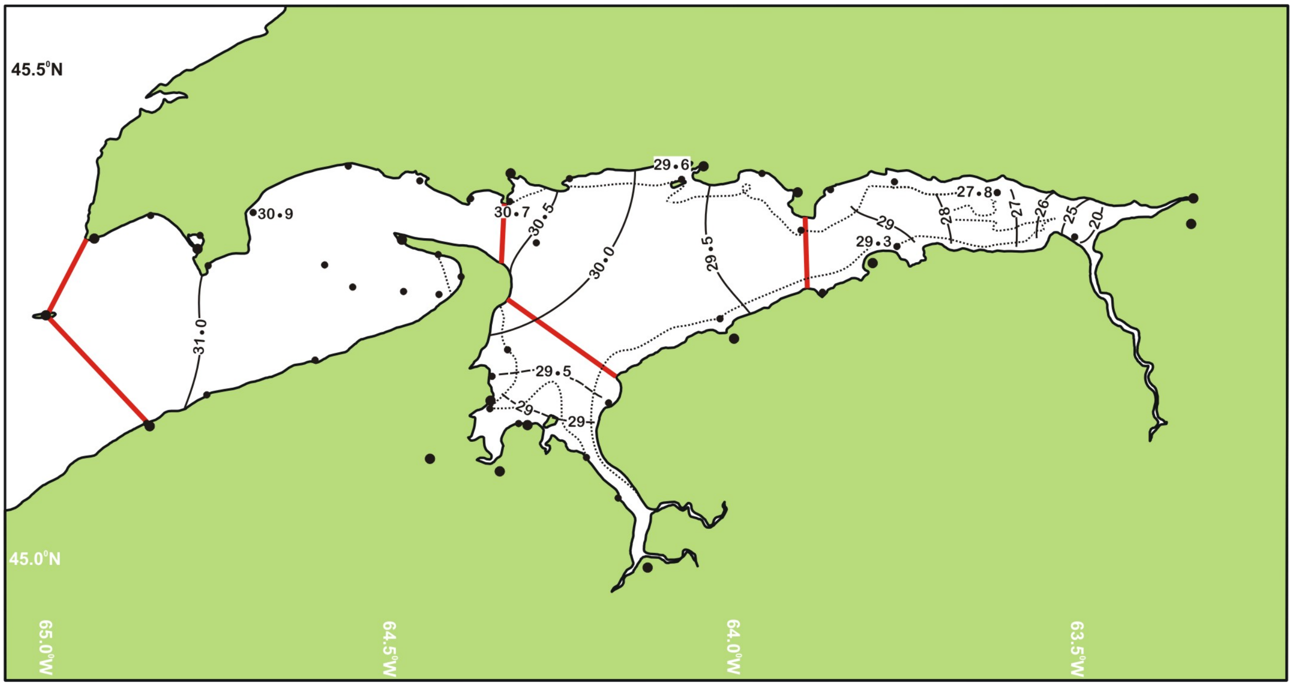


Figure 9.2 *Summer surface salinity (ppt) in the Minas Basin at low water from 25 June 2 August 1958*

Source: map by Lesley Carter in Bousfield and Leim (1959)

Data from a September 2002 sampling cruise of the Bay of Fundy (see Table 9.1) documents the lack of apparent stratification (halocline) within the Minas Basin, and the salinity increase as one moves westward from the Basin towards the Bay of Fundy. This lack of vertical gradient in water chemistry is a defining characteristic of the Minas Basin.

Table 9.1 *Average salinity from seven September 2002 Minas Basin water samples*

Location		Salinity
Minas Basin (1 m depth)	Average	31.11
	sd	1.18
Minas Basin (15–30 m depth)	Average	31.14
	sd	1.19

Note: sd = standard deviation.

Source: Yeats and Westhead (2007)

At the tidal Kingsport marsh in the Southern Bight, which is a distance away from the larger river estuaries of the Minas Basin, but still near the shoreline and smaller river systems, salinity has been shown to generally be near 28 ppt. However, the freshwater inputs have a localized effect through the tidal cycle: salinity was measured to vary from 22.1 ppt to 29.3 ppt during the May to July period of 1979 (Walker et al, 1981).

In short, the larger freshwater river systems that enter Cobequid Bay and the Southern Bight attempt to freshen salinities, whereas the mixing action of marine waters squeezing through the Minas Channel at Cape Split produce higher and more uniform salinities in the outer reaches of the basin. Little vertical gradient in salinity exists within the marine portion of the watershed.

9.3 Dissolved Oxygen: Areas of Hypoxia

Little discussion exists within the literature regarding dissolved oxygen in the coastal waters of the Minas Basin. Generally, authors describe the waters as being well oxygenated. Craig (1976) observed that the anoxic layer (the layer below which there is no oxygen) within the tidal mudflats was found dramatically closer to the surface at 0.5 cm to 1.0 cm deep in the winter months (compared with average depths in the summer ranging 5 cm to 7 cm). This is one of the only mentions of low oxygen conditions within the marine portion of the watershed.

9.4 Suspended Particulate Matter

Suspended particulate matter (SPM) samples collected at seven sites from the Minas Channel to Cobequid Bay in September 2002 showed no gradient with depth (see Table 9.2), supporting the position that the basin is generally well mixed. The averages of approximately 2.6 mg/l were the highest concentrations collected across the Bay of Fundy during the 2002 sampling cruise (Yeats and Westhead, 2007), reflecting the turbidity that arises from the large intertidal mud flats of the Minas Basin. Concentrations of more than 150 mg/l have been observed at the head of Cobequid Bay in the eastern portion of the Minas Basin (Greenberg and Amos, 1981, cited in Stone and Daborn, 1987). In the Central Basin, near Five Islands, SPM is typically less than 10 mg/l, demonstrating the logarithmic decrease of SPM seaward from the inner basins. Similarly, Daborn and Pennachetti (1979) recorded surface suspended sediment loads of less than 10 mg/l at the Central Minas Basin to levels greater than 100 mg/l near the mouth of the Cornwallis River in the Southern Bight. In the near shore areas of the Southern Bight, Walker et al (1981) documented SPM at the Kingsport Marsh to be typically near 24 mg/l during the four hours around high tide in early summer, but dropping to ~8.3 mg/l during slack tide over the late May to July period of 1979 (Walker et al, 1981).

Table 9.2 *Average SPM from seven September 2002 Minas Basin open water samples*

Location		SPM (mg/l)
Minas Basin (1 m depth)	Average	2.59
	Sd	1.99
Minas Basin (15–30 m depth)	Average	2.60
	sd	2.20

Note: sd = standard deviation.

Source: Yeats and Westhead (2007)

Walker et al (1981) noted that although there were variable, but high, SPM concentrations during the flooding and ebbing tide, the lower concentrations measured during the high slack tide were likely due to the settling of larger particulates. These particles would be resuspended and otherwise carried in the water column during the active tidal change.

Directly in the tidal flood channels of the Windsor marsh in the Southern Bight, ambient sediment concentrations of the summer and fall of 2002 ranged up to a very turbid 1700 mg/l in the bore or the wave front of the advancing tide (Daborn et al, 2003). Ambient sediment concentrations in floodwater over the marsh bodies ranged from high values of ~500 mg/l over muddy unvegetated sites to less than 100 mg/l at stations in the middle of the marsh. As accretion builds the mudflat sediments to an elevation that will support vegetation, the vegetation then helps to reduce localized tidal turbulence and causes suspended sediments to settle out during each flood tide. At the Windsor marsh, sediments settle during the slack water at an average of 7.8 mg/cm^2 (± 13.0 mg/cm^2) (Daborn et al, 2003).

9.5 ORGANIC CARBON (DOC/POC)

Phytoplankton production of carbon is often the primary source of new production in marine systems. Uptake of available marine nutrients, the presence of sunlight well into the water column and the resulting photosynthesis process forms the base of the food web. Although the same holds true within the Minas Basin, the balance of these components is somewhat different than is observed in more open marine systems.

The Minas Channel and parts of the Central Minas Basin are somewhat like the open water areas of the Inner Bay of Fundy. These areas have relatively non-turbid water that allows deep light penetration that facilitates photosynthetic processes. However, high turbidity, strong tidal currents and no stratification of the water column typify the Upper Bay of Fundy, of which the Minas Basin is part. These characteristics impact upon "typical" photosynthetic production processes. Regionally, the Minas Basin provides only a fraction of the total primary production in the entire Bay of Fundy. Brylinsky et al (1997) estimated the whole Upper Bay to contribute only 3.7% to the Bay of Fundy total of 1123.6 tonnes of carbon/year x 10^3. The Minas Basin alone would provide even less (approximately half or less of this amount). However, these more turbid areas still have significant production (up to 44 g of carbon/m^2/year average for all sources in the Cumberland Basin). The majority of this primary production is derived from the macrotidal salt marsh and mudflat areas (Prouse et al, 1984). Table 9.3 documents the balance of production from phytoplankton, salt marsh areas and exposed mudflat areas. Benthic diatoms will form a green brown mat on the mudflats of the basin, and are said to provide half of the primary production, with the remainder almost equally split between phytoplankton and salt marshes (BoFEP, 2001). Contributions from various processes in the Minas Channel are not as well documented.

The low salt marshes that occur in these areas of high tidal amplitude and that are relatively exposed to the ocean tend to export most of their production (i.e. organic matter exporters) (Gordon et al, 1985; Gordon and Cranford, 1994). As a result, Bay of Fundy salt marshes are considered to play a significant role in contributing organic matter to the lower intertidal and offshore food webs (Daborn et al, 2003).

As can be seen in Table 9.3, tidal marshes provide significant carbon production, particularly in the Southern Bight. Examination of dissolved organic carbon (DOC) in the water column of the Kingsport marsh in the Southern Bight, Minas Basin, showed little variance during the tidal cycle, and averaged 1.49 mg carbon/l for the period two hours before and two hours after high tide (Walker et al, 1981). However, 50 to 500 times the DOC has been measured within the interstitial spaces of the sediment relative to the overlying water column revealed (MaKinnon and Walker, 1979, cited by Walker et al, 1981). Particulate organic carbon (POC) in the marsh sediment was as high as 2.5% of the dry weight (MacKinnon and Walker, 1979, cited by Walker et al, 1981). Any tidal resuspension of marsh sediments could be expected to increase POC.

Table 9.3 *Carbon production estimates for the various habitats of the Minas Channel based on volume of each habitat type present: Results suggest that the marsh and microalgae production in the Southern Bight and Cobequid Bay, and the phytoplankton production in the Central Minas Basin, are significant sources within the Minas Basin*

Sub-watershed	Phytoplankton production (g $C/m^2/year$)	Total phytoplankton production (tonnes C/year x 10^3)	Low salt marsh production (g $C/m^2/year$)	Estimated net salt marsh production (tonnes C/year x 10^3)	Benthic microalgae production (g $C/m^2/year$)	Gross benthic microalgae production (tonnes C/year x 10^3)
Cobequid Bay	17	3.6	215	0.3	14	2.4
Central Minas Basin	17	10.3	215	0.2	9	0.8
Southern Bight	15	2.4	215	2.3	45	4.1
Minas Channel*	27	NA	215	NA	14	NA

Notes: * Minas Channel production rate/m^2 are derived from "Inner Bay" estimates by Prouse et al (1984) and area (m^2) of relevant habitat was not calculated specifically for the Minas Channel. Therefore, no total annual production numbers exist.
NA = not available.

Source: Prouse et al (1984)

Daborn et al (2003) showed that there is no correlation between chlorophyll values and the organic matter content of the sediment ($r^2 = -0.38$), suggesting that sediment organics are largely attributable to detritus (dead organic matter) derived from marsh plants. Hamilton et al (2006) measured total nitrogen in the sediments of the Avonport area of the Southern Bight as ranging from 0.09 to 0.14%. This result, combined with very low carbon–nitrogen ratios measured (mean of 6.8), suggests mineralization and rapid decomposition.

The large mudflat areas that exist in the Cobequid Bay and Southern Bight may appear to the untrained eye as barren and unproductive. However, microalgae that grow on the flats make them a very important contributor to carbon production within the Minas Basin. In 1983, Hargrave et al (cited in Prouse, 1984) estimated gross annual production of benthic microalgae in Cobequid Bay to be 26.6 g carbon/m^2. Prouse et al (1984) found values of between 14 and 45 g carbon/m^2 within the inner reaches of the Minas Basin, and suggest that net production would be about 10% less than the gross values shown in Table 9.3. It is estimated that the net above ground production of tidal salt marshes near Kingsport in the Southern Bight have been 215 g carbon/m^2. Over the past several hundred years, large areas of salt marsh has been dyked in the Minas Basin. This has effectively reduced the supply of non-living detritus and also lowered micro-algal production on mudflats as a source of organic matter by the proportion of intertidal area converted to agricultural land (B. Hargrave, DFO, in Wells, 1999). No detailed assessment exists on the magnitude of this change to the ecosystem.

Macrophytes, such as large kelps and seaweeds, do not exist in the turbid mudflat areas that typify much of the Minas Basin. However, shoreline and substrate character changes significantly in parts of the Central Minas Basin and westward through the Minas Channel. In these areas, strong tidal flows help to keep ledges, cliffs and rocky shoreline exposed. Prouse et al (1984) suggest that these rocky intertidal areas which exist in much of the Minas Channel would have an estimated net annual production from seaweeds of 845 g carbon/m^2/year. Compared to the production numbers presented in Table 9.3, this contribution is likely to be very significant to the Minas Basin ecosystem.

9.6 Nutrients: Flux and Budgets

There are virtually no published data on nutrients for the open water areas of the Minas Basin. Some nutrient data does exist for the coastal areas around the more studied marshes at Kingsport and Windsor. In order for phytoplankton to grow abundantly, marine scientists suggest that a nitrogen-to-phosphate ratio of approximately 16:1 is required. This widely used benchmark is called the Redfield ratio.

A study of a tidal marsh in the Southern Bight of the Minas Basin watershed was conducted in 1979 (Walker et al, 1981) in an attempt to determine if nutrient flux at the marsh occurred in conjunction with the tidal cycle. Inorganic nutrients were found to be generally higher during periods of flooding and ebbing tides, and lower during the high slack tide. Comparison of nutrients in the waters within the surface sediments of the marsh to mean concentrations in the overlying water column revealed 10 to 20 times the concentration of primary nutrients (nitrate, silicate and phosphate) within the surface sediment interstitial spaces (Walker et al, 1981). This suggests that the sediments function as a nutrient bank, and tidal resuspension serves as a mechanism to bring those nutrients into the water column. Keizer et al (1989), cited in Wells and Evans (1996) found that in the Cumberland Basin, to the north of the Minas Basin, there was a net import of nutrients to the intertidal mudflats during the early summer and a net export at all other times. These two studies would suggest that the tidal mudflats are likely to be a significant contributor to the production of these basin ecosystems.

Vertical distribution of chlorophyll in the intertidal sediments of the large mudflats indicates that diatoms may live to depths of as much as 15 cm in the mud. However, they can only carry out photosynthesis in the upper few millimetres where light is available (Prouse et al, 1984). Wave activity that creates the high turbidity for which much of the mudflat area of the Minas Basin is known helps to expose diatoms to the available light. Through a measure of chlorophyll production, seasonal maxima and minima of benthic diatom biomass in the Central Minas Basin, Cobequid Bay and Southern Bight occur in September and February/March, respectively (Prouse et al, 1984). It would follow that availability of nutrients in these more sheltered areas of the Minas Basin are greatest just prior to the seasonal maxima (therefore, in the summer). Less can be implied by the seasonal low that occurs in winter as the typically heavy ice cover would add a complicating factor to photosynthesis on the mudflats by restricting sunlight from reaching the mudflat surface.

9.6.1 Nitrate

On the Kingsport tidal salt marsh in the Southern Bight, nitrate concentration becomes undetectable in tidal waters by late July. As a key nutrient for production, its limited availability likely contributes to reduced primary production and the observed drop in chlorophyll *a* also observed by late summer (Walker et al, 1981). Walker et al (1981) suggest that unpublished data show that nutrient concentrations in offshore waters also become low at the same period of time after a period of high productivity during the spring bloom. However, at the same time, nutrient levels in the pore waters of sediments of the tidal marsh remain high. Higher localized nutrients and potential for resuspension through tidal activity likely eases the reduction in primary productivity through the marsh, although a sharp decrease still occurs.

Hamilton et al (2006) measured total nitrogen in the sediments of the Avonport area of the Southern Bight as ranging from 0.09% to 0.14%. Carbon-to-nitrogen ratios were very low, with a mean of 6.8 being measured ,suggesting mineralization and rapid decomposition.

9.6.2 Phosphate

Virtually no phosphate data for the Minas Basin is discussed in the available literature. The only exception is a note by Walker et al (1981) regarding the intertidal Kingsport marsh. Here, phosphate levels were observed to vary through the summer months in an unpredictable manner, with a mean for two hours before to two hours after high tide ranging from 0.5 µM to 1.88 µM, and averaging 1.11µM .

In the US, a number of chemical properties have been sampled, assessed and reported for the entire coastline of the country, including the North Atlantic coastline (NOAA, 1997). There, estuaries have been evaluated for eutrophication (excessive nutrient concentrations and resulting algae growth). A scale has been developed to categorize nutrient loads of nitrogen and phosphorous since they are the most likely to cause excessive plant growth. Table 9.4 identifies indicator categories; however, no available data for the Minas Basin exists to compare with these or any other guidelines.

Table 9.4 *The National Oceanic and Atmospheric Administration has established categories of nutrient enrichment for estuarine eutrophication in the North Atlantic*

Nutrient (maximum dissolved surface concentration)	**High** (mg/l)	**Moderate** (mg/l)	**Low** (mg/l)
Nitrogen	≥ 1.0	≥ 0.1 < 1.0	≥ 0 < 0.1
Phosphorous	≥ 0.1	≥ 0.01 < 0.1	≥ 0 < 0.01

Source: NOAA (1997)

9.6.3 Silicate

In the intertidal Kingsport marsh, silicate levels varied through the summer months with a mean for two hours before to two hours after high tide, ranging from 5.43 µM to 2.25 µM, and averaging 3.65 µM (Walker et al, 1981).

Silicate is a necessary component for diatom (a unicellular marine algae) growth. Although silicate supplies in the waters of the Minas Basin will not affect overall new production by allowing more growth of diatoms, it may affect the abundance of diatoms within the phytoplankton community. The high turbidity and levels of silicate measured by Walker et al (1981) are likely to make ample supply of silicate available for diatom growth. Prouse et al (1984) have documented the dominance of diatom species in the Minas Basin. And benthic diatoms are reported as forming a green brown mat on the mudflats of the basin, providing half of the primary production of the system (BoFEP, 2001).

9.6.4 Chlorophyll *a*

On the Kingsport tidal salt marsh in the Southern Bight, chlorophyll *a* has been observed to drop by late July as nitrate concentrations become undetectable (Walker et al, 1981). The chlorophyll *a* levels varied through the summer months with a mean for two hours before to two hours after high tide, ranging from 0.46 µg/l to 25.17 µg/l, and averaging 15.8 µg/l from late May to mid June. By late June, measures dropped to 2.6 µg/l until late July (Walker et al, 1981). Chlorophyll *a* values for surface samples in Cobequid Bay waters were below detection limits in a study by Strickland and Parsons (1968), and Brylinsky et al (1997) noted that general Upper Bay levels are generally quite low (<1.5 µg/l).

The Minas Basin is generally a well-oxygenated body of water, with moderate to high levels of suspended particulate matter that becomes resuspended as tides move over large intertidal mudflat areas. There is typically little temperature or salinity stratification as the basin remains well mixed, and the estuaries of Cobequid Bay and the Southern Bight quickly give way to near marine salinities in the Central Minas Basin and Minas Channel as the freshwater inputs are relatively small. The basin is relatively unaffected by anthropogenic contaminants; yet some dissolved metals, most notably copper, are elevated.

Sediment concentrations of chlorophyll *a* ranged from 2.3 µg/cm^2 to 18.2 µg/cm^2 (mean 9.8 µg/cm^2) during summer and fall 2002 surveys of the Windsor mudflat (Daborn et al, 2003). The highest concentrations were documented for sites that were unvegetated and bordered tidal channels. These were areas where grazing benthic invertebrates that would feed on chlorophyll *a*-producing phytoplankton were less abundant. Results indicate that the Avon River estuary mudflats, which have largely formed since 1970, are biologically as rich as any previously studied in the Bay of Fundy (Daborn et al, 2003). Chlorophyll *a* levels of 1.6 µg/cm^2 to 3.8 µg/cm^2 in the sediments of an older mudflat of the Southern Bight near the Cornwallis River are less than half the level observed in the newer mudflat (Daborn et al, 1993). A similar range of chlorophyll *a* measures for the Minas Basin has been presented by Prouse et al (1984) (see Table 9.5).

Table 9.5 *Average annual concentration of chlorophyll* a *based on 12 monthly means, within the surface 1cm of sediments of various sample locations collected around the Minas Basin*

Sub-watershed (n = locations sampled)	Upper intertidal chlorophyll *a* (µg.cm^2)	Lower tidal chlorophyll *a* (µg.cm^2)
Cobequid Bay (n = 4)	3.92	2.65
Central Minas Basin (n = 2)	1.85	1.70
Southern Bight (n = 3)	8.20	9.00

Source: Prouse et al (1984)

Daborn et al (2003) showed that there is no correlation between chlorophyll values and the organic matter content of the sediment ($r^2 = -0.38$), suggesting that the latter is largely attributable to detritus (dead organic matter) derived from marsh plants.

9.7 DISSOLVED TRACE METALS AND ORGANIC CONTAMINANTS

During 2002, Westhead (Fisheries and Oceans/Acadia University) collected surface sediment scrapes at 52 intertidal stations for an array of metal concentrations in the Minas Basin. Later that same year a research cruise collected water and sediment samples for various metals: the results were later analysed by staff at the Department of Fisheries and Oceans. The two data sets are reflected in a "traffic light" Marine Environmental Quality (MEQ) assessment for the Minas Basin depicted in Figure 9.3 (Yeats and Westhead, 2007).

These "colour decisions" for various metals at each station were performed by Yeats based on a combination of an estimate of background concentrations of each element and guidelines published by the Canadian Council of Ministers of the Environment (CCME). It is important to note that the various colours identified are not perfect indicators since they only reflect the presence of a heavy metal concentration within the environment and not direct biological effects. However, determining biological effects and linking it to exposure is often a difficult task, and clear guidelines are not readily available. Therefore, based on concentrations, a green dot indicates that levels found were similar to the estimated background levels. A red dot (none shown) would represent levels of probable effects from the CCME guidelines, and a yellow dot indicates levels inbetween these two values (sometimes referred to as a threshold effect level). The results shown in Figure 9.3 are those for which some threshold level exists. Since no red (probable effects) results were incurred, the results indicate that the overall sediment and water contaminant levels in the Minas Basin are low to moderate. The elevated copper (Cu) levels found in intertidal sediments depicted in Figure 9.3b are all on the north shore of the Minas Basin, an area known to have natural Cu enrichment from river sediments (see Table 8.1).

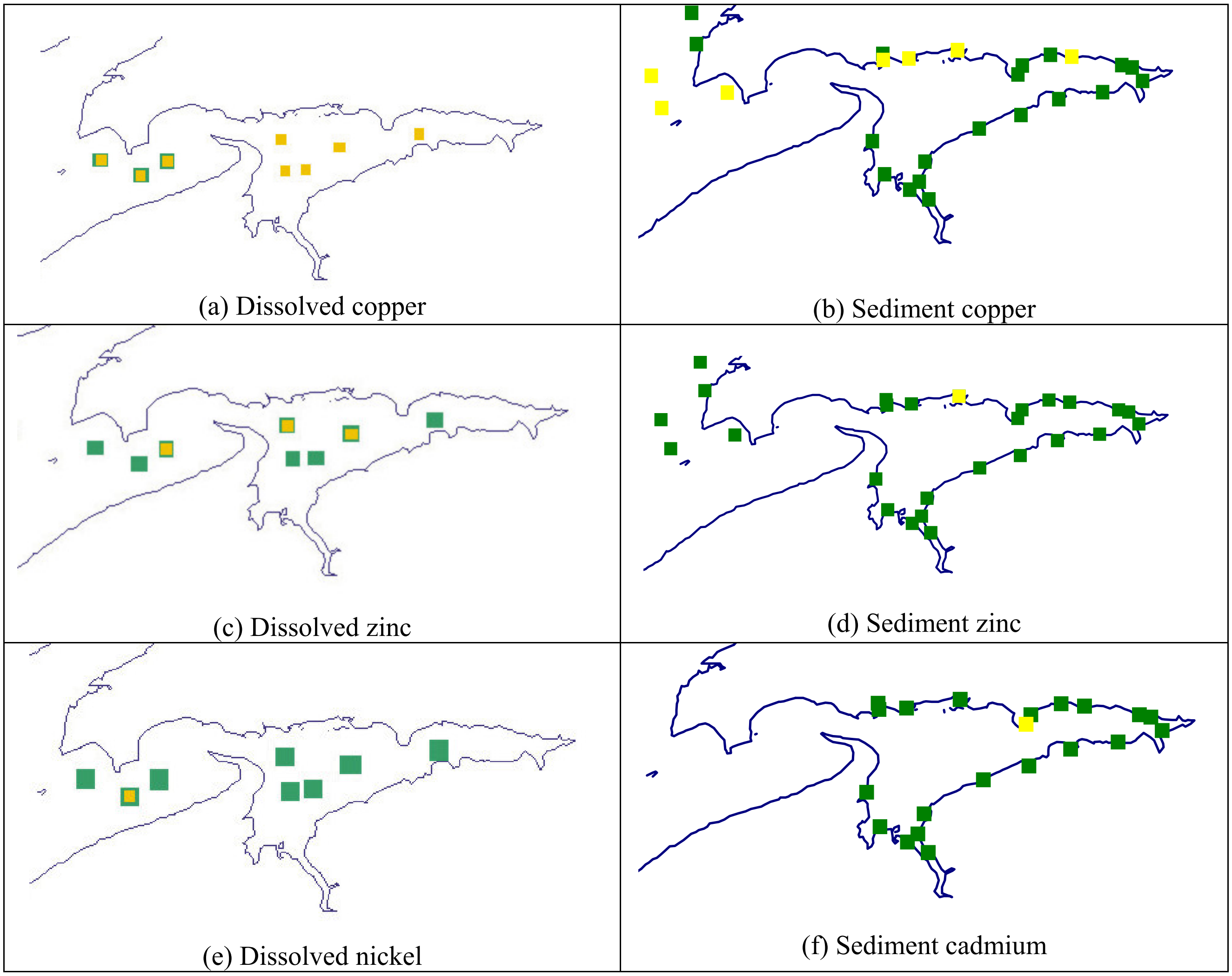


Figure 9.3 *Maps showing concentrations of select contaminants in the Minas Basin sediments and dissolved in water for which some moderate elevated levels were observed in 2002*

Source: unpublished data from Yeats and Westhead (2007); maps created by Phil Yeats, DFO

The results from dissolved and particulate metal collected in water samples from the Minas Basin showed virtually no gradient with depth based on samples taken at the surface (1 m) and depth (15 m to 30 m). This would suggest a well-mixed water column. As shown by the yellow dots in Figure 9.3a, c and d, several dissolved metal concentrations are above threshold effects but below probable effects levels within the Minas Basin (Yeats and Westhead, 2007). In order to interpret these results, it is necessary to examine metal relationships with salinity. Concentrations of heavy metals in coastal waters generally decrease with increasing salinity because the mixing of river water (high metal concentrations) and seawater (low concentrations) is typically the most important process in determining concentrations. The absence of an inverse relationship with salinity would indicate a likely additional source or process unrelated to estuarine mixing. The metal cadmium is the one exception to this general rule, and it will typically increase with increasing salinity. Dissolved copper concentrations observed within the Minas Basin, although high, appear in a linear relationship with salinity and are therefore likely derived from a high concentration natural source (Yeats, pers com, 2007). The relationships between salinity with zinc and nickel do not follow the anticipated pattern, although no potential sources are readily apparent for these metals.

Unlike the other metals, cadmium (Cd) can be expected to be higher in seawater. The concentrations observed are often strongly influenced by biological uptake by various organisms and by regeneration. Since much biological activity takes place near the surface of marine waters (such as photosynthesis and trophic interactions), Cd is more likely to be low in the surface water and increase with depth (Yeats, pers com, 2007). Recent data measurements of dissolved cadmium in the Minas Basin follow the predicted pattern (Yeats and Westhead, 2007).

The main sources for particulate metals in the water column of the Minas Basin and surrounding waters are expected to be from terrestrial sources via rivers and the resuspension of bottom materials.

In 1991, the Gulf of Maine Council on the Marine Environment developed a programme, Gulfwatch, to measure chemical contamination throughout the gulf. The blue mussel (*Mytilus edulis*) is used as an indicator for habitat exposure to organic and inorganic contaminants.

Gulfwatch rotates sampling stations as there is not enough funding to sample every site every year. The most recent data for the Minas Basin is from 1997 for the site at Five Islands on the north side of the Central Minas Basin. In 1997, low levels of silver, lead, zinc, cadmium and copper were measured within the tissues of the collected mussels. Slightly elevated concentrations of chromium, nickel and mercury were found. And, as had been observed during previous sampling in 1993 and 1994, very high iron and aluminium levels were discovered in 1997 (Chase et al, 1998). Dry weight of iron was as high as 1085 µg/g from the Central Minas Basin sample and 975 µg/g for aluminum. Concentrations of these metals tend to positively correlate to suspended sediment levels, and high turbidity is characteristic of much of the Minas Basin. The 1997 results also uncovered low levels of organic contaminants (organochlorine pesticides and DDT).

Based on Environment Canada's National Pollutant Release Inventory (NPRI), several potential land-based point sources of contamination exist around the Minas Basin watershed (see Figure 9.4). These industry businesses must report on a variety of potential contaminants (see Table 9.6).

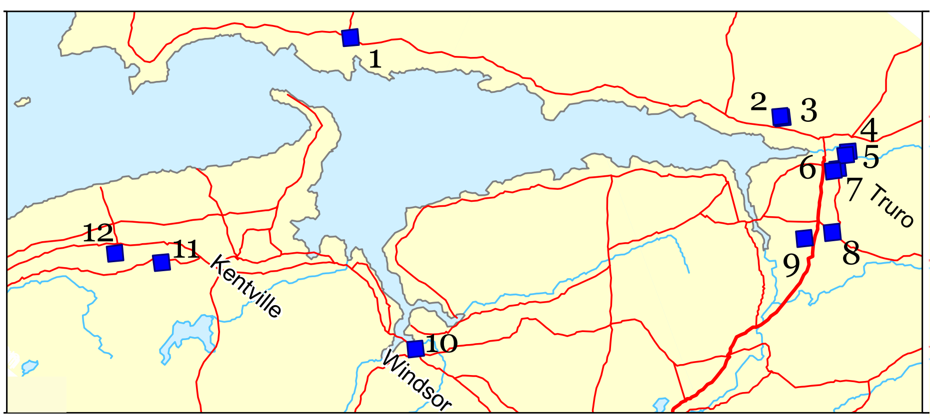


Figure 9.4 *Map of major companies in the Minas Basin area that are legally required to report to Canada's National Pollutant Release Inventory on an annual basis*

Source: map from the NPRI website (http://www.ec.gc.ca/pdb/npri)

A final consideration regarding the potential contamination of sediments and water of the Minas Basin relates to the physical structure and oceanographic processes that exist. The Cobequid Bay is home to the world's highest tidal amplitudes and waters rush through the Minas Channel at great speeds and volumes that are more than 40 times the flow of the entire St. Lawrence River. Yet, there is suggestion that actual exchange of water and flushing of the Minas Basin is minimal. This means that the area could be more susceptible to contaminants and wastes that may accumulate within the basin (BoFEP, 2001). Other studies appear to indirectly demonstrate that there are at least "cells" of water within the Central Minas Basin with which there is little exchange for a period of months (Bradford and Iles, 1993). Yet other studies indicate that the majority of the Minas Basin flushes to 1% retention of passive contaminants in five days (Ketchum and Keen, 1953, cited in Bradford and Iles, 1993). These apparent contradictions in evidence simply mean that the risk of contaminants accumulating within the Minas Basin is not well understood.

9.7.1 Copper

Copper deserves special mention as a contaminant based on the work of Chou et al (2000, 2002, 2003). Despite normal to slightly elevated copper concentrations in marine sediments and waters of the Minas Basin (see Figure 9.3), Chou's research has found extremely elevated copper levels in the digestive glands of lobster from the basin. Recent sample regression analysis of the salinity–dissolved copper relationship (dissolved metal being that readily available for biological uptake) indicates that above normal river concentrations of 3 μg/l to 8 μg/l are likely to exist as a potential source. Yet, initial sampling of 17 rivers that enter the Minas Basin contradicts this prediction (Yeats and Westhead, 2007), with 0.33 μg/l to 0.56 μg/l dissolved copper being observed (see Table 9.7). The highest copper levels found are in lobster digestive glands from Cobequid Bay (856 μg/g wet weight) – compare this to 110 μg/g in the Minas Channel area of the watershed (Chou et al, 2003). In contrast, 0.9 μg/g estimated wet weight of copper was found in tissues of mussels collected from the Five Islands area of the Central Basin in 1997 (Chase et al, 1998), a location inbetween the two lobster samples. Yeats and Chou (2001) have shown that elevated copper concentrations in lobster digestive glands generally co-vary with seawater concentrations; but 2002 dissolved copper concentrations are insufficiently high to explain the lobster observations. The source(s) of copper is still unknown at this point, and research is ongoing.

Table 9.6 *Listing of major companies in the Minas Basin area and information on key pollutants released and transferred annually*

Area (map reference)	Company name	On-site releases	Amount	Method	On-site disposal	Off-site disposal	Amount	Method
Parrsboro (1)	Parrsboro Metal Fabricators Ltd.	Volatile organic compounds	32.12 t	Air				
Debert (2)	Industrial Environmental Services					Ethylene glycol	0.16 t	
Debert (3)	Clean Harbours Canada Inc.					Chromium Ethylene glycol Hexavalent chromium comp. Hydrochloric acid Lead Mercury Methanol Sulphuric acid Tetrachloroethylene	30.175 t 128.32 t 14,294 kg 11.235 t 8045 kg 1090 kg 23.75 t 30.842 t 10.113 t	CS, I/T CS, I/T I/T CS, I/T CS CS, I/T CS, I/T CS, I/T CS
Truro (4)	Stella-Jones Inc.					Anthracene Arsenic Biphenyl Chromium Copper Napthalene	0.011 t 20 kg 0.005 t 0.009 t 0.016 t 0.050 t	CS CS CS CS CS CS
Truro (5)	Stanfield's Limited	Particulates <10 µm Particulates <2.5 µm Sulphur dioxide	1.52 t 0.99 t 29.46 t	Air Air Air				
Truro (6)	Intertape Polymer Group	Isopropyl alcohol Volatile organic compounds	83.8 t 260 t	Air Air				
Truro (7)	Shur Gain (Aquaculture)	Chlorine	33.532 t	Air				
Brookfield (8)	Marwood Ltd.					Arsenic Copper Hexavalent Chromium comp.	67.8 kg 0.048 t 10.2 kg	CS CS CS
Brookfield (9)	Lafarge Canada	Dioxins and furans Hexachlorobenzene	0.085 gTE*	Air Air	Manganese		11.59 t	Landfill

Area (map reference)	Company name	On-site releases	Amount	Method	On-site disposal	Off-site disposal	Amount	Method
		Mercury	50.01 g	Air				
		Carbon monoxide	5.9 kg	Air				
		Nitrogen oxides	32.36 t	Air				
		Total particulates	673.612 t	Air				
		Particulates <10 µm	67.23 t	Air				
		Sulphur dioxide	24.71 t	Air				
			766.051 t					
Windsor (10)	Sepracor Canada Ltd.	Methanol	1.309 t	Air			44.064 t	I/T
Waterville (11)	Michelin Canada Inc.	Carbon monoxide	4.86 t	Air		Cobalt	0.645 t	CS
		Nitrogen oxides	53.48 t	Air		Zinc	8.186 t	CS
		Total particulates	21.17 t	Air				
		Particulates <10 µm	9.176 t	Air				
		Particulates <2.5 µm	3.412 t	Air				
		Sulphur dioxide	198.46 t	Air				
		Volatile organic compounds	447.46 t	Air				
Berwick (12)	Maple Leaf Foods	Particulates <10 µm	2.15 t	Air				
		Particulates <2.5 µm	1.4 t	Air				
		Sulphur dioxide	34.52 t	Air				

Notes: * grams of toxic equivalents; CS = containment landfill; I/T = incineration or thermal treatment prior to final disposal.

Source: data compiled from Environment Canada's National Pollutant Release Inventory website (http://www.ec.gc.ca/pdb/npri)

Table 9.7 *2003 copper concentrations of 17 rivers entering the Minas Basin (mean and standard deviation)*

Dissolved or particulate metal	North Shore Minas Basin		South Shore Minas Basin	
	May (n = 10)	October (n = 10)	May (n = 7)	October (n = 7)
SPM (mg/l)	0.74 (0.42)	1.59 (1.45)	6.78 (4.62)	37.4 (42.6)
Cu_d (µg/l)	0.39 (0.07)	0.33 (0.10)	0.56 (0.24)	0.41 (0.18)
Cu_p (mg/kg)	61 (17)	63 (17)	30 (11)	30 (7)

Notes: XX_d = dissolved; XX_p = particulate.

Source: Yeats and Westhead (2007)

In short, metal concentrations and the relationships to salinity and particle size generally follow the expected patterns for coastal waters and sediments with little impact from heavy metal pollution. However, the dissolved copper concentrations in the Minas Basin are anomalously high. Yeats (pers com, 2007) believes this is likely the result of natural mobilization of particulate Cu, particularly from north shore rivers, into the high energy environment of the Minas Basin, although the potential for industrial sources within the basin also exists from identified (see Table 9.6) and unidentified activities.

10. Oceanographic Information Gaps

Large gaps exist in our understanding of the chemical and physical oceanography of the Minas Basin. Some processes have been explored in reasonable depth for the tidal mudflats and marshes that are part of the defining character of the Minas Basin – in particular, the Southern Bight and Cobequid Bay. However, virtually no current and in-depth study of the system exists for the more open water areas of the Central Minas Basin and Minas Channel. This prevents us from understanding the dynamics of how the turbid shallow inner bays interface with the deeper open waters that connect the basin to the Bay of Fundy. We understand, in part, the importance of the mudflats and marshes to such variables as sedimentation, ice formation, heavy metals and carbon production within the inner bays, but we have a not examined in detail how these functions and processes, characteristics and observations impact upon the outer portion of the Minas Basin and how the flux of such critical components as nutrients and water masses work. Addressing the following information gaps is critical to understanding the Minas Basin as an ecosystem, not only in terms of the oceanographic character, but also the biological systems. It is the oceanographic character that helps define the available habitats for biota. Understanding such elements as the seasonal fluctuations in chemistry and the physical movements of the water will lead to a much better comprehension of why certain biota exist and behave as they do within the Minas Basin.

As noted, a spatially large gap exists regarding the *oceanographic character of the deeper water* areas of the Minas Basin, such as the Minas Channel and portions of the Central Basin. Many of the existing oceanographic studies that have examined the Bay of Fundy have only covered to the entrance of the Minas Channel, not to within the channel and the Central Minas Basin. The near-shore fringe has been somewhat more closely studied, but more from a biological than a truly oceanographic perspective. Oceanographic characteristics, primarily chemistry, have been measured, but not with the intent of understanding the fluxes and budgets. Near-shore studies generally do not use larger vessels; so data typically would not be collected outside of the intertidal zone.

Nowhere within the existing literature reviewed has there been presented discussions, measurements or modeling of *heat exchange and transfer budgets* between the marine waters of the Minas Basin and the surrounding atmosphere. Review of the literature has not revealed any discussion on the heat exchange between the marine waters and atmosphere of the Minas Basin. Nor has there been discussion recorded on the geothermal exchange between the ocean floor and the waters of the basin.

Nutrient data for the open water areas of the Minas Basin are not reported in the literature; what is available for the inner bays is restricted to preliminary investigation of a couple of tidal mudflat areas. As nutrients drive primary production, and primary production is the foundation of the trophic structure, understanding the mechanisms of replenishment and consumption is important for comprehending the broader ecosystem. We understand that there is a relatively large contribution from the tidal marshes; but we do not know how significant this is to the whole ecosystem and, therefore, how significant their protection/restoration may be to the future of the basin. We know virtually nothing of the nutrient flux from, and carbon production in, the Minas Channel and outer Central Minas Basin. The contributions of nutrients and carbon production to the Minas Basin watershed from these areas are not likely to be insignificant, yet they remain a gap in our knowledge.

Assessment of the *metal contamination in sediments and water* of the Minas Basin is relatively limited temporally to recent investigations (Yeats and Westhead, 2007; Chou et al, 2000, 2002), providing most of the known data. Given the elevated levels of some metals being found in the tissues of lobster, more evaluation is necessary to understand the linkages between freshwater systems, the marine systems and the potential biological impacts.

Based on study to date, there appear to be contradictions to the rate of *exchange of waters* between the Minas Basin and the Bay of Fundy, and this presents a critical gap in our knowledge in terms of understanding the ecosystem links to external populations of fauna and nutrient exchange, as well as various other critical relationships. Ketchum and Keen (1953) calculated the exchange ratio to be ~0.60 per tidal cycle, with 1% retention of passive contaminants to be five days. Bradford and Iles (1993) have shown that a localized distribution of larval herring (fish that are primarily passive in their motility and drift in the water until they grow larger) in the Central Minas Basin remains relatively spatially static for a period of at least 60 days. This would suggest little movement and exchange of water. Greenberg (1983) has modeled currents within the Minas Basin and identified four circular gyres around the Minas Channel, with large energy movements of water between the Bay of Fundy and Minas Basin. Finally, BoFEP (2001) points to Bousfield and Leim's (1959) observations that little actual exchange occurs through the Minas Channel, as evidenced by the flotsam that remains in the "cedar swamp" of the channel. A detailed assessment and modeling of the currents and tidal exchange of the Minas Basin would allow us to better interpret the biological observations being made and the chemical isolation of the basin, and to better assess many of the processes and risks that would characterize the basin.

The more temporally broad gap that exists for all areas of the Minas Basin is our understanding of *oceanographic processes that occur over winter*. With the exception of some assessment of ice formation and processes, no formal study has been completed over the winter. This is likely due, in part, to problems associated with ice cover. However, even in the open water areas of the Minas Channel and Central Minas Basin, there is a void of study through the late fall to early spring.

Some gaps have been identified by other authors as necessary to forwarding our understanding of the Minas Basin Ecosystem.

> Gordon and Cranford (1994, cited in Percy et al, 1996) concluded that salt marshes around the Bay of Fundy, including the Minas Basin, have the greatest export potential of organic matter of any salt marshes in the world and warrant further study. Although some study has been conducted on their productivity within the Minas Basin, no study on their export to the rest of the basin has been conducted.

During the 1996 Bay of Fundy Ecosystem Partnership workshop, the attending scientists identified a list of 14 physical and chemical oceanographic questions that require further investigation (Percy and Wells, 1996). Through the review completed to produce this document, it is noted that virtually all of the gaps that were identified remain outstanding for the Minas Basin watershed ten years later.

PART C – BIOLOGICAL SYSTEM

11. FLORA AND FAUNA

A list of marine fauna for the Minas Basin was compiled in 1979 by Bromley (1979), and a provincial listing of mammals includes several marine species (Scott and Hebda, 2004). Both of these lists have been compiled based on the printed works and studies conducted in the province. Others have more recently compiled lists of the variety of fishes in the Minas Basin (Dadswell et al, 1984) and in a particular sub-basin (the Southern Bight) (Isaacman and Beazley, 2004), or even within a particular portion of a sub-basin (the Avon Estuary) (Daborn and Brylinsky, 2004). No broad-scale marine flora or aquatic macrophyte inventories appear in the literature for the Minas Basin.

11.1 PLANKTONIC COMMUNITIES

Planktonic communities are the base of the food web within the Minas Basin as they are in all aquatic environments. The tiny plants (phytoplankton) undertake photosynthesis and are grazed by microscopic aquatic animals (zooplankton). Productivity at this level of the food chain has significant implications for higher-level production and how many levels of food chain may be supported (trophic levels). Low nutrient levels and light tend to be primary limiting factors to planktonic production in aquatic systems.

11.1.1 Phytoplankton and Zooplankton

Like all plants, phytoplankton needs light to carry out photosynthesis and grow. The distance that light reaches into the water column is referred to as the photic zone. In the Central Minas Basin, the photic zone is about 4 m to 8 m (Prouse et al, 1984); but in the very turbid waters of the Southern Bight and Cobequid Bay, the photic zone is reduced to centimetres (Jermolajev, 1958) and thus can be a limiting factor in phytoplankton production. In 1959, Bousfield and Leim suggested that the phytoplankton community is a minor contributor of flora due to turbid waters.

In general, the Minas Basin is the most barren part of the Bay of Fundy in terms of plankton (Huntsman, 1952), primarily because of the high turbidity (Yeo, 1977). Huntsman found that the few zooplankton encountered in the Minas Basin were nearly devoid of oil. This indicates that they were underfed, further suggesting that the phytoplankton densities in the Minas Basin are insufficient as a food base for zooplankton. However, preliminary zooplankton collections by Jermolajev (1958) in the Shubenacadie Estuary during the early 1950s documented large concentrations of microcrustacea that increased in numbers with increasing turbidity. Where photic zone depth was to be measured in centimetres or millimetres, phytoplankton were considered almost totally absent.

However, more recent study shows that although the turbidity severely limits phytoplankton growth, epibenthic diatoms are not affected and remain quite abundant on the intertidal mudflats. Benthic microalgae is likely the most important flora in the Minas Basin (Yeo, 1977), consisting mainly of benthic diatoms (Brylinsky et al, 1997) and carring out significant photosynthesis in the intertidal areas as waters recede and sunlight reaches the surface sediments of the mudflats.

For fish that migrate into the Minas Basin, stomach analyses have often provided mixed answers about the value of the supposed feeding migration to the fish. However, evidence from body condition studies as they leave the areas of the Minas and Cumberland basins seems to support the idea that the Upper Bay has much more to offer than was first surmised. Apparently the production and energy transfers through biota are a more subtle pattern than previously thought (Daborn, 2006).

Jermolajev (1958) found the general diversity of zooplankton followed a gradient of abundance at the mouth of the Bay of Fundy and a steep decline as one travels towards the Upper Bay, including the Minas Basin. Although it was hypothesized that the lack of zooplankton in the inner reaches of the Minas Basin was due to the high turbidity preventing phytoplankton growth, it has since been suggested by Brylinsky et al (1997) that the Minas Basin zooplankton that dominate the area are "very small" and pass through coarse nets commonly used for zooplankton sampling. As a result, zooplankton populations are now thought to be a quite abundant and a major contributor to the nutrition of estuarine fish.

As shown in Table 11.1, it is now understood that phytoplankton, in fact, dominate the upper basins of Cumberland and Minas. Based on 1979 to 1980 surveys of the Cumberland Basin, 127 species of diatoms, 12 species of dinoflagellates and one green algae were identified (Prouse et al, 1984). Samples for sediment chlorophyll *a* content have been used in the Southern Bight to provide an estimate of benthic diatom abundance (Daborn et al, 2003).

Table 11.1 *Diatoms sampled as the dominant summer planktonic species found in the Minas Basin*

Nitzschia seriata	Phytoplankton	*Melosira nummulloides*	Phytoplankton
Coscinodiscus eccentricus	Phytoplankton	*Coscinodiscus concinmus*	Phytoplankton
Coscinodiscus centralis	Phytoplankton	*Biddulphia aurita*	Phytoplankton

Source: unpublished data cited by Prouse et al (1984)

The amount of zooplankton available for fish and the amount of fish both increase from the Minas Basin to Cobequid Bay to the Shubenacadie Estuary. Shubenacadie zooplankton consist of the estuarine species *Acartia tonsa* and *Pseudodiaptomus coronatus* (Huntsman, 1952), which suggests that they could not have come from outer waters and are a self-sustaining population. Tows from Jermolajev (1958) found increasing zooplankton densities from west to east (see Table 11.2).

Table 11.2 *Zooplankton abundances encountered by Jermolajev (1958) during field sampling in 1951*

Area (depth)	Zooplankton abundance*
Minas Channel (up to 57 fathoms)	4700–5700
Southern Bight (up to 13 fathoms)	14,800–25,400
Cobequid Bay (up to 10 fathoms)	50,200–89,900
Shubenacadie Estuary (up to 3 fathoms)	253,800

Note: * Units unspecificed, but thought to be total individuals captured in tow (duration and aperture of town unknown)

Source: adapted from Jermolajev (1958)

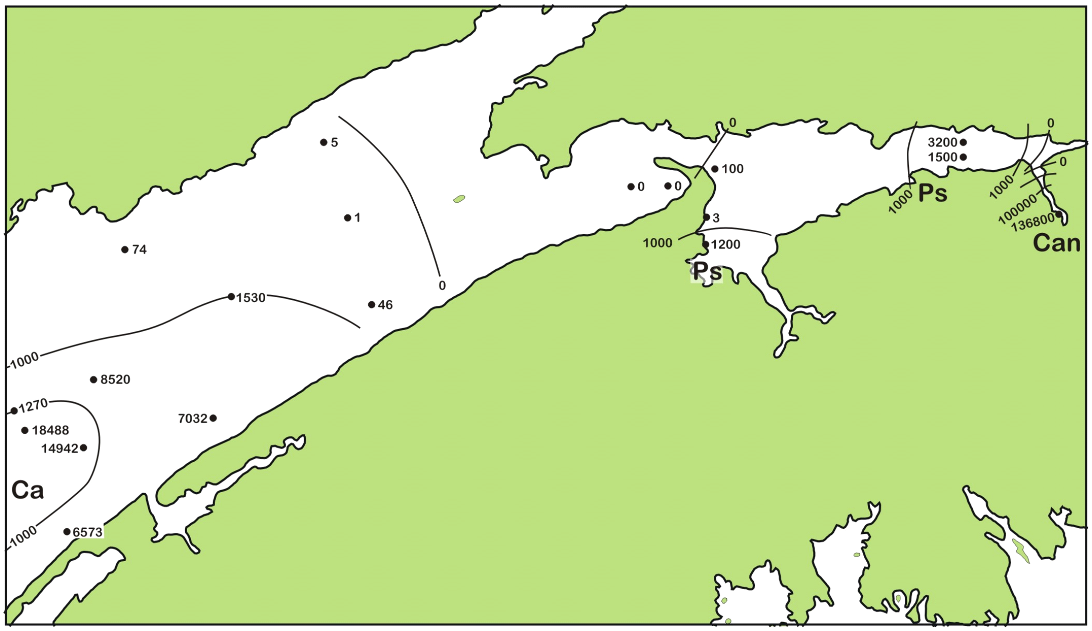


Figure 11.1 *Average numbers (total individuals encountered in tow) of the copepods* Calanus finmarchicus *(Ca),* Pseudodiaptomus coronatus *(Ps) and* Canuella Canadensis *(Can)*

Source: adapted from Jermolajev (1958)

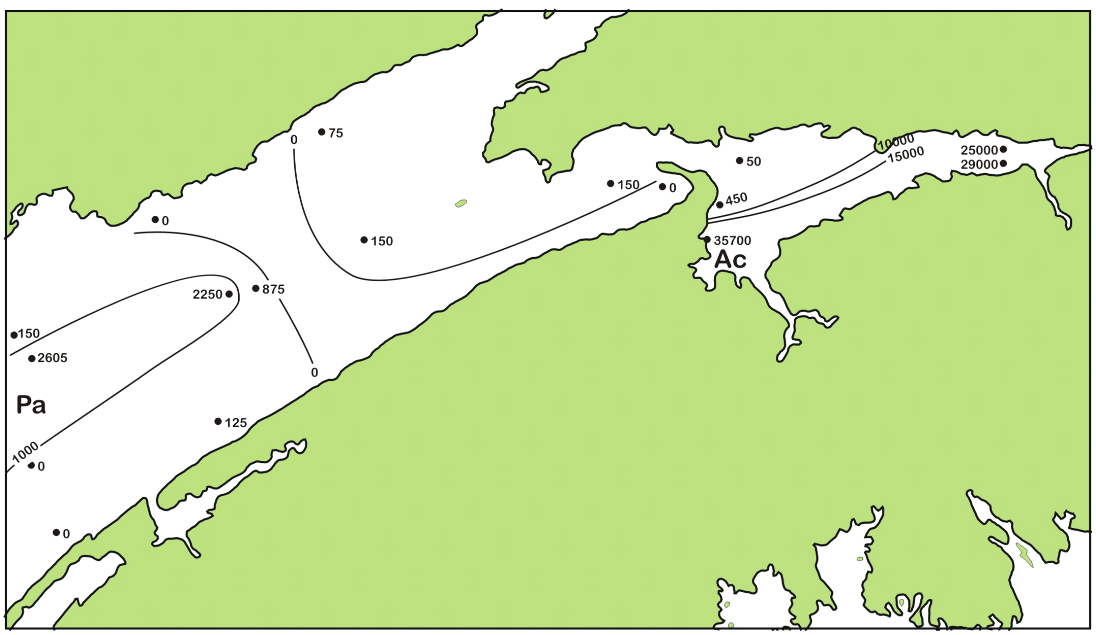


Figure 11.2 *Average numbers (total individuals encountered in tow) of the zooplankton* Parafavella gigantea *(Pa) and* Acartia tonsa *(Ac)*

Source: adapted from Jermolajev (1958)

The most abundant (endemic) species in the Minas Channel, Southern Bight and Minas Basin area are *Acartia tonsa* and *Eurytemora herdmani*. In the Minas Basin, common species are the copepods *Pseudodiaptomus coronatus* and *Centropages hamatus*. Restricted to the Shubenacadie River but extremely abundant is the copepod *Canuella canadensis* (Jermolajev, 1958) (see Figures 11.1 and 11.2).

Copepods and mysids form principal food items for many fish in the Minas Basin. Daborn and Pennachetti (1979) noted that at the entrance to the Southern Bight, the summer zooplankton community was a moderately heterogeneous assemblage of copepods, of which *Eurytemora herdmani* was most abundant. They found that this dominance increased landward into the Southern Bight as the waters became more turbid. Non-quantitative plankton samples around the Windsor mudflat in the Southern Bight indicate that the 2002 plankton community was dominated by copepods (especially *Pseudodiaptomus coronatus*) and the mysid shrimp *Neomysis Americana* (Daborn et al, 2003).

Our knowledge, to date, about the planktonic community of the Minas Basin helps us to define it as a heterotrophic system that is supported by the microbial processing of organic matter derived from the vast intertidal marshes, from various upstream sources and/or from the epipelagic diatoms of the intertidal zone (Hargrave et al, 1983; Prouse et al, 1984; Brylinsky and Daborn, 1987).

11.2 BENTHIC COMMUNITIES

The benthic communities play a significant role in the Minas Basin ecosystem. In many areas of the basin, the bottom is truly the "base" of the food web as high turbidity means that a much more significant amount of the new production occurs with the microalgae that live on the mudflats and with the plants of the intertidal salt marshes. This contrasts somewhat to more open water areas where primary production takes place in the surface waters where the sun's rays reach phytoplankton, allowing them to undertake photosynthesis. Since much primary production takes place on the intertidal mudflats of the Southern Bight and Cobequid Bay, what follows are the first zooplankton that graze on the microscopic plants and the next trophic level of bottom-dwelling invertebrates, some of which attract various fish species to the turbid waters. Although this somewhat unique benthic "model" exists in much of the Minas Basin, portions of the Central Minas Basin and Minas Channel are the interface with the Bay of Fundy and the character of the benthos changes as the waters become deeper and clearer toward the bay.

11.2.1 Macrophytes and Microalgae

Microalgae are the unicellular aquatic plants, and diatoms are the dominant example within the Minas Basin. Macrophytes, or macroalgae, are those plants that are large enough to be visible to the naked eye and in the marine environment include the seaweeds. Seaweeds include all of the red, green and brown algae found in the marine environment.

Within the Bay of Fundy, macroalgae is dominated by native rockweeds, including *Fucus vesiculosus* and *Ascophyllum nodosum* (Yeo, 1977; BoFEP, 2003). This is true within the Minas Basin as well, although there is generally very little macroalgae present due to a lack of suitable rocky and coarse grain substrates. Most appropriate substrates exist in the Minas Channel and outer portions of the Central Minas Basin. Based on the limited amount of rocky intertidal area for the Cobequid Bay, Central Minas Basin and Southern Bight, Prouse et al (1984) identified only trace amounts of seaweeds to be present. However, in areas of the Minas Channel, where appropriate habitat becomes more plentiful, the estimated net annual production from seaweeds is estimated to be 845 g carbon/m^2/year of available habitat. Although detailed calculations do not exist for this area, their contribution to the Minas Basin ecosystem could be significant given the high production estimate.

On the tidal marshes of the Minas Basin, *Spartina* species are used to define the high and low marsh areas. *Spartina patens* is characteristic of the high marsh areas, whereas *Spartina alterniflora* is a low marsh species. *Spartina alterniflora* will rapidly colonize exposed mudflats once these flats have aggraded to the high water level of neap tides, and if there is a seed or rhizome source nearby. One of the most effective means by which colonization occurs on isolated mudflat can be seen at the expanding Windsor mudflat. There, rhizome fragments from *Spartina* spp are frozen in, and torn off in, ice blocks, and drift with tides to new locations, where they are deposited and eventually root when the ice melts (van Proosdij et al, 2006). The large volumes of fragmented material are also seen to accumulate as a "wrack" along the shoreline (van Proosdij, 2005).

Through collecting measurements of *Spartina alterniflora* height on the Windsor mudflat of the Southern Bight, Daborn et al (2003) showed that the plants reached an average of 121 cm (range of 49 cm to 170 cm) by the end of August. These values far exceed other salt marshes that have been studied in the Bay of Fundy. The biomass of these plants averaged 1107 g dry weight/m^2 (range of 637 g dry weight/m^2 to 2189 g dry weight/m^2). This value is roughly two to four times that obtained during studies of other salt marshes in the Minas Basin and Bay of Fundy. The vigorous growth of the Windsor marsh may be related to its high elevation and the ready availability of nutrients. A wastewater outfall on the east side of the marsh is a potential source of additional nutrients (Daborn et al, 2003).

Some other green macroalgae (*Ulva* and *Cladophora*) are found scattered around the Minas Basin, mainly in the intertidal streams or the lower intertidal areas where they can attach to bedrock or large cobbles. Dulse, a species of rhodophyte (red algae), often collected and dried as a snack food, is found in the Central Minas Basin around Parrsboro. However, given the general scarcity of macroalgae within the Minas Basin, it is unlikely that it contributes much to the detrital cycle of the Basin (Yeo, 1977).

Very little discussion on the microalgae of the Minas Basin exists. Yet, intertidal sediments contain abundant benthic diatoms, dominated by the pennate forms of *Navicula* and *Pinnularia* that are described as producing locally significant levels of chlorophyll *a* (Walker et al, 1981; Prouse et al, 1984; Daborn et al, 1993) Blue-green microalgae slicks are also commonly found. This, combined with the active bacterial community, provides the primary food source for most intertidal organisms on the Minas Basin mudflats. The benthic diatoms will form a green brown mat on the mudflats of the basin and it is expected that they may provide half of the primary production of the system, with the remainder almost equally split between phytoplankton and salt marshes (BoFEP, 2001).

11.2.2 Invertebrates

Infauna, those species that live in the sediments on the bottom of the Minas Basin, come in a range of sizes. The larger organisms are referred to as macroinfauna, and meiofauna are those that cannot be seen with the naked eye. The smaller sediment particles (clay/silt) of the mudflats where these organisms are found have more total surface area than larger particles such as sand. This provides more area for attachment and growth of bacteria and other microorganisms that are an important food source for both meiofauna and macrofauna (Green, 1968).

In general, the intertidal flats of the Minas Basin support a high density–low diversity assemblage of benthic invertebrates (Craig and Risk, 1975; Craig, 1976; Yeo, 1977; Westhead, 2002). Wildish et al (1983) identified 126 species and partially identified another 60 of macroinfauna organisms in the sublittoral waters of the Minas Basin. In the shallower intertidal areas, a different community of macroinfauna exists, where species must be able to survive higher turbidity, varied salinities and periods of time without water coverage. The nature of the Minas Basin environment is reflected in the macrobenthos, in that deposit-feeding organisms are dominant. Deposit-feeders feed on materials that drop to the floor of the ocean, not actively searching out their food. In most cases, population densities of the major organisms exceed values found in the literature for other areas (Risk, 1976). Westhead (2002), using a fine mesh (250 µm), found a maximum invertebrate density of just over 190,000/m^2 in the Cobequid Bay at Bass River (comprised mostly of the deposit-feeders *Corophium* and Capitellids). As shown in Figure 11.3, benthic animals of the Minas Basin mudflats are numerically dominated by the amphipod *Corophium volutator* and the polychaete *Nereis diversicolor* (Daborn et al, 2003). Other species include *Macoma balthica* and *Heteromastus filiformis*.

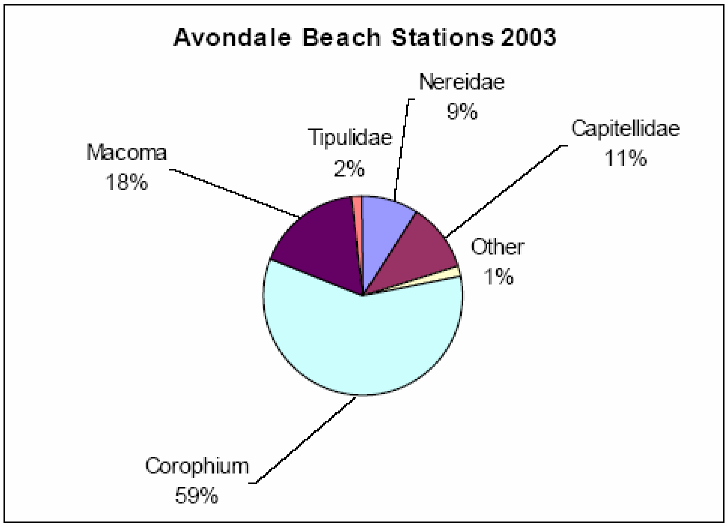


Figure 11.3 *Relative abundance of invertebrates on a mudflat of the Avon River estuary, Southern Bight, Minas Basin*

Source: Daborn and Brylinsky (2004)

Spatially, three surveys of the Windsor mudflats in 2002 showed us that benthic invertebrates are rare in areas of dense *Spartina*, and much more abundant in the unvegetated areas bordering tidal channels. The majority of sampled vegetated areas had less than 1300/m^2 in July, whereas unvegetated areas gave estimates of *Corophium* abundance of 31,000/m^2 (Daborn et al, 2003). *Corophium* numbers on the Newport Bar, a mudflat north of the Windsor mudflat and Avon River causeway, were an average of 17,033/m^2 (range of 13,248/m^2 to 24,224/m^2) (Daborn and Brylinsky, 2004).

It is also important to note another spatial variance within the Minas Basin watershed's invertebrate community, as there is an anomaly to the "high density–low diversity" generalization. Gratto (1978) found that in Scots Bay of the outer Minas Channel, closest to the Bay of Fundy, a high diversity–low density assemblage of intertidal invertebrates existed. Overall densities of invertebrates ranged from 1358/m^2 in May to 1660/m^2 in June (Gratto, 1979). The same study found total invertebrate densities of 17,000/m^2 in the western Minas Basin, one of the high density–low diversity locations. Gratto reasoned that the difference was due to cooler waters and finer substrate in Scots Bay (Gratto, 1979) since it was found that areas of "soft mud" had the lowest diversity (four or five species) and the greatest densities of organisms, with an average of 17,000/m^2. Areas of "firm mud" or sand had higher diversity (nine or ten species) and an average organism abundance of 10,000/m^2 (Gratto, 1978).

Meiobenthos is a term for the smaller benthic organisms ranging in size from 0.1 mm to 0.5 mm. The most common groups of meiofauna in the Minas Basin are harpacticoid copepods and nematode worms. Westhead's survey (2002) of the basin based on 41 stations around the basin found very high numbers of both harpacticoids and nematodes, which are thought to have a significant stabilizing effect on the sediment (Schratzberger, 1998; Varon, 1988). Spatially, harpacticoid copepods were ubiquitous throughout the basin, found at 52% of the stations, but showing a slight preference for the south shore of the basin. Nereid worms are most abundant in Cobequid Bay, whereas Spionid worms were least abundant there (Westhead, 2002). The amphipod *Corophium*, and Capitellid and Nematode worms, showed no clear preferences for specific areas, suggesting that they are generalists in nature. Nematodes were the most common organism encountered, found at 90% of the stations around the Minas Basin. The highest abundance found was 87,744 (at Parrsboro in the Central Minas Basin), with the average being 10,144 (Westhead, 2002).

Hardiness to ice formation is a principal factor in the distribution of intertidal species in the Minas Basin. Largely immobile shell-bound intertidal organisms, such as snails and mussels, can face exposure times of six hours or more in –20°C or lower during the winter months. To survive this, many animals become super cooled and have internal body temperatures within a few tenths of a degree of the air temperature. A study by Kanwisher (1955) revealed that intertidal organisms can have up to 75% of their body water frozen solid at temperatures of –15°C, with ice beginning to form at –3°C. In colder temperatures, it is well known that the activity of invertebrates decreases. Craig (1976) observed that most Minas Basin tidal flat fauna were still *in situ* in the winter months, but that very little feeding or other activities were occurring during exposure at low tide. Mud flat temperatures at a depth of 5 cm ranged from –2 C to –3 C, and the anoxic layer (the layer below which there is no oxygen) was found dramatically closer to the surface at 0.5 cm to 1.0 cm deep (average depths in the summer range from 5 cm to 7 cm). This depth reduction suggests less mixing of, and burrowing within, the sediment. Most of the mudflat fauna, especially *Macoma*, *Corophium* and *Neanthes*, are cold resistant (Kinne, 1963; Crisp, 1964) and have no need to migrate to subtidal regions like some gastropod species (Cranford, 1988).

There are some benthic species of jellyfish, crab, barnacle, planktonic copepod, snail and bivalve that survive in relative isolation in the Minas Basin. These warm water species are removed from their nearest neighboring populations in the southern Gulf of Maine or Gulf of St. Lawrence (BoFEP, 2001). They are likely "relict" species that have survived in the warmer waters of the basin as the deep waters of the Bay of Fundy cooled and isolated them some 4000 years ago.

Crustaceans (*Corophiu* and *Balanus*)

There is one crustacean, in particular, that deserves special mention because of its role in the ecological functions of the Minas Basin. *Corophium* is a small amphipod and a non-specialized feeder, able to deposit feed and filter feed (Meadows, 1966). It occurs in very large numbers around the Minas Basin's large tidal mudflats. *Corophium* live in U-shaped tubes that are 3 cm to 4 cm deep and forage for diatoms at low tide. Highest densities were reported to be found in association with edges of the tidal channel that drain the large mudflats (Risk, 1976) and lower portions of mudflats (Yeo, 1977). Densities, biomass and secondary production of *Corophium* in the Minas Basin are some of the highest found in the literature (Yeo, 1977). A variety of the densities observed is shown in Table 11.3. It is important to note that Gratto (1978) found no *Corophium* in Scots Bay of the outer Minas Channel. Further discussion of *Corophium* can be found under section 5.1.2 "Biogeochemistry: The Ecological Role of Sediments" and section 16.2 "Biological Interactions".

Balanus balanoides, or the common rock barnacle, is an opportunistic settler and where exposed rock is available, surfaces can appear completely white. "Enormous" concentrations of larval stages in the Minas Basin can be found during the spawning season (Bousfield and Leim, 1959). The adult form occurs in localized patches, particularly where bedrock is exposed, such as Burntcoat Head in Cobequid Bay (Westhead, pers observation).

Table 11.3 *Densities of the amphipod* Corophium *as reported by various studies of the Minas Basin:* Corophium *is the primary food source for the migrating shorebirds that stop in the Minas Basin every year*

Researcher (year)	**Average** (per m^2)	**Maximum** (per m^2)	**Mesh size**
Risk et al (1976)	8000–15,000	63,000	
Yeo (1977)	1800– 15,000	63,100, East Noel – Cobequid Bay	0.5 mm
Gratto (1978)	–	75,000, Avonport – Southern Bight	425 m mesh
Turk et al (1980)	–	16,700, Mungo Brook – Cobequid Bay	1 mm mesh
Hamilton et al (2000)	–	~120,000, Avonport – Southern Bight	250 m mesh
Westhead (2002)	36,600	139,120, Kempt Shore – Southern Bight	250 m mesh

Polychaetes

A study by McCurdy (1979) found that polychaetes (marine annelid worms) were the most abundant and diverse group of intertidal invertebrates in Scots Bay, the southwestern portion of the Minas Channel. Approximately 12 Polychaete families are found in the Minas Basin. The most common are shown in Table 11.4, broken down into two "artificial" groups based on mobility – Errantia (free-moving) and Sedentaria (stationary).

Table 11.4 *Common Minas Basin polychaete families (with approximate number of species comprising the group) and their grouping*

Errantia (free moving)	**Sedentaria (stationary)**
Capitellidae (2)	Cirratulidae (2)
Glyceridae (1)	Maldanidae (2)
Nephtyiidae (2)	Sabellidae (1)
Nereidae (1)	Spionidae (6)
Orbiniidae (2)	Arenicolidae (1)
Phyllodocidae (4)	
Syllidae (4)	

In general, Errantia includes worms with an errant (freely moving) lifestyle. Of these, the Glycerids, or bloodworm, as they are known, are the most "popular". In 1950, bloodworm explorations began to provide clam diggers with an additional source of income. Studies showed a substantial stock, and high fecundity, leading scientists to conclude that the regulation of the industry was unnecessary (Hart, 1958). Bloodworms (also known as baitworms) have occurred in relatively high densities in the Southern Bight area of the Minas Basin. As an industry, Fisheries and Oceans first regulated bloodworms in 2002. During 2002 surveys around the Minas Basin, Glycerids were found only in the Southern Bight and in low densities (maximum of 368/m^2) (Westhead, 2002). Glycerids in the Minas Basin generally mature at an adult weight of between 1.5 g and 6 g. Data collected by Fisheries and Oceans as part of the regulated harvest in 2002 and 2003 suggest an average bloodworm density of between 6 and 34 worms per 15 m^2. The highest densities were found at Avonport, with the next highest at Blomidon, both areas of the Southern Bight.

Other errant polychaetes include the Nephtys, which were most common in the Southern Bight, with a maximum density of 23,520/m^2 (Westhead, 2002). Nereids were found throughout the basin and were most common in Cobequid Bay. The maximum density was 6608/m^2 at Cheverie; however, most of these were very small. The largest Nereids were found in Cobequid Bay. The Phyllodocids are much smaller in size than the groups described above and show a clear preference for the Southern Bight area. Densities of over $1000/m^2$ have been found here (Gratto, 1979; Westhead, 2002).

The Capitellids are a distinct group of errant polychaete, occurring in extremely high numbers. Capitellids have long been thought of as indicator organisms for contaminants (PCBs, PAHs, etc.) and nutrient loading from sewage and/or agricultural runoff. Westhead's 2002 survey found Capitellids to be abundant throughout the basin, with the maximum density occurring on the north shore of the Central Minas Basin ($113,808/m^2$) near Parrsboro. The Bass River area of Cobequid Bay also had very high densities at $55,072/m^2$.

The Sedentaria are mostly sessile, tube-dwelling or burrowing polychaetes. These largely immobile worms include the Spionids, a group of tube-building polychaetes found in high densities throughout the Minas Basin. The Spionids are conspicuously less common in Cobequid Bay (Westhead, 2002). Gratto's (1978) survey found densities up to $266,000/m^2$, Risk (1976) found densities as high as $330,000/m^2$, yet Westhead (2002) found densities of only $42,400/m^2$. The frequency and density of another polychaete Maldanid are lower in Cobequid Bay than other areas of the Minas Basin. The maximum recorded population density of *Clymenella* (also known as bamboo worm) within the Minas Basin ranges from $425/m^2$ (Risk, 1976) to $3000/m^2$ (Westhead, 2002). These observations document apparent spatial variance of a number of polychaetes around the Minas Basin; however, explanation as to the distributions has not been explored in detail.

Bivalves (*Mytilus*, *Macoma* and *Mya*)

The bivalve *Macoma balthica* is one of the more common bivalves found on the Windsor mudflat in the Southern Bight (Daborn et al, 2003). Tunnicliffe (1977) found a strong correlation between bacterial density and the density of the bivalve *Macoma* within the Minas Basin. Because smaller sediment particles (clay/silt) have more total surface area than larger particles such as sand, mudflats provide more area for attachment and growth of bacteria and other microorganisms that are an important food for many mudflat infauna (Green, 1968). This relationship is the most apparent explanation for *Macoma* distribution.

The infaunal (living within the sediments) deposit-feeding bivalves such as *Macoma* and *Mya* are quite abundant within the Minas Basin. *Macoma balthica* can occur in densities of over $4200/m^2$ and clearly prefers Cobequid Bay to other areas of the basin (Westhead, 2002). It has adapted the ability to function as a deposit-feeder when tides are low and a filter-feeder when covered in water. A long incurrent siphon moves around the surface of the flat, taking in surface detritus and bacteria. If the detritus is not acceptable, it is blown out as loose coils of pseudofeces. It is estimated that the *Macoma balthica* population within the Minas Basin produces 10,000 m^3 of fecal material a day. This material contributes a significant amount to the fixation of intertidal mud through the pelletization process (Risk, 1977).

Bousfield and Leim (1959) found blue mussels (*mytilus*) to be “remarkably scarce” during their 1950 survey, finding only isolated specimens. This filter-feeding bivalve has difficulty finding hard surfaces for attachment and is likely limited by the availability of phytoplankton due to turbid waters within much of the Minas Basin. However, substantial mussel beds are found in the Parrsboro area of the Central Minas Basin. This location is periodically sampled as part of the Gulfwatch programme, which examines environmental contaminants through evaluation of mussel tissues.

Mya arenaria, also known as the soft-shelled clam, was probably one of the first marine species to be exploited due to its relatively easy access during low tides. The Minas Basin is one of three major clam harvesting areas in the Bay of Fundy, and catch records date from as early as the late 1800s (Fisheries and Oceans Canada, 1997). The north shore of the Central Basin is where most of the clam production and harvesting occurs. *Mya* is the only suspension feeder found in high densities within the Minas Basin. In 2002, a survey found soft shell clams at a density of over 4700/m^2 in Parrsboro (Westhead, 2002). However, individuals were very small (weighing less than 1 mg each). The same survey found an area of adults east of Economy Point in the Cobequid Bay, with abundances reaching 970/m^2. The distribution of *Mya* tends to be sporadic within the basin, showing no clear preference for any one area (Risk, 1977); however, as adult *Mya* resorb most of their food, they are not able to burrow very effectively and can be killed *in situ* by events of high sedimentary deposition (Risk, 1977). This characteristic limits their distribution in the very turbid inner bays of the Minas Basin.

11.2.3 Gastropods

There are many different types of gastropods in the Minas Basin – from slipper limpets to mud snails. Bousfield and Leim (1959) recorded a total of 26 genera in 1958. However, it is likely that not all genera present were captured in this survey. The most common genera found intertidally are *Nassarius* and *Ilyanassa*, both belonging to the family Nassariidae. Westhead (2002) found Nassarids only in the Southern Bight and Hydrobids only on the north shore of the Minas Basin.

The mud snail (*Ilyanassa obsolete*) (see Figure 5.8) has been identified as an interspecific competitor with the amphipod *Corophium,* and is a significant force in controlling sediment dynamics (Hamilton and Diamond, 2000; Hamilton et al, 2006). Recent surveys have documented the change in *Corophium* numbers at several locations, particularly in the Southern Bight. At the same time, it has been noted that sediments appear to have higher water content; and counts of the migratory shorebirds that feed on the *Corophium* have apparently dropped significantly (Shepherd et al 1995). In many of these mudflats, the mud snail is now a very conspicuous member of the fauna for reasons that are unclear (Daborn, 2006).

11.2.4 Lobsters

The Minas Basin falls in Lobster Fishing Area (LFA) 35, which has a split season schedule. The area is open from 15 October to 31 December, and again from 1 April to 31 July. The lobster fishery is concentrated in the rockier areas where faster currents predominate, mainly to the west of the Minas Channel, near Advocate Harbour. Due to the cold water temperatures, Bay of Fundy lobsters have the largest average size at maturity. Of concern is the finding that lobster tissues from the Minas Basin have been found to have extremely elevated levels of copper (Chou et al, 2000). Levels 30 to 100 times that of more industrialized harbours such as Saint John, New Brunswick, occur in Minas lobster (BoFEP, 2004). The highest copper levels found are in lobster digestive glands from the Cobequid Bay (856 µg/g wet weight). Within the Minas Channel, much lower concentrations of 110 µg/g have been found (Chou et al, 2003). Similar high concentrations are not found in other organisms, and although Yeats and Chou (2001) have shown that elevated copper concentrations in lobster digestive glands generally co-vary with seawater concentrations, collected data for dissolved copper in the water column are not high enough to explain the lobster observations.

11.2.5 Benthic and Ground fish

Benthic fish are those that live on or near the bottom of a body of water, in this case the Minas Basin. Ground fish are usually considered to be those benthic species for which there is commercial value, and which comprise or have comprised an active commercial fishery. In this report we have grouped them together for the purposes of presenting the biota of the Minas Basin ecosystem. The commercial interest in some species and the history of fishing effort in the Minas Basin are discussed in detail elsewhere by Willcocks-Musselman (2003).

During 2004, a ground fish survey of the Scots Bay portion of the Minas Channel, and portions of the Central Basin and the Southern Bight, (Dyer et al, 2005) reported catching 21 species of fish. Of those species dogfish (*Squalus acanthias*), Atlantic sturgeon (*Acipenser oxyrhynchus*), winter flounder (*Pseudopleuronectes americanus*) and windowpane flounder (*Scophthalmus aquosus*), and skates (*Raja* spp) were the most abundant and consistently caught over the June to September survey period. A full 85% of the total fish caught during the surveys were winter flounder. Local fishermen in the Minas Basin have commercially harvested winter flounder for many years, taking volunteer measures to ensure a sustainable harvest. During the late 1980s, larger, more powerful boats overfished the area and left a much smaller fishery behind (Percy, 2001). In 1999, landings for winter flounder from Kings County were 2461 tonnes and the Cape Split area of the Minas Channel landed 9668 tonnes in 1996 and 9117 tonnes in 1999.

A total of 35 benthic species have been identified within the Minas Basin, and their historic relative abundances were assessed by Dadswell et al (1984). Dyer et al (2005) and Dadswell et al (1984) provide a preliminary list of the benthic species found in the Minas Basin, as well as an idea of their changes in abundance over time (see Table 11.5). Many of these fish follow the incoming tide to feed on the invertebrates living on and in the tidal mudflats.

Table 11.5 *Relative abundances of Minas Basin fish as reported by various authors*

Species	Common name	Wehrell (2004)*	Gillmurry, Dadswell, Salinas, Scully (1978–1983)**	Bleakney and McAllister (1973)**	Leim (1919–1923)**
Squalus acanthias	Dogfish	A	R	–	R
Raja erinacea	Little skate	A	C	C	C
Raja ocellata	Winter skate	A	–	R	–
Raja laevis	Barndoor skate	–	–	–	C
Acipenser oxyrhynchus	Atlantic sturgeon	C	R	–	R
Gadus morhua	Atlantic cod	R	R	R	C
Microgadus tomcod	Atlantic tomcod	R	A	A	A
Merluccius bilinearis	Silver hake	R	R	R	A
Macrozoarces americanus	Ocean pout	R	–	R	C
Cyclopterus lumpus	Lumpfish	C	–	R	–
Myoxocephalus octodecemspinosus	Longhorn sculpin	R	R	–	R
Myoxocephalus aenaeus	Grubby	R	R	C	–
Myoxocephalus scorpius	Shorthorn sculpin	C	–	R	–
Hemitripterus americanus	Sea raven	C	C	C	R
Pseudopleuronectes americanus	Winter flounder	A	A	A	C
Liopsetta putnami	Smooth flounder	R	A	C	A
Limanda ferruginea	Yellowtail flounder	R	–	–	–
Hippoglossus hippoglossus	Atlantic halibut	R	R	–	–
Scophthalmus aquosus	Windowpane flounder	A	A	C	A

Lophius piscatorius	Monkfish	R	–	–	–
Brevoortia tyrannus	Atlantic menhaden	–	C	R	–
Enchelyopus cimbrius	Fourbeard rockling	–	–	R	–
Urophycis tenuis	White hake	–	C	R	C
Pollachius virens	Pollack	–	R	–	C
Menidia menidia	Atlantic silverside	–	A	A	A
Fundulus heteroclitus	Mummichog	–	C	–	A
Fundulus diaphanous	Banded killifish	–	R	–	A
Syngnathus fuscus	Northern pipefish	–	R	R	R
Liparis atlanticus	Atlantic seasnail	–	C	C	–
Pholis gunnellus	Rock gunnel	–	–	C	–
Lophius americanus	Goosefish	–	–	R	A
Ammodytes americanus	Sandlance	–	–	–	R
Peprilus triacanthus	Butterfish	–	C	–	R

Notes: A = abundant, usually collected in large numbers at all times; C = common and frequently collected in moderate numbers; R = rare, seldom encountered and few individuals.

Source: adapted from *Dyer et al (2005) and **Dadswell et al (1984)

Thirty-nine Atlantic sturgeons were captured during summer 2004 groundfish surveys of the Minas Basin. They averaged 152 cm in length and were estimated to weigh up to a maximum of 100 kg for the largest fish (Dyer et al, 2005). Atlantic sturgeon (*Acipenser oxyrhynchus*) was also noted as common in the Minas Basin in June and July of the early 1980s. Specimens were relatively large at approximately (80 cm to 150 cm) (Dadswell et al, 1984). The importance of the Minas Basin to this species has not been explored through research. However, in other Atlantic Coast locations, this species' primary diet comprises a number of benthic invertebrates that are also common to the Minas Basin (see Table 11.6), particularly polychaete worms (Cameron and Mitchell, 1999). As shown in studies of the Minas Basin, polychaetes are one of the most abundant McCurdy (1979) and widely dispersed group of invertebrates (Gratto, 1979; Westhead, 2002). The Atlantic sturgeon is a bottom-dwelling species, can live to be over 100 years of age, and may not become sexually mature until over 20 years old. These factors make it susceptible to human impact. Although it is not listed under the provincial Species at Risk Act and afforded protection by the act, it has been assessed a General Species Rank of Red in the province, meaning that it is "known to be, or is thought to be, at risk" within the province (NSDNR, 2007).

Of the 41 reported species of fish in the Minas Basin and Cobequid Bay (Bousfield and Leim, 1959; Craig, 1976), 24 feed on benthic invertebrates and produce distinct feeding pits. These include flatfish and tomcod feeding on the amphipod *Corophium* and bivalve *Macoma*, and skates and rays foraging for the shrimp *Crangon* and worms (Risk, 1976). Near-shore trawl surveys in waters of less than 60 m around the Bay of Fundy during the mid 1980s captured 34 species dominated by cod, winter flounder and lobster, with taxa such as Atlantic tomcod and seasnails being restricted to the Inner Bay of Fundy, including the Minas Basin (Simon and Campana, 1987).

Table 11.6 *Stomach contents of 275 Atlantic sturgeon, collected off the New Jersey coast; percentage by weight, seasonal data*

PREY ORGANISM	Spring 1993, 1994	Autumn 1992, 1993
Hydrozoans	**0.1**	**9**
Nematodes	**0.2**	**< 0.1**
Polychaetes	**37.8**	**65.4**
Arthropods	**66**	**20.5**
Isopods	53.9	13.4
Amphipods	< 0.1	0.6
Decapods	12.1	6.2
Stomatopods	0	0.3
Molluscs	**0**	**3**
Bivalves	0	3
Echinoderms	**0**	**1.8**
Fish larvae	**1.6**	**0**

Source: adapted from Cameron and Mitchell (1999)

Using fisheries landings numbers from 1941, Huntsman (1952) estimated fish abundances for the Minas Basin in terms of number of pounds per acre. From this approach he felt that Scots Bay and the southern Minas Channel area to be the most productive (3.5 lbs/acre) in the basin, while the north Minas Channel and north Central Minas Basin were the least productive.

Dadswell et al (1984) noted that during the summer, two fish assemblages existed within the Minas Basin. Included in these assemblages were a number of ground fish and benthic species. In the inner portions of the basin, such as the Southern Bight and Cobequid Bay, an estuarine–mudflat group of juvenile and adult tomcod, smelt, silversides and smooth flounder were found, whereas in the outer reaches a seaward oceanic–sand beach group of juvenile herring, white hake, winter flounder, and adult and juvenile three-spine sticklebacks were present (see Figure 11.4).

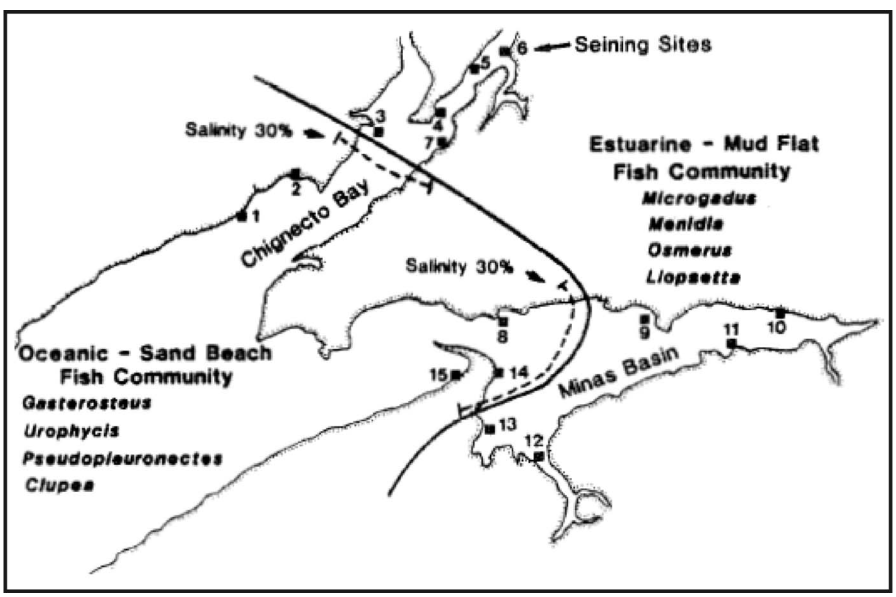


Figure 11.4 *Dadswell et al (1984) provided approximate delineation for fish communities based on catch data from a number of sources collected prior to 1984*

Source: Dadswell et al (1984)

11.3 PELAGIC COMMUNITIES

The large tides, strong currents, and heavy turbidity that exist throughout much of the Minas Basin challenge the pelagic community of the Basin. Yet some fish species have met this challenge of what would appear to be less than ideal conditions, forming unique stocks or populations. Many other fish simply forge through the Minas Basin on their way to and from spawning grounds in the larger river systems of Cobequid Bay and the Southern Bight. Little information exists on the use of the Basin by pelagic fish. Our knowledge is based more on harvest data from individual fisheries than on a biological examination of the lifecycle functions within the Basin for the species present.

11.3.1 Pelagic Fish

Pelagic fish are those that generally live below the low tide mark but that frequent the upper sunlit regions of the water column and that depend upon the food chain that originates with phytoplankton growing in the photic zone. Within the Minas Basin, more than 50 species of fish occur (Dadswell et al, 1984) and more than 40 of those species can be considered fixed residents. However, the majority of species tend to be benthic species. The turbid and turbulent waters of much of the Minas Basin inhibit many marine species that otherwise forage and reproduce in coastal waters. Yet, several pelagic species do live in the more open, less turbid areas of the basin, such as the Minas Channel and the Central Minas Basin, or pass through the turbid regions of Cobequid Bay and the Southern Bight as they migrate to spawning grounds in some of the rivers of the watershed. A list of some of these species and their relative abundance changes over time is shown in Table 11.7.

Table 11.7 *Relative abundances of further Minas Basin fish as reported by various authors*

Species	Common name	Wehrell (2004)*	Gillmurry, Dadswell, Salinas, Scully (1978–1983)**	Bleakney and McAllister (1973)**	Leim (1919–1923)**
Alosa pseudoharengus	Alewife	R	A	–	C
Osmerus mordax	American smelt	R	A	C	A
Morone saxatillis	Striped bass	R	R	–	A
Alosa aesticalis	Blueback herring	–	A	–	C
Alosa sapidissima	American shad	–	A	R	A
Clupea harengus	Atlantic herring	–	C	R	A
Salmo salar	Atlantic salmon	–	R	–	R
Gasterosteus aculeatus	Threespine stickleback	–	C	–	C
Gasterosteus wheatlandi	Blackspotted stickleback	–	C	–	C
Apeltes quadracus	Fourspine stickleback	–	R	–	C
Pungitius pungitius	Ninespine stickleback	–	R	–	R
Menidia menidia	Atlantic silverside	–	A	A	A
Fundulus diaphanous	Banded killifish	–	R	–	A

Notes: A = abundant, usually collected in large numbers at all times; C = common and frequently collected in moderate numbers; R = rare, seldom encountered and few individuals.

Source: adapted from *Dyer et al (2005) and **Dadswell et al (1984)

Some of the more common pelagic species within the Minas Basin are the Atlantic herring, alewife, blueback herring, American shad, smelt, striped bass and Atlantic salmon (Davis and Browne, 1996a).

On sub-watershed scales, as many as 34 marine, diadromous and freshwater species of fish have been identified in the Avon River and estuary of the Southern Bight (Isaacman and Beazley, 2004). During near shore surveys in May and July 2003 of the tidal channels in the Windsor mudflat, only six species were captured (Daborn and Brylinsky, 2004). Five of those six, including alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), striped bass (*Morone saxatilis*), white perch (*Morone americana*) and American eel (*Anguilla rostrata*), would be considered pelagic. Fish surveys of Pesaquid Lake and the lower Avon River were carried out from late May to early October 2003. Although 11 species were captured, the only anadromous species caught above the causeway were alewife, blueback herring and white perch (Daborn and Brylinsky, 2004).

Porbeagle shark (*Lamna nasus*) and spiny dogfish (*Squalus acanthias*) are found in the Minas Basin area. Sharks are typically pelagic and are therefore discussed here. However, the spiny dogfish, which is the most plentiful shark species in the Minas Basin, does spend considerable time roaming the bottom of the Bay of Fundy in search of food and can easily be caught by various ground-fishing methods. A directed fishery has been established for dogfish in the Bay of Fundy, and a number of fishermen use long lines to fish these sharks in the Minas Channel area out of the ports of Halls Harbour and Harbourville between August and October. The dogfish seasonally migrate into the bay in mid June, after their young are born in the warmer waters off of North Carolina or New England during the winter months (CSRL, 2007). The large females that congregate in the Inner Bay of Fundy and Minas Channel begin to move down the bay in September. By November, most of the dogfish have completely left the bay. Dogfish are documented as being as far inland as the Avon Estuary in the Southern Bight of the Minas Basin watershed (Isaacman and Beazley, 2004), although recent surveys have not captured any of this species (Daborn and Brylinsky, 2004).

Diadromous species are those that have both freshwater and marine portions within their lifecycles. Of the pelagic fish within the Minas Basin, the most common are diadromous, migrating through the Minas Basin to the tidal estuaries and freshwater rivers that enter the basin. These include striped bass, herring, Atlantic salmon, gaspereau and shad.

Striped Bass

The striped bass (*Morone Saxatillis*) population within the Bay of Fundy is currently listed by COSEWIC (2007) as a threatened species. The population that spawns in the Shubenacadie River of the Minas Basin is considered the only viable reproducing population left within the bay (Lanteigne, 2006). The primary spawning location is in the brackish waters at the confluence of the Shubenacadie and Stewiacke rivers. Spawning occurs in May and June, with the greatest activity occurring when the water warms to about 18 C. The eggs drift in currents until they hatch one to three days after being fertilized. Within five days of hatching, the egg yolk is exhausted and tiny fish move to near shore river shallows (Douglas et al, 2003). Post-spawned adults then migrate to ocean feeding areas until late autumn. As winter arrives, the adults re-enter estuaries, rivers and lakes, where they stay mostly inactive for the season. Many of the Shubenacadie–Stewiacke striped bass move to Shubenacadie–Grand Lake for the winter; but their range in other river systems is not known (Douglas et al, 2003). Although striped bass have been surveyed at the Avon River Estuary in the Southern Bight as recently as 2003, they were only captured from late June to late July on the seaward side of the causeway. The fish sampled ranged from two to five years of age, and were not engaged in a spawning run (Daborn and Brylinsky, 2004).

The Shubenacadie fish have been shown to be a distinct population, separate from the US and Gulf of St. Lawrence populations (Douglas et al, 2003). US fish appear to migrate into the Minas Basin during the summer month; yet, evidence suggests that the Shubenacadie fish rarely leave the basin during their summer migration to marine waters. In 2003, Douglas et al (2003) estimated over 10,000 mature striped bass in the Shubenacadie–Stewiacke population.

Additional discussion on striped bass can be found in section 12.1 “Species at Risk: COSEWIC”.

<u>Salmon</u>

Historically, the second most important fishery in the Minas Basin was for the Atlantic salmon (*Salmo salar*) that crowded into the many rivers surrounding the basin to spawn. However, on the basis of 1999 data, Inner Bay of Fundy (iBoF) salmon were officially classified as “endangered” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2001. During the ten years between 1989 and 1999, wild anadromous Atlantic salmon (*Salmo salar*) of the entire Inner Bay of Fundy decreased by 90% or more, placing them at high risk of extinction (Amiro, 2003).

Salmon are known to have been in at least 18 rivers of the Minas Basin watershed, with the Shubenacadie/Stewiacke River hosting the most abundant population (Amiro, 2003). The Stewiacke also happens to be the largest system without a barrier to salmon migration within the basin. In general, forestry and agricultural practices, as well as barriers to migration (large and small), are the primary impacts on the former salmon rivers. Acidification, which is a major concern of many Maritime salmon rivers, is not an issue in the Minas Basin due to the underlying geology (Amiro, 2003). However, it is quite widely acknowledged that the decline of salmon in the Minas Basin is related to poor survival at sea (Amiro, 2003), although the cause of this poor sea survival is unknown. In the Shubenacadie/Stewiacke River, as the density of juvenile Atlantic salmon has declined, juvenile brown trout have increased in numbers. It is suggested that this is not a competitive interaction that has facilitated the decline of the salmon, but is more likely an indicator that the freshwater habitat in the Stewiacke is still suitable for juvenile salmon (Amiro, 2003).

Large salmon of 20 to 25 pounds and up to 50 pounds would historically congregate on the southern side of the outer Minas Channel early in the season (Huntsman, 1936). Huntsman and Rice (1946) further noted that after the large numbers of salmon began arriving along the southern shoreline of the Minas Channel between Margaretsville and the Cape Split/Scotts Bay area in May, they were successively followed by congregations of grilse and, finally, out-migrating post-smolts right through until August. Tagging revealed that the mature fish were not only entering the Minas Basin, but that a larger proportion were distributing around the Bay of Fundy to as far as Dipper Harbour, west of Saint John, New Brunswick. The Minas Basin fish demonstrate more local migration by staying largely within the Bay of Fundy, and also reach maturity at an earlier age, depending more frequently upon repeat spawning (Amiro, 1987, cited in Amiro, 2003). Of the salmon stocks within the Minas Basin, only the Gaspereau River has an early run of predominantly two-sea winter fish and few repeat spawners (Amirault et al, 1989). All of the others are a late run dominated by grilse and repeat spawners.

When plentiful, the largest numbers of fish were caught in the Avon and Economy rivers, and in Cobequid Bay (Department of Fisheries and Oceans, 1990). Huntsman (1936) noted that catches in the Shubenacadie and inner Minas Basin were greater in years when there was a mild winter with less ice and spring freshet, but higher in the outer Minas Channel area during cold, hard winters with a large freshet. The general observation has been made that marine-phase salmon occupy the middle and upper layers of the water column (Cairns, 2006).

Additional discussion on Atlantic salmon can be found in Section 12.1 “Species at Risk: COSEWIC”.

Herring (Family Clupeidae)

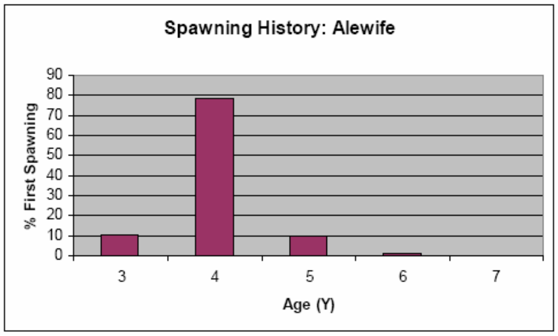
As part of an important local fishery, herring were caught in some Minas Channel weirs as early as the 1800s. It has been quoted that "they deposit such quantities of spawn that it can be shoveled up on the beach" (Perley, 1852). Like the Atlantic salmon, Huntsman and Rice (1946) noted that herring would congregate along the southern shore of the Minas Channel centred near Harbourville.

Although much of the Bay of Fundy and southwestern Nova Scotia herring are fall spawners, those of the Minas Basin are a spring spawning population. Not only is spring spawning unusual for Atlantic herring (*Clupea harengus* L.) within the Bay of Fundy, but unlike other spring spawning populations, the Minas fish spawn in a tidally energetic environment, and they feed intensively during gonad maturation up to and including spawning. This has not been previously documented for Atlantic herring (Bradford and Iles, 1992). These fish tend to spawn in shallower water of the immediate sub-tidal areas down to about 5 m depth on coarse substrate and algae (Stewart and Arnold, 1994). Spawning areas in the Minas Basin are from Scots Bay east through the Minas Channel to the Central Minas Basin area. The high fecundity of the Minas Basin fish is expected to result from increased gonad production, given the fishes' uncharacteristic feeding during gonad maturation (Bradford and Iles, 1992). Larvae are retained in relatively high density clusters for at least 60 days, primarily in the south Central Minas Basin (Bradford and Iles, 1993). The spawning-stock biomass, the smallest of any in the region, is estimated to be about 500 tonnes (Bradford and Iles, 1992). The size is not a point of immediate concern as it has supported a low yield fishery for over 100 years (Perley, 1852).

Gaspereau (Alewife and Blueback Herring)

Both the alewife (*Alosa pseudolarengus*) and the blueback herring (*Alosa aestivalis*) are commonly referred to as "gaspereau" in Atlantic Canada ("river herring" along the Atlantic coast of the US). They look physically very similar, with internal features allowing for clear identification. There was concern that the Minas Basin population was declining as early as the mid 1800s (Perley, 1852) because of such factors as industrial development, over-fishing resulting from lack of enforcement, and tidal restrictions caused by mill dams.

Alewives occur in almost all rivers in the Scotia–Fundy area. Blueback herring are found in fewer rivers and are consistently less abundant where both species co-exist (Jessop, 1999). The gaspereau stock in the Black River–Gaspereau River system of the Southern Bight, Minas Basin, is almost exclusively comprised of alewife, with only a very small number of blueback herring contributing to the fishery (McIntyre et al, 2007). The gaspereau run into the Avon River watershed in the Southern Bight consists of both alewife and blueback herring. Alewives made up the first part of the run beginning in late May, while blueback herring dominated the run in June. Gaspereau are sexually mature around the age of three (Jessop, 1999) although, as shown in Figure 11.5, in some Minas Basin locations, the age of four is more common (Daborn and Brylinsky, 2004). The age of fish migrating into freshwater in the Avon system was typically three to seven years for alewives, and three to six years for blueback herring (Daborn and Brylinsky, 2004). Overall sex ratios were 1.13 females per male for the alewife, and 0.70 females per male for Bluebacks (Daborn and Brylinsky, 2004).



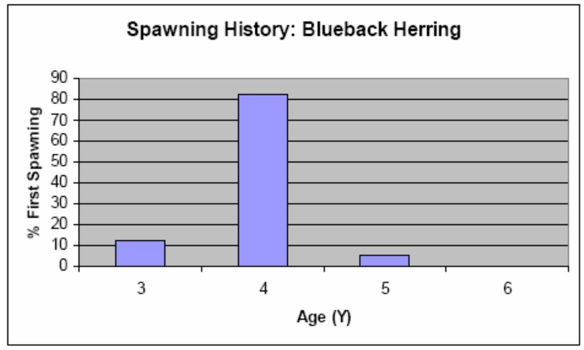


Figure 11.5 *Relative age frequency at first spawning for alewife and blueback herring sampled from the Avon River watershed*

Source: Daborn and Brylinsky (2004)

Alewives of the Minas Basin typically begin their return to freshwater spawning areas in the basin from late April to early May (depending upon area and water temperature). Spawners peak in late May/early June and return to the sea by mid July (Huntsman and Rice, 1946; Jessop, 1999; McIntyre et al, 2007). Blueback herring complete the same cycle, but a few weeks later than the alewives. Overwintering is thought to occur in the central and southern Scotian Shelf and Georges Bank areas (Jessop, 1999).

The anadromous alewife (*Alosa pseudoharengus*) population of the Black River–Gaspereau River, Nova Scotia, currently supports both recreational and commercial fisheries of local importance. Average landings between 1960 and 1995 are just over 200 tonnes for the Gaspereau River (Jessop, 1999). Stock assessment in 2001 found that high exploitation rates approached 80% of the run, and the majority of fish in the spawning run belonged to only two age classes (McIntyre et al, 2007). Between 1964 and 2000, the run averaged 537,000, and peaked at over 1 million fish. A five-year management plan introduced in 2002 saw exploitation rates drop to an average of 57% over the following three years for which reporting is available, but only saw the run achieve the target escapement of 400,000 fish once during that time. This is well below the ~40-year average. Recruitment to the Gaspereau River adult population can occur as early as age three, but most do not mature until ages four and five, with full recruitment to the adult population (and fishery) at age six (McIntyre et al, 2007).

Within the Minas Basin, the two dominant species of alewives (*Alosa pseudoharengus and A. aestivalis*) prey on substantially different organisms, even though there is a large overlap in the temporal presence of the two within the basin (Stone and Daborn, 1987). Alewives were found to feed on benthic amphipods, mysids and crangonids, whereas the blueback herring centred their consumption on the microzooplankters, calanoid copepods, cypris larvae and molluscan veligers. This difference in targetted prey may be the result of space limitation created by the high tides of Minas Basin. The theory is that the two species can largely avoid competitive interaction by foraging at different times of the tidal cycle (Stone and Daborn, 1987).

Shad (Alosa sapidissima)

American shad were at one time the dominant fishery in the Minas Basin (BoFEP, 2001). Shad began their precipitous decline in the Minas Basin around 1880. During 1921, the catch was about one 200th of the maximum in 1879. Between 1984 and 2000 in the Minas Basin, landings have fluctuated between a minimum of 8 tonnes and a maximum of 90 tonnes, with the average being 40 tonnes (Chaput and Bradford, 2003). These levels remain but a fraction of the historic harvest. Due to the spawning cycle, landings peak in the Minas Basin in May.

Similar to salmon born in eastern Canadian rivers migrating to Greenland for the summer, American shad from eastern US rivers migrate north to the Bay of Fundy. In clear ocean water, shad find their preferred level of light intensity at depths of 100 m to 200 m. Since they are in deep water they are seldom encountered. In the Upper Bay of Fundy, however, the turbidity of the water shifts the preferred light intensity zone up to depths less than 10 m (Dadswell et al, 1983).

The migration of American shad in the Bay of Fundy has been shown to be complex. During late May and early June, ocean-feeding shad arrive in large numbers to migrate around the bay in a counter-clockwise direction following the tidal swell referred to as the Coriolis effect. Congregations of fish pass the head of the bay during summer, with spawners running in the Minas Basin from June to August. Many of the shad in the Minas Basin are, in fact, migrants and not part of a local spawning population, but include fish from most of the spawning rivers on the eastern seaboard of North America (Dadswell et al, 1984). Today, the Shubenacadie and Stewiacke rivers are the primary spawning grounds for shad in the Minas Basin, although some fish are known to travel up Southern Bight rivers, such as the Avon, St. Croix and Kennetcook rivers. There is no recent evidence that shad in the Avon River estuary have been spawning (Daborn and Brylinsky, 2004).

11.3.2 Marine Mammals

Approximately 32 species of marine mammals can be found in the waters around Nova Scotia (Scott and Hebda, 2004). However, very few appear to spend significant time in the Minas Basin. Harbour porpoise (*Phocoena phocoena*) and Atlantic white-sided dolphin (*Lagenorhynchus acutus*) may voyage into the basin during the summer months. Rare strandings have been recorded on the mudflats for larger whales such as pilot, minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae*) (BoFEP, 2001).

One record from 1786 states: "A whale appeared in the Avon River. When the tide went out, the whale was found in the area of the Falmouth Great Dyke. It was 30 feet long and yielded a great quantity of oil" (Duncanson, 1965, cited in Daborn and Brylinsky, 2004).

11.4 Marine and Coastal Avian Community

Figure 11.6 *Semipalmated sandpiper, a keystone species within the Minas Basin, waits for the tide to fall*

Historically, little attention has been given to Bay of Fundy avian communities. Early biological studies on the occurrence of birds in the Bay of Fundy described, in qualitative terms, aspects of migration, abundance and distribution in specific areas within the bay (e.g. Pettingill, 1939) or as part of broader surveys (e.g. Tufts, 1973; Squires, 1976). Hicklin and Smith (1984) explain that it was not until the advent of tidal power and deepwater oil ports in the Bay of Fundy during the 1960s and early 1970s that scientists began to examine more seriously the avifauna of the area in light of these developments and their potential environmental impacts (e.g. Pearce and Smith, 1974; Hughson, 1977; Morrison, 1977). There is no single publication currently available on the distribution and abundance of birds in the Bay of Fundy, although data on populations and distributions have been summarized by the Canadian Wildlife Service and Erskine (1992) has published an *Atlas on the Breeding Birds of the Maritimes*.

With its famous tides and sediment-rich waters, the Bay of Fundy provides vast expanses of coastal, estuarine and marine habitats for aquatic birds. Intertidal muds and their associated fauna, for example, form critical feeding grounds for migrant sandpipers (Scolopacidae) and plovers (Charadriidae) during the late summer and fall. These flats, at low tide, cover an area of approximately 35,000 ha (Hicklin and Smith, 1984), of which nearly 82% falls in Chignecto Bay, the Minas Basin and Cobequid Bay (see Figure 11.7). The abundant mud-dwelling amphipod *Corophium volutator* and large polychaetes are the main food items of these shorebirds (Hicklin and Smith, 1979).

Approximately 5000 ha of salt marsh borders the Bay of Fundy and nearly 83% lies in the upper reaches (see Figure 11.7). Various species of dabbling ducks, geese and shorebirds, such as the greater yellowlegs (*Tringa melanoleuca*) and lesser yellowlegs (*T. flavipes*) (see Figures 11.9 and 11.10), and the least sandpiper (*Calidris minutilla*) inhabit these salt marshes during migration. Pearce and Smith (1974) noted that counts of Canada geese (*Branta Canadensis*) and six species of dabbling ducks – black duck (*Anas rubripes*); mallard (*A. platyrhyncos*); pintail (*A. acuta*); green-winged teal (*A. crecca*); blue-winged teal (*A. discors*) and American wigeon (*A. Americana*) – in these marshes can exceed 7000 birds during March to May (see Table 11.8). The population turnover of these migrants, however, is unknown and it is not unreasonable to expect that much higher numbers may be found in Bay of Fundy salt marshes throughout late winter to early spring.

In the Lower Bay of Fundy, tens of thousands of pelagic shorebirds, the red phalarope (*Phalaropus fulicaria*) and the red-necked phalarope (*P. lobatus*) congregate in the fall off of Brier Island. Other species of pelagic birds, such as the greater shearwater (*Puffinus gravis*) and sooty shearwater (*P. griseus*), are also numerous during this time, particularly near Brier Island (Hicklin and Smith, 1984). Another seabird group, the alcids, including razorbills (*Alca torda*) and the Atlantic puffin (*Fratercula arctica*), breed on Machias Seal Island alsongside a mixed colony of Arctic terns (*Sterna paradisaea*) and common terns (*S. hirundo*) (see Figure 11.8 for a distribution of shorebirds and seabirds).

Hicklin and Smith (1984) explain that the two extreme reaches of the Bay of Fundy are of the greatest importance to birds. The mouth of the Bay of Fundy, roughly the area between Brier Island and Passamaquoddy Bay, on the one hand, and the Upper Bay of Fundy, Chignecto Bay and the Minas Basin, on the other, support vast numbers of a few ecologically distinct species. In the mouth of the bay, pelagic species (which rely on rocky islands to breed and clear water and fast currents to concentrate food for foraging) dominate, whereas in the upper reaches, shorebirds and waterfowl occupy the muddy intertidal zone and salt marshes. The region in between, characterized by steep sandstone cliffs, rocky intertidal habitats and turbid water, is little used by birds.

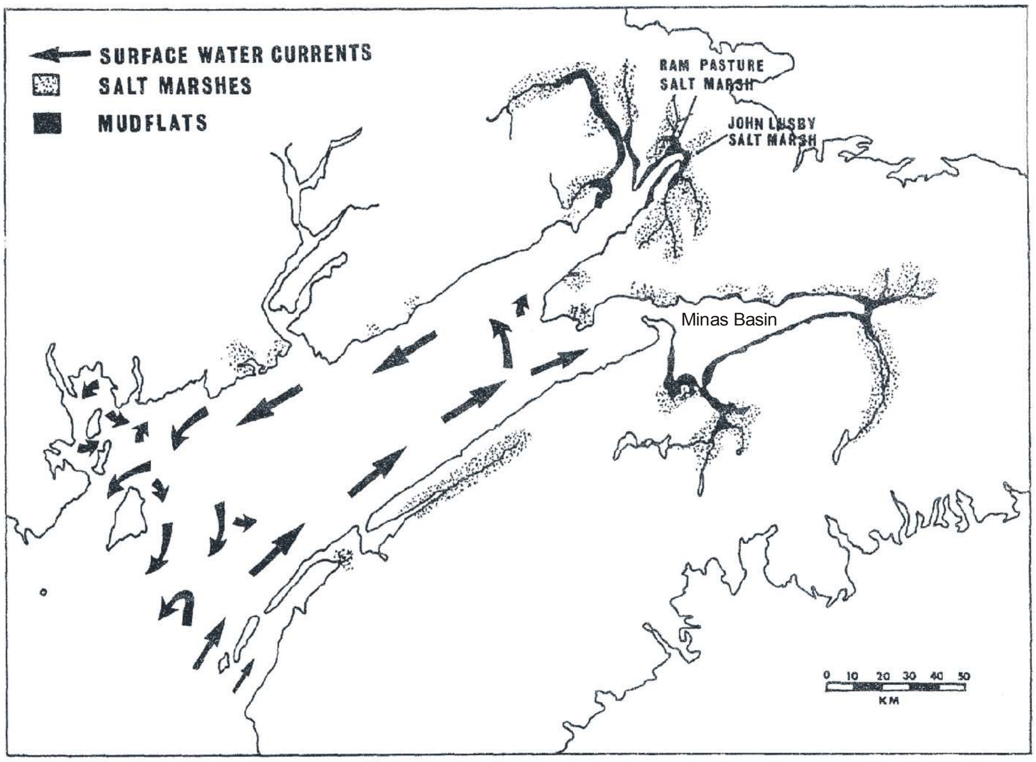


Figure 11.7 *Habitat types of importance to avian communities within the Bay of Fundy, Nova Scotia*

Source: Hicklin and Smith (1984)

11.4.1 Waterfowl

The Minas Basin is a magnet for waterfowl that congregate in huge flocks in the wetlands and marshes around the basin, foraging for food during spring and fall migrations. The shallows of the Southern Bight and Cobequid Bay are important wintering areas for black duck, dabbling duck, blue-winged teal, American wigeon, red-breasted merganser and geese. Unfortunately, as Hicklin and Smith (1984) point out, there are no detailed ecological studies on individual species in relation to habitat use, diets, energy consumption, fat deposition, movements or inter- and intra-specific competition. Information is especially needed on brant geese in Passamaquoddy Bay and the Grand Manan Archipelago, and on Canada geese in the John Lusby salt marsh, the Harvey marsh and the Canard River, which are major staging grounds for geese in the Bay of Fundy (Hicklin and Smith (1984).

Table 11.8 *Maximum numbers (single-day counts) of waterfowl and coastal shorbirds in zones 1 to 5 (see Figure 11.8) in the Bay of Fundy. Minas Basin is Zone 4.*

Species	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Waterfowl[1]:					
Canada goose	100[3]	200[3]	6100[3]	750[3]	200[3]
Brant	4000[3]	350[3]	50[3]	500[3]	500[5]
Black duck	12,500[3]	1000[5]	1550[4]	2250[5]	1050[5]
Other dabblers[6]	< 25[3]	< 25[3, 4, 5]	2200[4]	< 25[3, 5]	100[4]
Divers[5]	1300[5]	500[5]	350[3]	100[3]	500[3]
Sea ducks[8]	13,550[3]	1200[3]	2100[3]	50[3]	3550[3]
Shorebirds: (July–October)					
Semipalmated plover	1000	4283	2788	3808	
Black-bellied plover	300	388	1488	2543	
Greater yellowlegs	75	333	154	59	
Lesser yellowlegs	50	283	1356	59	
Knot	26	2	1447	116	
White-rumped sandpiper	55	646	707	561	
Least sandpiper	702	7564	3503	9945	
Dunlin	60	35	2655	388	
Short-billed dowitcher	422	1651	1405	1068	
Semipalmated sandpiper	6366	25,094	456,355	69,550	
Sanderling	200	1909	1150	1151	

Notes:
1 From Pearce and Smith (1974).
2 From Morrison (1978–1979); Elliott (1977); R. McManus, A. J. Erskine, P. MacDonald, pers comm.
3 March to May.
4 September to November.
5 December to February
6 Mallard, pintail, green-winged teal, blue-winged teal, American wigeon.
7 Ring-necked duck, scaup, goldeneye, bufflehead, merganser.
8 Oldsquaw, eider, scoter.

Source: Hicklin and Smith (1984)

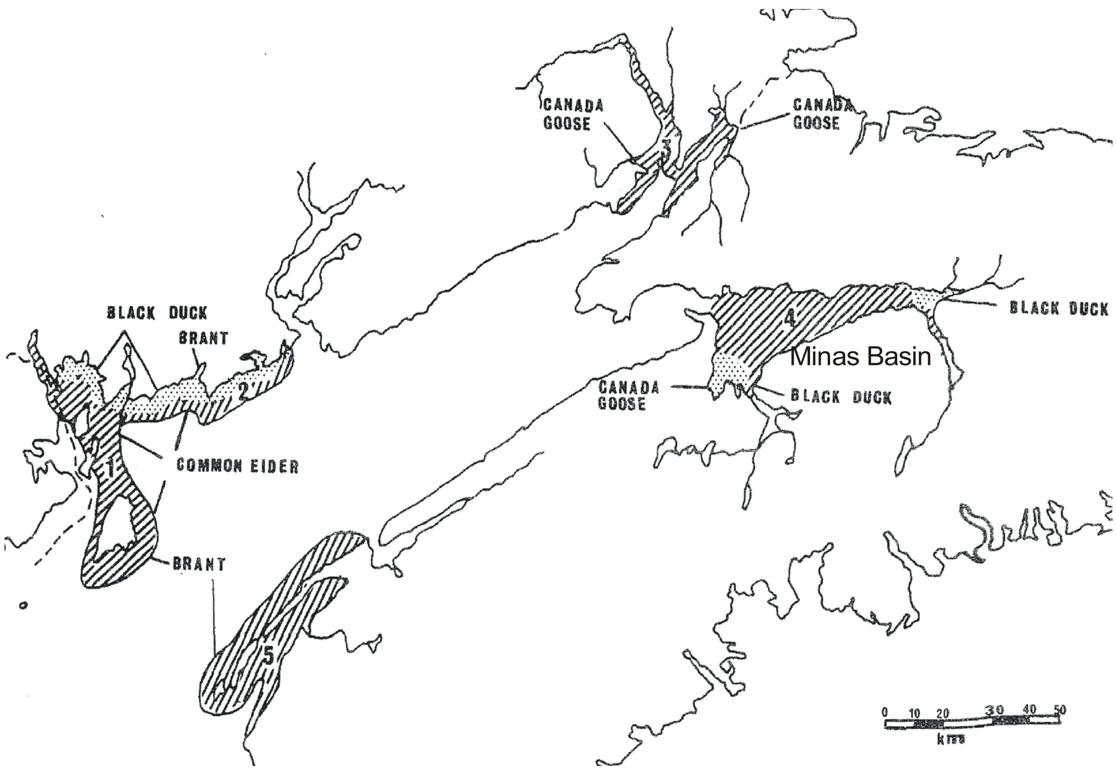


Figure 11.8 *Areas of importance to waterfowl in the Bay of Fundy: Zones 1 to 5 (hatched) are adapted from Pearce and Smith (1974); stippled areas indicate areas of importance mainly to black ducks. Minas Basin is Zone 4.*

Source: Hicklin and Smith (1984)

11.4.2 Shore Birds

Shore birds are especially prevalent in the Bay of Fundy's intertidal zone, especially in its salt marshes during late summer and fall, where birds can accumulate fat supplies sufficient to allow non-stop flights to South America (Davis and Browne, 1996a) (see Figure 11.11). No areas farther south on the Atlantic seaboard are known to allow comparable feeding opportunites in summer. As a group, shorebirds include plovers, turnstones, sandpipers (see Figure 11.12), curlews, yellowlegs (see Figures 11.9 and 11.10), dowitchers, godwits and phalaropes, and shorebirds form one of the most important components of the Canadian avifauna (Morrison, 1976). The entire range of Minas Basin mudflat is of significance for many migratory birds and shorebirds (see Tables 11.9 and 11.10); however, the Southern Bight is particularly critical. Most shorebirds feed in the intertidal zone on benthic invertebrates. The main prey species, used by over 2 million semipalmated sandpipers and many thousands of other shorebird species in late July through early September each year, is the burrowing amphipod *Corophium volutator* (the mud shrimp), which occurs in intertidal mudflats in North America only in the Bay of Fundy and Guld of Maine (Davis and Browne, 1996a). In the Bay of Fundy, densities of *Corophium* approach 20,000 per square metre of mud, and *Corophium* reproduces at the time that the first shorebirds arrive in late July. Shorebirds forage in highest densities on the mud flats that support the greatest numbers of *Corophium*. The larger shorebirds, especially the short-billed dowitcher and the black-bellied plover, also feed on the bloodworm *Glycera dibranchiata* and the small clam *Macoma balthica*. The smaller semipalmated plover concentrates on the worm *Heteromastus filiformis*, as well as *Corophium* (McNeil and Cadieux, 1972; Peer et al, 1986; Hicklin, 1987; Gilliland et al, 1993).

Most of the birds that use the Bay of Fundy are migrants. The largest concentrations of birds are found where the large tidal range has resulted in intertidal areas; tidal marsh development is also important, particularly for the export of nutrients upon which the mudflat invertebrate population depend (Davis and Browne, 1996a). Greater and lesser yellowlegs (see Figures 11.9 and 11.10) and least sandpipers frequently forage in the tidal marsh zone, while other species retreat there during periods of high tide when the flats are covered. Hildebrand (1981) suggests that the yellowlegs' feeding cycle is related to the behavioural activities of macroinvertebrates in salt marsh pools. Since in some areas, particulary in Cobequid Bay, high marshes may no longer be flooded following the construction of tidal barrages, habitats of importance to yellowlegs are thought to be increasingly threatened.

By far the greatest numbers of shorebirds are found in the Inner Bay of Fundy, where enormous areas of mudflats are exposed (see Tables 11.9 and 11.10). More birds (at least twofold to threefold) are seen in Chignecto Bay and Cumberland Basin than in the Minas Basin and Cobequid Bay (Davis and Browne, 1996a). Maximum same-day numbers in these areas are of the order of 400,000 versus 150,000 birds, and the differential between the areas is consistent over 20 years of study, despite wide fluctuation in annual numbers (McNeil and Cadieux, 1972; Peer et al, 1986; Hicklin, 1987; Gilliland et al, 1993; Davis and Browne, 1996a). One hypothesis is that there are more extensive salt marshes providing richer food resources in the Chignecto Bay area; another is that larger proportions of favoured particle sizes exist in the sediments (more sandy mud with less sand and less silt) than in the Minas/Cobequid Bay area.

Since 1976, shorebirds feeding on intertidal flats have been the most intensively studied group in the Bay of Fundy (Hicklin and Smith, 1984). A substantial amount of research has focused on the semipalmated sandpiper (*Calidris pusilla*), largely because of its higher numerical abundance and widespread distribution (Elliot, 1977; Boates, 1980; Hicklin, 1981). A great deal of the information available on the semipalmated sandpiper in the Minas Basin includes foraging behaviour, energy budgets and prey (*Corophium volutator*)–predator relationships (Boates and Smith, 1979; Boates, 1980; Wilson, 1990; Hamilton et al, 2003) and habitat use (Hicklin, 1981).

Figure 11.9 *Greater yellow legs (*Tringa melanoleuca*), which occupy the high marshes in the Bay of Fundy*

Figure 11.10 *Lesser yellow legs (*Tringa flavipes*): a shorebird that favours the upper fringes of marsh flooded mainly on spring tides*

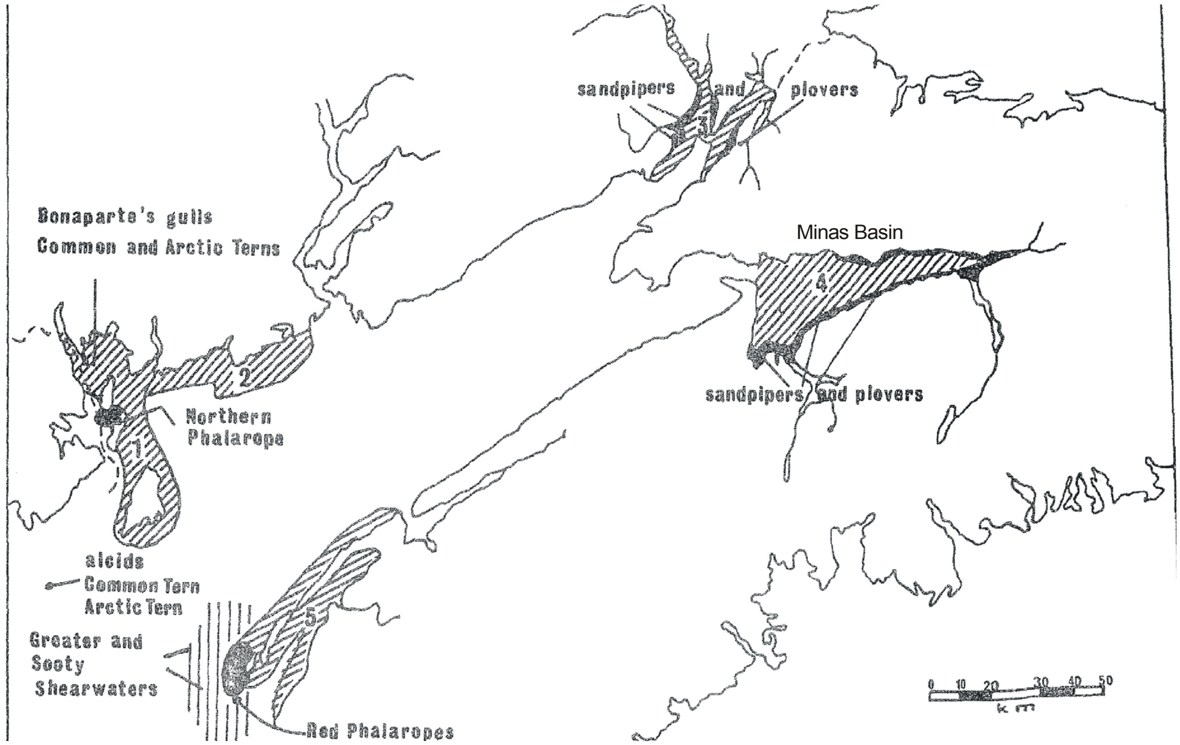


Figure 11.11 *Areas of importance to coastal shorebirds (sandpipers and plovers), northern and red phalaropes, greater and sooty shear waters, alcids, Bonaparte's gulls and common and Arctic terns in the Bay of Fundy: Zones 1 to 5 (hatched) are adapted from Pearce and Smith (1974). Zone 4 represents Minas Basin.*

Note: The dark areas specify the sites utilized by sandpipers and plovers and concentrations of phalaropes. Pointers indicate specific sites of importance within each zone to the species shown.

Source: Hicklin and Smith (1984)

Table 11.9 *Aerial survey data for shorebirds in the Upper Bay of Fundy, 1974 (areas of mudflats and salt marsh from Pearce and Smith, 1974)*

Area	Total shorebirds observed	Length of coastline surveyed in km (miles)	Area of mudflats in ha (acres)	Area of salt marsh in ha (acres)
Minas Basin and Cobequid Bay	55,000	231 (143.5)	22,660 (56,000)	2000 (4950)

Source: Morrison (1976)

The southward migration of shorebirds into the Bay of Fundy occurs from mid July to mid November. Semipalmated sandpipers are most numerous in the latter part of July and the first week of August, whereas plovers (the piping plover is listed by COSEWIC as endangered within Nova Scotia) reach peak numbers during mid to late August. Numbers of least sandpipers, short-billed dowitchers and semipalmated sandpipers peak quickly within 10 to 14 days following the arrival of the first flocks in July (Hicklin and Smith, 1984). Sanderlings and dunlins are present largely through October and early November. The black-bellied plover is the only species that migrates to the Bay of Fundy in spring in substantial numbers.

Table 11.10 *Autumn distribution of shorebirds in the Minas Basin, 1976–1983.*

Place	Semipalmated sandpiper	Semipalmated plover	Black-bellied plover	Lesser golden plover	Least sandpiper
Burncoat (Cobequid Bay)	45,000	1200	1500	75	100
Economy (Central Basin)	1500	450	750	0	185
Evangeline Beach (Southern Bight)	10,000	1500	1875	1500	450
Five Islands (Central Basin)	10,500	300	375	0	75

Source: adapted from data collected by the Canadian Wildlife Service

Figure 11.12 *The pectoral sandpiper is a fairly common transient, especially in the fall: In the Minas Basin, it can be found on all types of beaches, from mud to cobble, depending upon food abundance*

Source: Photo by M. Elderkin in Davis and Browne (1996a).

The abundance of food available to birds on mudflats within the Bay of Fundy is a major factor in determining which sites are likely to be used by the greatest numbers of birds (McNeil and Cadieux, 1972; Peer et al, 1986; Hicklin, 1987; Gilliland et al, 1993). Hicklin et al (1980) and Hicklin (1981) sampled the larger flats within Chignecto Bay and the Southern Bight during 1976 to 1978. Yeo's (1977) study on animal–sediment relationships in Cobequid Bay followed a similar sampling regime between 1973 and 1976. More recently, Wilson (1990) examined the relationship between prey abundance and foraging site selection by semipalmated sandpipers on extensive intertidal mudflats near Avon in the Minas Basin, while Hamilton et al (2003) sampled mudflats in the Upper Bay of Fundy for *Corophium volutator*, predicting bird activity as a direct result of snail abundance. Based on such research, it is clear that the amphipod *Corophium vulutator* is by far the most numerous and important species, with average densities of 10,000 to 20,000 per m^2 (Hicklin and Smith, 1984) in the mid to lower regions of the flats in Chignecto Bay and the Southern Bight in the Minas Basin. *Corophium* is the primary prey of semipalmated plover, dowitcher, and least and semipalmated sandpipers.

11.4.3 Seabirds

The term seabird is used to denote avifauna that obtain the majority of their food from coastal waters (neritic species) or from the open ocean (pelagic species), although often only the latter term is used. Neritic (secondary) seabirds use the land for feeding or resting at times, whereas pelagic (primary) seabirds are largely independent of the land, except for nesting (Tufts, 1986; Erskine, 1992; Davis and Browne, 1996a). According to this definition, marine ducks, such as eiders and scoters, and shorebirds, such as phalaropes, are seabirds, as well as the pelagic species of which three species of alcid, three saltwater terns, three gulls, two cormorants, one eider and one storm petrel breed in Nova Scotia (Erskine, 1992; Davis and Browne, 1996a). Seabirds feed almost exclusively on fish and marine invertebrates. Spatial and temporal variations in the abundance of food species (such as immature herring, sand lance and capelin) are crucial in determining breeding seasons, colony locations and movement of seabirds. The abundance of food for seabirds, furthermore, depends upon such factors as ocean currents, seasonal phytoplankton blooms, localized upwellings and the presence of a fishery.

Seabirds known to be breeding in Nova Scotia at present are as follows:

Pelagic species:

Leach's storm petrel (*Oceanodroma leucorhoa*);
Atlantic puffin (*Fratercula arctica*);
razorbill (*Alca torda*);
black-legged kittiwake (*Rissa tridactyla*).

Neritic species:

double-crested cormorant (*Phalacrocorax auritus*);
great cormorant (*Phalacrocorax carbo*);
common eider (*Somateria mollissima*);
black guillemot (*Cepphus grylle*);
herring gull (*Larus argentatus*) (see Figure 11.13);
great black-backed gull (*Larus marinus*);
Arctic tern (*Sterna paradisaea*);
common tern (*Sterna hirundo*).

roseate tern (*Sterna dougallii*) (Erskine, 1992; Davis and Browne, 1996a).

Outside the breeding season, the pelagic species retreat out to sea, some species completely leaving Nova Scotia waters in winter (David and Browne, 1996a). Non-breeding birds of these species, and pelagic migrants, seldom come in sight of land during the summer except when storm driven or where upwelling concentrates feeding opportunities.

11.4.4 Bald Eagle

In the Maritimes, the most important wintering area for the bald eagle, (*Haliaeetus leucocephalus*), a bird of prey at the top of the food chain, is in the Shubenacadie River, which flows into Cobequid Bay. Reid (1982) studied their behaviour and feeding ecology during the winter months, recording peak numbers of 45 to 75 birds between 1977 and 1982. The tide affects the Shubenacadie River 40 km upriver from Cobequid Bay and the stretch most frequented by wintering eagles extends 16 km to 21 km from the river mouth (Hicklin and Smith, 1984). The main food source for bald eagles here is the winter-spawning run of tomcod (*Microgadus tomcod*), which is especially important for the eagles' survival during January and February.

Bald eagles can be an important indicator of the health of other wildlife species and the environment. In late April, these birds nest in tall, strong-limbed trees surrounded by discontinuous canopies near open water and buffered from human activity (Macdonald and Austin-Smith, 1989). The young generally hatch a month later. Reproduction has averaged 1.2 young for each nest (Cash et al, 1985). Cape Breton has had the highest concentration of breeding bald eagles in eastern North America, with up to 24 nests in a 10 km^2 area (MacDonald and Austin-Smith, 1989).

11.5 AQUATIC INVASIVE SPECIES

As with all marine areas in which shipping occurs between ports separated by significant distances, the potential for transport and accidental introduction of aquatic invasive species exists. Although species can naturally migrate to and invade new areas, it is the speed and distance over which humans introduce species that allow some to have significant ecological impacts. Within the Minas Basin, some invasives such as the common periwinkle (*Littorina littorea*) were introduced long ago and have come to balance within the ecosystem. The periwinkle is now the dominant snail species in the Bay of Fundy, and yet most residents would not think of it as an invasive (BoFEP, 2003). Other invasives, such as the amphipod *Corophium volutator* would be considered by many people to be beneficial to the ecosystem. *Corophium* is a dominant species on the large tidal mudflats of the Southern Bight and Cobequid Bay areas of the Minas Basin, supporting millions of migrating shorebirds every year (BoFEP, 2003), while contributing to the diet of several species of ground fish, and even the Atlantic sturgeon.

Other aquatic invasives are known to have come to the waters of the Inner Bay of Fundy, although they do not exist in the literature for the Minas Basin. Whether they enter the basin or not, they can have significant detrimental impacts to local biota, and directly or indirectly affect the Minas Basin ecosystem. Recent spread of the green crab (*Carcinus maenas*), which has a voracious appetite for molluscs, and various tunicates (*Ciona* sp) that can foul habitats that support other biota, are two examples of newer invasives altering the coastal ecosystems around Nova Scotia.

12. BIODIVERSITY AND SPECIES AT RISK

The Atlantic Canada Conservation Data Centre (ACCDC) has records of 391 different species found in the Minas Basin watershed that have been either assessed federally by the Council on the Status of Endangered Wildlife in Canada (COSEWIC) or provincially by the ACCDC (see Appendix A). In total, ten species are now afforded some protection under federal or provincial regulations (see Table 12.1). Most of the species assessed are terrestrial or freshwater in nature and are broadly distributed around the Minas Basin watershed (see Figure 12.1). Marine species at risk may exist within the marine waters of the Minas Basin, but they are not documented within the data compiled by the ACCDC. Others may have been assessed and categorized, but not offered protection under the relevant act. For example, the striped bass is listed by COSEWIC as threatened; but it has not yet been added to Schedule 1 of the Federal Species at Risk Act and is therefore not offered protection under the act.

Table 12.1 *A summary of species confirmed in the Minas Basin watershed and sub-watersheds that are protected under the Endangered Species Act (ESA) of Nova Scotia or the federal Species at Risk Act (SARA)*

Species name	Common name	COSEWIC/SARA	ESA	Watersheds*
Birds				
Falco peregrinus anatum	American peregrine falcon	**Special concern**	**Threatened**	NCB, NMC, SMC,
Euphagus carolinus	Rusty blackbird	**Special concern**	–	CB, SB, SCB
Asio flammeus	Short-eared owl	**Special concern**		SB
Plants				
Isoetes prototypes	Prototype quillwort	**Special concern**	**Vulnerable**	CB, NCM
Thuja occidentalis	Northern white cedar	-	**Vulnerable**	SB, CB
Mammals				
Alces americanus	Moose	-	**Endangered**	CB, NCB
Glaucomys volans	Southern flying squirrel	**Special concern**	–	SB
Reptiles				
Glyptemys insculpta	Wood turtle	**Special concern**	**Vulnerable**	CB, NCB, SB,
Fish				
Morone saxatillis	Striped bass (Bay of Fundy)	**Threatened→**	**–**	CB
Salmo salar	Atlantic salmon (iBoF)	**Endangered**	**–**	SB, CB
Amphibians				
None				
Insects				
Danaus plexippus	Monarch butterfly	**Special concern**	–	SB, NCB, CB

Notes: Distribution of these species within the Minas Basin watershed may be wider than the sub-watersheds indicated; but these are the locations confirmed by data at the Atlantic Canada Conservation Data Centre.
* CB = Cobequid Bay; NCB = north Central Minas Basin; SCB = south Central Minas Basin; SB = Southern Bight; NMC = north Minas Channel; SMC = south Minas Channel.
→ Not yet a SARA Schedule 1 listed species and therefore not afforded SARA protection.

Source: Atlantic Canada Conservation Data Centre

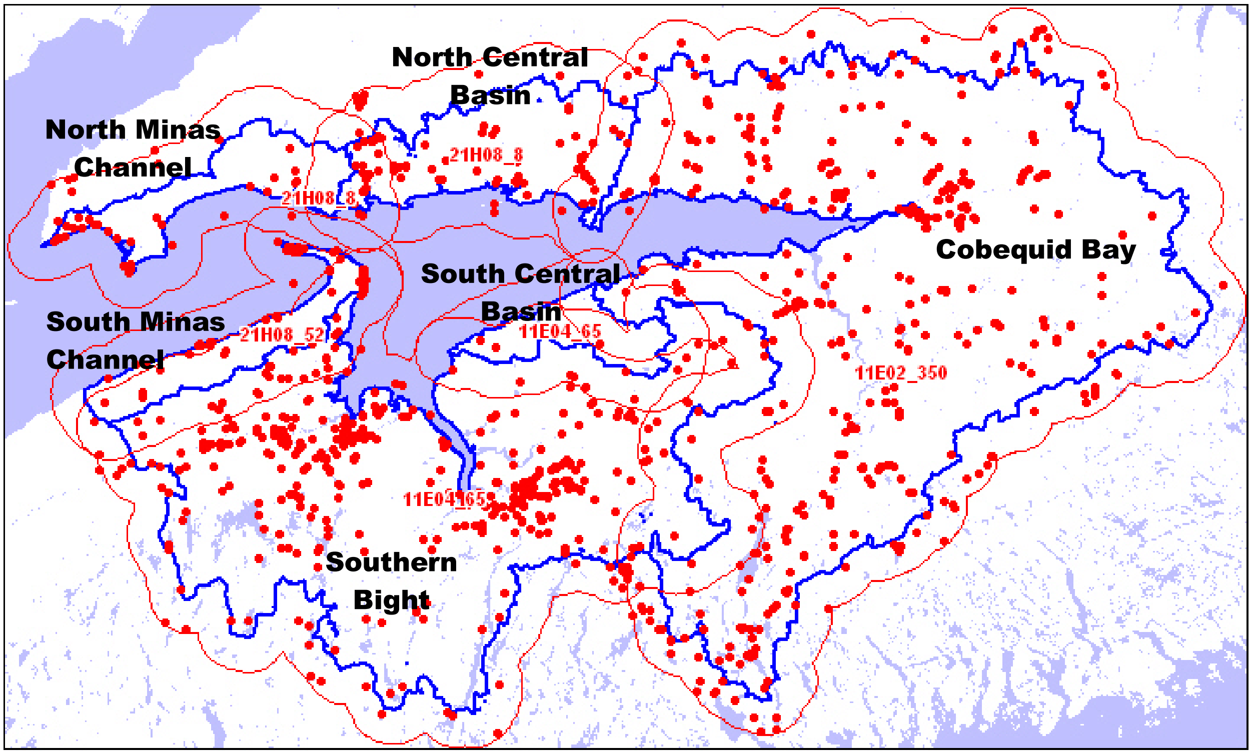


Figure 12.1 *The general distribution of provincially and federally assessed species at risk observation points around the Minas Basin*

Source: adapted from Atlantic Canada Conservation Data Centre

Of the 391 assessed species of biota, the Atlantic Canada Conservation Data Centre has documented within the Minas Basin watershed, 242 species are listed as being provincially rare to extremely rare in the province of Nova Scotia.

Provincially rare to extremely rare species are given an S1 or S2 rarity ranking, described as follows:

> *S1:* extremely rare throughout its range in the province (typically five or fewer occurrences, or very few remaining individuals). May be especially vulnerable to extirpation.
>
> *S2:* rare throughout its range in the province (6 to 20 occurrences or few remaining individuals). May be vulnerable to extirpation due to rarity or other factors.

Regardless of this ranking, a species is only offered protection under the Nova Scotia Endangered Species Act if it is listed within the act. Five of the S1 and S2 ranked species from the Minas Basin watershed are listed under the ESA for the province of Nova Scotia (see Table 12.1).

Geographically, the Southern Bight and Cobequid Bay sub-watersheds are home to the greatest number of protected species, with seven and eight species, respectively, being protected under either or both the federal and provincial legislation for species at risk (see Table 12.2).

Table 12.2 *Summary of various species that are protected provincially and nationally for the total watershed and sub-watershed areas of Minas Basin*

Watershed and sub-watersheds	Species with national protection (COSEWIC)	Species with provincial (ESA)	Provincial rare species (S1–S2)	Total species at risk
Minas Basin watershed	**1 endangered, 1 threatened, 7 special concern**	**1 endangered, 1 threatened, three vulnerable**	**242**	**11**
North Minas Channel	1 special concern	1 threatened	–	1
South Minas Channel	1 special concern	1 threatened	–	1
North Central Basin	3 special concern	1 endangered, 1 threatened, 1 vulnerable	–	4
Southern Central Basin	1 special concern	-	–	1
Southern Bight	1 endangered, 5 special concern	2 vulnerable	–	7
Cobequid Bay	1 endangered, 1 threatened, 4 special concern	1 endangered, 3 vulnerable	–	8

Source: adapted from Atlantic Canada Conservation Data Centre

12.1 SPECIES AT RISK: COSEWIC

Of the 391 ACCDC documented species, one is federally listed as endangered, one is listed as a threatened species, and seven are listed as species of special concern based on assessment by COSEWIC. Such listing gives these species special protection under the Federal Species at Risk Act once they are added to Schedule 1 of the Act (SARA, 2003). Although the Bay of Fundy striped bass (*Morone saxatillis*) population has been listed by COSEWIC as threatened, it has not been added to Schedule 1 of the act. Therefore, the population is not afforded protection under the act at this time.

The only federally endangered species in the Minas Basin watershed is the Inner Bay of Fundy (iBoF) population of the Atlantic salmon (*Salmo salar*). This population has declined in abundance by 90% or more since 1989 (Amiro, 2003) as a result of low marine survival rates. The causes of this low survival are not well understood, although some potential causes have been largely ruled out with recent research. Numbers are estimated to have declined by more than 95% during the last 30 years, and most rivers no longer have either adults or juveniles. In 2003, fewer than 100 adults are estimated to have returned to the 32 rivers known to have historically contained the species (see Figure 12.2). All of the Minas Basin sub-watersheds would have had some salmon at some point in time, and known distribution was within at least 18 rivers in the Minas Basin. There is no likelihood of rescue for this population as neighbouring regions also harbour severely depressed and genetically dissimilar populations (COSEWIC, 2007). Future research is focusing on determining total population estimates, juvenile population estimates and survival rates in order to help focus recovery strategy development.

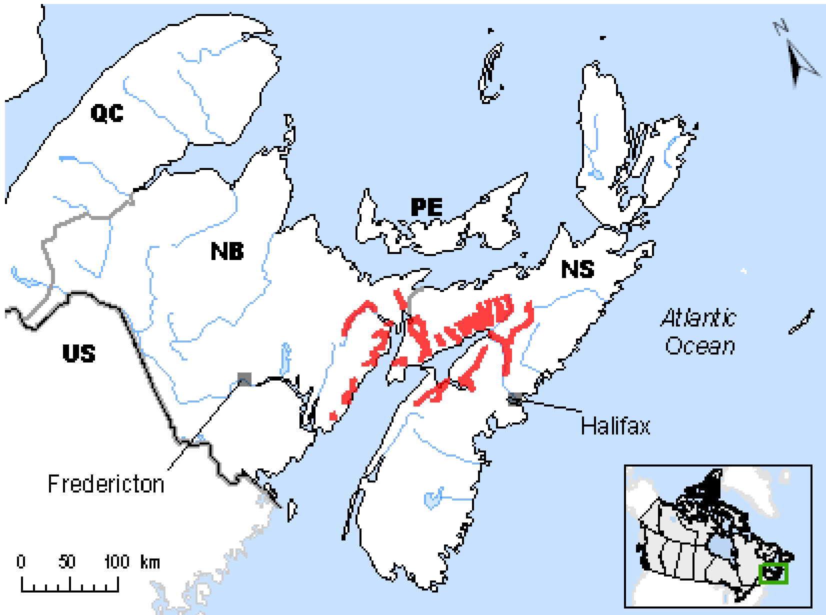


Figure 12.2 *Distribution map for the historic range of rivers inhabited by the now endangered Inner Bay of Fundy Atlantic salmon includes 18 rivers of the Minas Basin watershed*

Source: Environment Canada (2007)

Unlike all other salmon in North America, evidence suggests that Inner Bay of Fundy Atlantic salmon exhibit very limited migration, staying within the Bay of Fundy and the Gulf of Main for extended periods. This limited or delayed migration may be a factor in their decline (Environment Canada, 2007). The Minas Basin portion of the iBoF population is a rare and distinct lineage, different from other iBoF salmon, Atlantic Canadian salmon and European salmon (Verspoor, et al, 2002, cited in Amiro, 2003).

Within the Inner Bay of Fundy endangered Atlantic salmon population, the Minas Basin fish are a unique stock, as demonstrated by a unique genetic haplotype. The Gaspereau River fish, which spawn in the Southern Bight River, seem to further vary from the remaining Minas Basin fish (Verspoor et al, 2002, cited in Amiro, 2003). Unlike the Minas Basin salmon, Gaspereau River salmon leave the boundaries of the Bay of Fundy, as is evidenced by tagged fish being caught in Newfoundland and Greenland fisheries. Although the Gaspereau River stock has declined less than other Minas Basin rivers, it has still produced as little as 30% of the conservation requirement required for the river during recent years (Amiro, 2003).

Scientists have been tagging smolts and recovering tags from post-smolts and adults in the Inner Bay since 1967. Since 1999, salmon smolts have been tracked with acoustic tags during their first three months at sea to monitor their distribution. Post-smolts have also been live captured in special trawls during their second month at sea to establish their health, condition, feeding habits and association with prey and predator fish species. None of these variables have yet suggested apparent reasons for any unusual rates of mortality (Environment Canada, 2007).

There is an ongoing brood stock management programme that includes both captive and wild components, aimed at maximizing the genetic diversity of released young. Remaining Inner Bay of Fundy salmon are DNA fingerprinted and placed into population-specific pedigrees. Using the pedigree, a mating scheme is developed to minimize inbreeding. Most of the offspring are released into the wild, where they are subject to natural selection. A small portion from each family is kept in captivity for the following year's breeding programme. When it is time to produce the next generation, juveniles about to go to sea will be recovered from the wild, DNA fingerprinted, pedigreed and captive reared to adults. This brood stock management programme, coupled with a strategy that involves river exposure of juvenile salmon, is hoped to increase the wild fitness of salmon and result in an eventual population recovery.

Additional discussion of Atlantic salmon is presented in Section 11.3.1 of this report.

The Bay of Fundy striped bass (*Morone saxatillis*) population meets the COSEWIC criteria for endangered species, but has been designated threatened because the one remaining spawning population within the Shubenacadie/Stewiacke River of the Minas Basin does not appear to be at imminent risk (COSEWIC, 2007). At this point the Bay of Fundy bass has not been added to Schedule 1 of the federal Species at Risk Act and therefore is not offered protection under the act. Repeated spawning failures have led to the disappearance of the two other Bay of Fundy populations on the Annapolis and Saint John rivers. In the Minas Basin, the Shubenacadie River population contends with the presence of the introduced chain pickerel in overwintering sites as a potential threat. Another threat to the population is as a catch to various commercial fisheries in the Bay of Fundy and Minas Basin (COSEWIC, 2007). Along with its recent confirmed presence in the Shubenacadie River, it has also been surveyed near the Windsor Causeway in the Southern Bight of the Minas Basin, although it is unlikely to have been spawning there (Daborn and Brylinsky, 2004). The Shubenacadie/Stewiacke River population has been shown through mitochondrial and nuclear DNA to be genetically distinct from the eastern US populations (Douglas et al, 2003). It appears that this same population maintains a summer marine range within the Minas Basin, rarely straying beyond the limits of the watershed defined in this report. Young-of-the-year Shubenacadie/Stewiacke striped bass appear to stay in the turbid, relatively warm water portions of the Minas Basin (Douglas et al, 2003).

For the Minas Basin striped bass population that spawns within the Shubenacadie River, recovery has been labelled "potentially feasible" (Lanteigne, 2006). The Shubenacadie River population continues to produce new individuals annually, and it is felt that mitigation of current human activities believed to negatively affect abundance is possible through a combination of changes to existing regulations, enforcement and best management practices. The most negative human activities with regard to the striped bass of the Shubenacadie River are the recreational fishery, the aboriginal food fishery, the commercial fishery for gaspereau and shad, and the commercial Inner Bay of Fundy weir fishery for herring and flounder (Lanteigne, 2006). It is believed that these activities are directly having a negative impact on the bass population or on bass habitats. Further discussion on striped bass is found in this document under Section 11.3.1, or a detailed account is provided in COSEWIC (2004) and in Douglas et al (2003).

An additional seven species documented by ACCDC within the Minas Basin watershed and listed under SARA as species of special concern are peregrine falcon, rusty blackbird, short-eared owl, prototype quillwort, southern flying squirrel, wood turtle and monarch butterfly. These are largely freshwater or terrestrial species and therefore are not discussed further here. There has been note of a humpback whale (*Megaptera novaeangliae*) (BoFEP, 2001) within the basin, although the habitat of the basin is admittedly not favourable. This record is not documented by the ACCDC. Humpback whales were moved from a species of special concern to tot at risk following a 2003 COSEWIC reassessment.

12.2 PROVINCIAL LISTED SPECIES

Five of the 242 ACCDC assessed rare to extremely rare (S1 and S2 ranking) Minas Basin species are offered protection under the Nova Scotia Endangered Species Act. They include the endangered mainland moose (*Alces americanus*); the threatened peregrine falcon; the vulnerable northern white cedar (*Thuja occidentalis*); the prototype quillwort (*Isoetes prototypes*); and the wood turtle (*Glyptemys insculpta*).

The peregrine falcon (*Falco peregrinus anatum)* is offered protection both under federal (SARA) and provincial (ESA) Species at Risk acts. It has an ecological link to the marine portion of the watershed both through its nesting and through its foraging areas. In the Minas Basin, the peregrine has historically been found nesting along cliffs both north and south of the Minas Channel (Museum of Natural History, 2007) and in the Parrsboro area of the north Central Channel. There are nests within a limited portion of the southern Minas Channel sub-watershed area today (Elderkin, pers com, 2007). During the later summer, the peregrine will feed on the annually migrating shorebirds that congregate in large numbers around the Minas Basin (NSDNR, 1994). The shorebirds come to feed on the plentiful *Corophium* amphipod found in the mudflats that are exposed by the receding tides. The basin area is undoubtedly important early in the peregrine lifecycle as fledged chicks begin to move away from the parent territory (Elderkin, pers com, 2007). On the Minas Basin mudflats they will prey on semipalmated (*Calidris pusilla*) and least (*Calidris minutilla)* sandpipers.

13. HABITAT USE AND FUNCTIONAL AREAS

Although the Minas Basin marine habitat is dominated by intertidal mudflats of small diameter particles and a relatively well-mixed, turbid water column, a great deal of diversity still exists within the basin. The Minas Basin is characterized by a horizontal gradient of temperature and salinity, and to the organisms that live in the basin, there is a huge difference between silt and sand. As one moves towards the Bay of Fundy, the water becomes clearer and more saline, rocky outcrops and shorelines begin to dominate, and tidal currents reach their maximum within the ecosystem. These changes in physical and chemical oceanography, and bathymetry provide a wide array of habitat types. The flora and fauna of the basin then colonizes those habitats and niches that best suit their life-cycle requirements. Some areas are used for spawning, others for rearing or migration, and, of course, all living things look for the best place in which to eat. In this way, the diverse habitats of the Minas Basin become functional areas to the biota present.

The following discussion considers habitats from the perspective of life-cycle functions of various species of the Minas Basin watershed, as noted in the reviewed literature. Although the existing literature details a moderate amount of knowledge of spawning areas, very little is described in detail about the importance of specific Minas Basin habitats as rearing, foraging or migration for resident and migrating species.

13.1 SPAWNING/REPRODUCTION AREAS

As might be expected, within any watershed the larger river systems tend to hold the most potential for spawning. Within the Minas Basin watershed, the Shubenacadie River could likely be considered the most significant spawning area, at least during recent times.

The Shubenacadie River is a primary spawning location for gaspereau, shad, Atlantic salmon and striped bass within the Minas Basin watershed. The Bay of Fundy striped bass (*Morone saxatillis*) population has been designated threatened, and the one remaining spawning population occurs within the Shubenacadie/Stewiacke River (COSEWIC, 2007). This population is genetically distinct from the eastern US populations (Douglas et al, 2003) and will spawn in the river during the early spring. Douglas et al (2003) indicate that the Stewicake, just upstream of the confluence with the Shubenacadie, is a key spawning area for striped bass. Next in the seasonal line to use the Shubenacadie system are the gaspereau. The large accessible Shubenacadie Grand Lake is a significant draw for the two species of gaspereau. Fish have been observed to enter the lake and then head up the larger tributaries named Lower Rawdon River and Waverly Fish Run, as well as up very narrow streams and brooks (Huntsman and Rice, 1946). Huntsman and Rice (1946) noted that gaspereau fish would begin to ascend the rivers during the latter part of April, with the main body of the migration occurring in mid May.

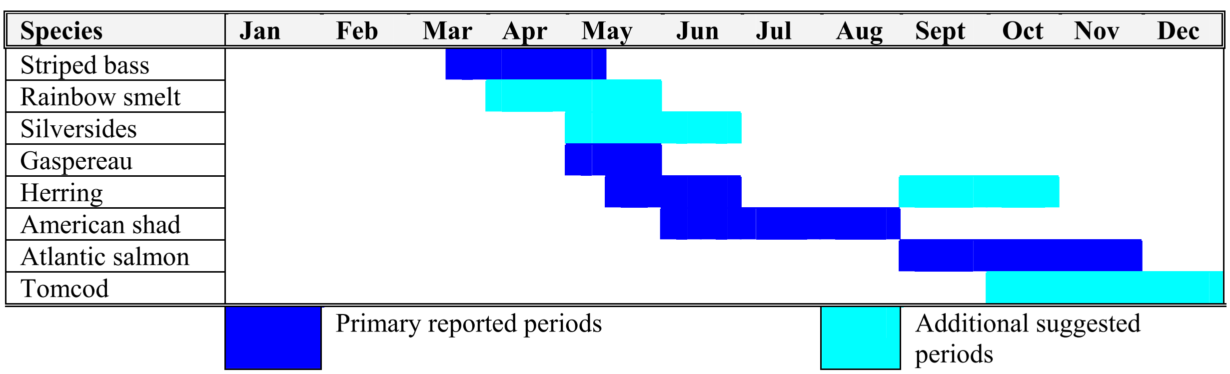
Next into the Shubenacadie and Stewiacke rivers is the spawning run of shad. This is the main spawning location for shad within the basin. In the Shubenacadie River, they reach up river as far as Elmsdale and Enfield, and a few even swim to Grand or Shubenacadie Lake. In the Stewiacke River they are found as far as Middle Stewiacke. The duration of the run of ocean-feeding American shad in the Minas Basin has been recorded as June to August (Dadswell et al, 1984).

Finally, late in the fall the Atlantic salmon arrive to spawn in the Shubie system. At one time the Stewiacke River had the most abundant Atlantic salmon spawning population in the Minas Basin watershed (Amiro, 2003). The run is no longer abundant. The Minas Basin fish, along with the whole Inner Bay of Fundy population, have virtually disappeared. However, the volume of habitat is plentiful and of adequate quality to support much higher numbers of fish. If issues of poor marine survival are resolved either naturally or through management, the Shubenacadie River will likely be a key location for re-establishment of the species within the Minas Basin.

Although details of tomcod (*Microgadus tomcod*) spawning are described for the Minas Basin, it was reported during the early 1980s that there was such an abundance of these fish spawning in the Shubenacadie River that a large population of bald eagles would overwinter there, feeding on the concentration of spawning fish (Reid, 1982, cited in Dadswell et al, 1984).

As shown in Table 13.1, various anadromous spawning stocks enter the Shubenacadie River from as early as March until November or later of every year. Each species will use a slightly different portion of the river because of the habitat characteristics presented to meet the fish's functional needs for spawning.

Table 13.1 *Approximate spawning times in the Minas Basin for selected species, as noted in the reviewed literature*



The Gaspereau River is another significant area for salmon and gaspereau spawning. The large run of gaspereau makes their way upriver to spawning grounds in Gaspereau Lake. Shad will enter a number of systems, including the Avon, St. Croix and Kennetcook Rivers, but not in numbers comparable to the Shubenacadie. Recent surveys for juvenile fish in the Avon Estuary would seem to indicate that no fish have been spawning in the system (Daborn and Brylinsky, 2004). Historically, some 18 rivers around the Minas Basin had annual spawning of Atlantic salmon, constituting more than 50% of the known rivers for the Inner Bay of Fundy population (Amiro, 2003).

Outside of the major river systems, other areas of the Minas Basin support spawning activities for various species, often in near-shore brackish or shallow areas. Silversides (*Menidia menidia*) have been most commonly found near Kingsport, in the Southern Bight of the Minas Basin (Irmrie and Daborn, 1981, and Gilmurray and Daborn, 1981, cited in Dadswell et al, 1984). There they likely spawn during May or June, as has been observed in the Cumberland Basin.

The Minas Basin is the only documented location for spring spawning herring in the Bay of Fundy–Gulf of Maine region (Bradford and Iles, 1992). Although much of the Bay of Fundy and southwestern Nova Scotia herring are fall spawners, those of the Minas Basin are a spring spawning population. These fish tend to spawn in shallower water of the immediate subtidal to about 5 m in depth on coarse substrate and algae (Stewart and Arnold, 1994). Spawning takes place during May to June. Spawning areas in the Minas Basin are distributed from Scots Bay east through the Minas Channel to the Central Minas Basin area. The fish that spawn inside of the Minas Channel tend to be spring spawners and those that spawn outside the Minas Channel around Scots Bay are predominantly fall spawners.

13.2 Rearing Areas

Rearing areas are those places where young fish live until they become more able to fend for themselves in the open and hostile environments that adults of the species will inhabit. Such areas are extremely important to many species and if high-quality rearing areas exist, survival to adult is likely reflected in the strength of the population. However, because young are often difficult to capture and track, our knowledge of rearing areas is usually less than perfect. This means that detailed descriptions of rearing areas do not exist. Instead, much of what exists is incidental observations made by scientists while conducting other species-related study.

One study of larval fishes does provide some significant insight into the rearing area for Atlantic herring within the Minas Basin. It appears that the unique spring spawning population of Atlantic herring that occur in the Minas Basin spend the early larval portion of their life cycle completely within the Minas Basin (Bradford and Iles, 1993). Furthermore, much of the rearing population is centred in the south Central Minas Basin off the Walton River Estuary. Because these early larval fish primarily drift with the currents of their surrounding waters, it appears that local currents help to maintain the larvae in a local distribution for at least 60 days (see Figure 13.1) (Bradford and Iles, 1993) while the fish develop. This is a significant observation in that the majority of the basin is believed to flush to 1% retention of passive contaminants in five days (Ketchum and Keen, 1953, cited in Bradford and Iles, 1993). The suggestion from such knowledge would be that larval fish would be flushed completely out of the Minas Basin within a week. However, the work by Bradford and Iles (1993) demonstrates that this is not the case. It also highlights the significance of a very small area for a very important life-cycle stage of a relatively abundant fish species within the basin.

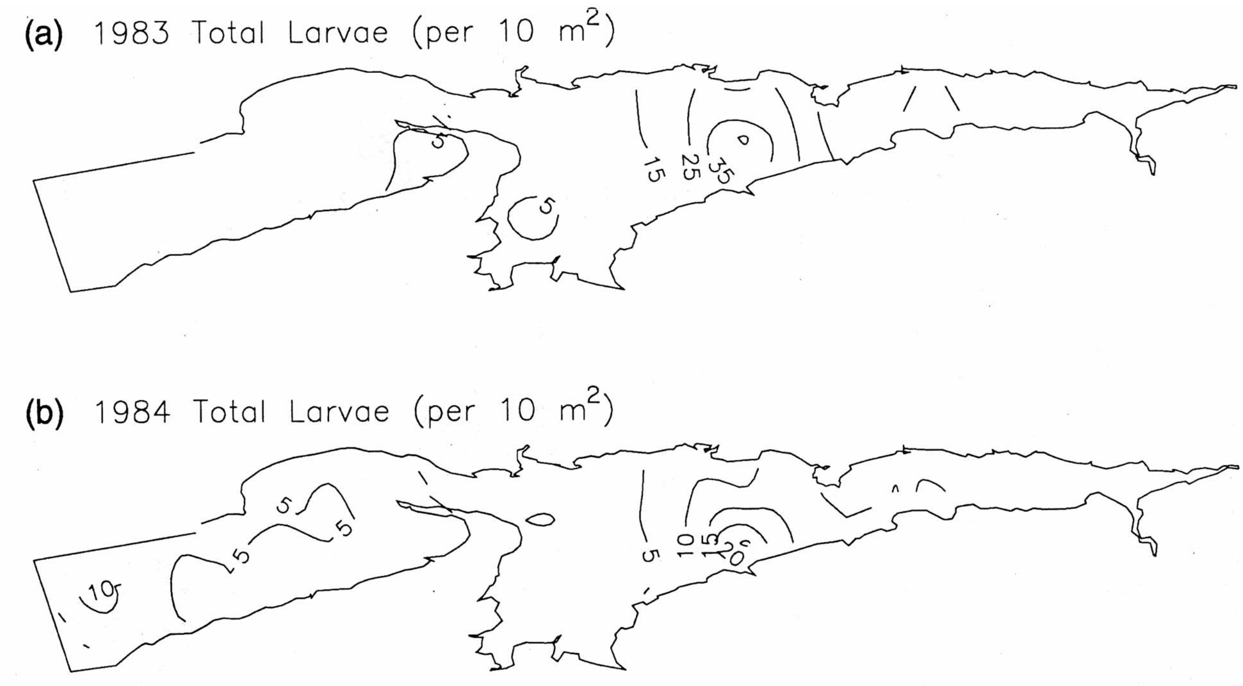


Figure 13.1 *Density contours of larval herring sampled in the Minas Basin in 1983 and 1984 show that the highest densities exist in the south Central Minas Basin near Walton*

Source: Bradford and Iles (1993)

On the other end of the spectrum, computer modeling has been used to categorize Atlantic salmon habitat in the rivers of the Minas Basin. In total, the 18 historic salmon rivers of the Minas Basin have an estimated 7.56 million m^2 of accessible rearing habitat (Amiro, 2003), or about 59% of all available rearing in the Inner Bay of Fundy. The Shubenacadie, Stewiacke and Salmon rivers (Truro), all of which enter Cobequid Bay, each have more than 1 million m^2 of estimated rearing. This volume of rearing habitat would not be considered limiting to the production of the Inner Bay of Fundy population and is not considered a cause for its downturn.

A brief observational statement of functional rearing area for the threatened Bay of Fundy striped bass population has been made. Douglas et al (2003) noted that young-of-the-year Shubenacadie–Stewiacke bass appear to stay in the turbid, relatively warm water portions of the Minas Basin.

13.3 FORAGING/FEEDING AREAS

Foraging and feeding areas are much easier to observe for terrestrial and avian species than aquatic species simply because we, as humans, need to move beyond our natural element and into the aquatic world to be able to make such observations of fish. The effectiveness of our aquatic observations becomes somewhat limited by the technology that allows us to function in marine and freshwater environments. So we begin here with two of the "easier" terrestrial observations that have linkages to marine biota. Many species of birds have adapted through evolution to feed in aquatic environments, primarily on the rich invertebrate and fish communities.

Hunting activity by peregrine falcon has been noted on the tidal flats of Evangeline Beach in the Southern Bight of the Minas Basin (Museum of Natural History, 2007). During recent years, peak counts of migrating shorebirds in the Minas Basin and Bay of Fundy have increased from 60,000 in 1977 to over

200,000 individuals in 1994. It is expected that foraging peregrines on the New Brunswick side of the Bay of Fundy may have caused shorebirds to shift their distribution (NSDNR, 1994) and, more recently, to congregate in areas along the Nova Scotia side of the Minas Basin, where they feed primarily on the amphipod *Corophium* in the tidal mudflats. However, some peregrines have been sighted on the Nova Scotia side, and areas such as the Evangeline Beach in the Southern Bight of the watershed appear to now be a significant forage area for newly fledged chicks as they begin to move away from their parents' territory (Elderkin, pers com, 2007).

The success observed in the recovery of the peregrine falcon population is likely due, in part, to the quality of foraging areas around the Inner Bay of Fundy, including the Minas Basin watershed. Examination of prey remains shows that small inland birds such as robins, blue jays and flickers are an important food source, and they are likely hunted on the numerous blueberry fields and cultivated lands of the Inner Bay (Elderkin, pers com, 2007).

As shown in Figure 13.2, observations of bird use around the Windsor mudflats during the summer of 2002 revealed specific patterns of foraging on the mudflat (Daborn et al, 2003). Black ducks (*Anas rubripes*) and herons (*Ardea herodias*) were commonly present in the tidal channels, while greater black-backed gulls (*Larus marinus*) were common foragers on the mudflats. Cormorants (*Phalacrocorax auritus*) commonly foraged in the West Channel of the Southern Bight mudflat, while migratory shorebirds (principally semipalmated sandpipers) seemed to forage primarily on the unvegetated areas seaward of the outflow of the St. Croix Estuary. Semipalmated plovers (*Charadrius semipalmatus*) were seen to forage on unvegetated areas near the marsh, where polychaetes were abundant (Daborn et al, 2003). The principal users of the marsh and mudflats nearer to the causeway appear to be plovers, herons, black duck and gulls.

Although there appears to be a high use of the Windsor mudflat next to the Avon River causeway, the major foraging area for shorebirds in this area of the Southern Bight may be on the distant mudflats beyond the St. Croix Estuary channel (Daborn et al, 2003). This seaward area, called the Newport Bar, is separated from the Windsor Causeway marsh/mudflat by a channel of the St. Croix Estuary. It has a well-developed benthic fauna that is dominated by *Corophium volutator* in abundances that approach the higher range observed on other productive mudflats in Minas Basin that are frequented by migratory shorebirds. Observations have indicated that this bar has recently become the principal feeding area for semipalmated sandpipers in the upper Avon Estuary (Daborn and Brylinsky, 2004).

The final avian foraging observation made with a particularly marine linkage is that of eagles and tomcod. Reid (1982, cited in Dadswell et al, 1984) reported that tomcod (*Microgadus tomcod*) spawned in the Shubenacadie River in such high numbers during the early 1980s that a large population of bald eagles (*Haliaeetus leucocephalus*) would overwinter there, feeding on the concentration of spawning fish.

As noted, identifying fish forage areas can be more of a challenge to scientists. However, through examination of stomach contents, tagging and tracking of fish, and other techniques, we can learn much about what areas are spatially important to various species as feeding grounds.

On a very local and small scale, Stone and Daborn (1987) suggest that the two *Alosa* species, blueback herring and alewives, likely forage at different locations within the Minas Basin and at different periods of the tidal cycle during their overlapping presence in the basin. By examining their stomach contents, alewives appear to feed primarily on benthic organisms, many of which can only be accessed as the high tides cover the Minas mudflats, while bluebacks appear to feed within the water column and closer to the sub-tidal portion of the near shore.

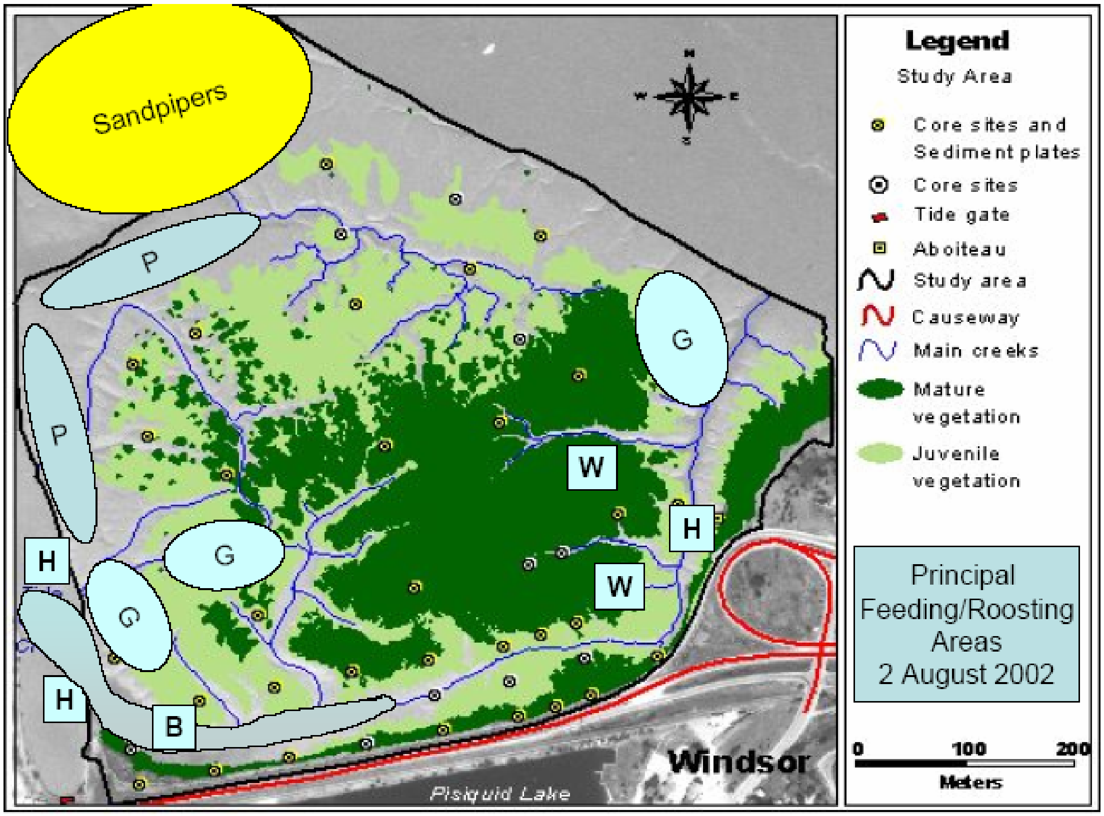


Figure 13.2 *Spatial observations of coastal birds on the Windsor marsh/mudflat next to the Avon River causeway*

Notes: B = black duck; G = black-backed gull; H = blue heron; P = semipalmated plover; W = willet

Source: Daborn et al (2003)

Striped bass have been surveyed at the Avon River Estuary in the Southern Bight as recently as 2003. Stomach contents indicated that they feed on epibenthic animals, especially the shrimps *Crangon septemspinosa* and *Neomysis Americana* (Daborn and Brylinsky, 2004). It appears that the spawning population from the Shubenacadie–Stewicake River system maintains a summer marine range within the Minas Basin, rarely straying beyond the limits of the watershed defined in this report (Douglas et al, 2004). This means that populations must also forage within the confines of the Minas Basin. Along with the Shubenacadie/Stewiacke bass, tagged fish returns tell us that striped bass from waters of the Eastern Seaboard of the US also come to the Bay of Fundy and Minas Basin to forage during the summer (COSEWIC, 2004).

13.4 MIGRATION ROUTES

By physical structure alone, the Minas Channel is the "gateway" to the rest of the Minas Basin, and any diadromous species that moves between fresh and deeper marine waters will migrate through the relatively narrow passage of the Minas Channel. For some species, such as Atlantic salmon (which, in the Minas Basin, rely on a more frequent repeat spawning than coastal Atlantic salmon; Amiro, 1987, cited in Amiro, 2003), an individual fish may pass through the area as many as eight or nine times between when it leaves as a smolt and returns on successive spawning runs. Eels, shad, gaspereau, dogfish and herring will all pass through the channel during life-cycle migrations. Others such as Bay of Fundy striped bass and Atlantic sturgeon likely move through the channel infrequently, but are known to be within and beyond the channel. Yet other populations from far away, such as the striped bass that spawn in estuaries in the eastern US, appear to seasonally pass through the Minas Channel (Douglas et al, 2004). Unfortunately, as significant as this area is as a simple conduit to the open ocean, we do not know how our current activities of fishing and shipping, or proposed activities of tidal power, may affect the various species that travel at various depths of the water column.

Huntsman (1936) noted from data collected on salmon catches that early in the season salmon tended to follow the south shore of the Minas Channel up Scots Bay towards Cape Split. He was able to graphically demonstrate (see Figure 13.3) what appeared to have been a key migration route, for there are no significant salmon rivers that flow from the North Mountain in the area that would otherwise entice such a congregation. Huntsman (1936) noted that salmon could first be observed at the surface of the water near Cape Split in early May, but much later along the remainder of the Bay of Fundy coast. He further suggested that the buildup of fish just east of Cape Split along the southern shoreline could be the result of the intense mixing of waters that impeded their ability to sense their natal waters; thus, he called them “lost” salmon. He felt this was so because the salmon landed in the larger rivers of the Minas Basin

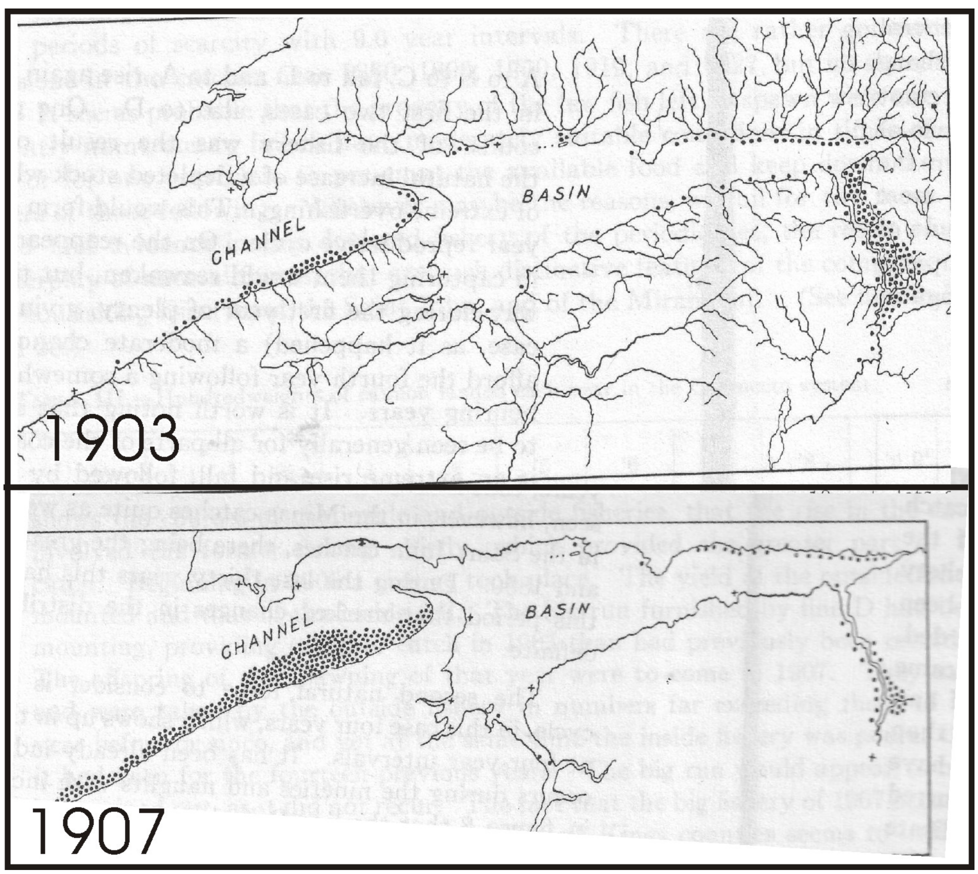


Figure 13.3 *Approximate locations of Atlantic salmon catches in 1903 and 1907 demonstrate the congregation of fish along the south side of the Minas Channel and in the spawning grounds of the Shubenacadie River*

Source: Huntsman (1936)

tended to be smaller grilse, and not the larger fish captured in the outer Minas Channel. If this observation were accurate, the Minas Channel would appear to have been a staging area for salmon from rivers around the Inner Bay of Fundy. Further study by Huntsman revealed that both mature salmon and post-smolts congregated along the shoreline between Margaretsville and Scots Bay, with the largest fish arriving in May and the post-smolts present in August (Huntsman and Rice, 1946). We now understand that a number of species such as herring (Huntsman and Rice, 1946) and dogfish travel a similar route up the southern shoreline of the Bay of Fundy towards the Upper Bay, likely following the tidal swell that runs strongest along that shore, known as the Coriolis effect.

The Minas Basin has a unique population of spring spawning Atlantic herring. Analysis of parasite infection suggests that these herring migrate out of the Minas Basin through the Minas Channel to the southwestern edge of the Scotian shelf for the summer, where they feed with other Bay of Fundy herring populations (Bradford and Iles, 1992).

The semipalmated sandpiper migration is one of the Minas Basin's most significant, as 70% of the world's population congregate annually on the tidal mudflats (Hicklin, 1987) to forage on the marine invertebrates that the basin produces. During recent years, peak counts of migrating shorebirds in the Minas Basin and Bay of Fundy have increased from 60,000 in 1977 to over 200,000 individuals in 1994 (NSDNR, 1994).

13.5 Critical Marine Habitats (SARA)

Under SARA (the federal Species at Risk Act), critical habitat is defined as the habitat that is needed for population survival or recovery. For the Inner Bay of Fundy, Atlantic salmon (*Salmo salar*) recovery targets are needed in order to determine critical habitat for this species. For the Shubenacadie River, which enters the Cobequid Bay of the Minas Basin, recovery targets of 772 small and 289 large salmon, or between 568 to 1923 salmon per iBoF rivers, have been calculated (Trzcinski et al, 2004). However, this only provides part of the answer in defining critical habitat. Determining the habitat quality and quantity necessary to support the recovery target number of fish is yet another question. To date, it has been determined that the quality and quantity of freshwater habitat is not limiting to this species production, and therefore designation of SARA freshwater critical habitat would have little effect on the population. Although we do know that poor marine survival is the most apparent cause for the population collapse, we do not know why survival at sea is poor. Therefore, it has not been possible to determine where critical marine habitats exist, as defined under SARA, resulting in no critical marine habitat being designated for the Atlantic salmon (Trzcinski et al, 2004).

Other than the report regarding Atlantic salmon by Trzcinski et al (2004), no other critical habitat reports or statements exist for any of the nine Minas Basin SARA designated species today (SARA, 2007). However, the topic has been more generally discussed in relation to the striped bass.

SARA prohibits damaging or destroying the residence of a listed threatened, endangered or extirpated species, such as the Atlantic salmon and striped bass of the Minas Basin. A residence is defined by SARA as a dwelling place that is similar in either form or function to a den or nest. Relative to the striped bass, there is insufficient information to determine if the concepts of residence and critical habitat as defined by SARA would apply to the Minas Basin (Lanteingne, 2006). Scoping of the issues did, nonetheless, reveal that pre-spawning staging areas, spawning sites and wintering areas represent habitat that is essential for completing the life cycle, and which are potentially definable in time and space. For the Minas Basin, the locations of these sites are identifiable in general terms and could be protected under the Fisheries Act (Lanteingne, 2006).

13.6 Coastal Habitats

A number of coastal habitats support both marine and terrestrial fauna. These near-shore areas include the full intertidal range, or that portion of land that becomes flooded by rising tides and is exposed by receding tides twice daily. It also includes immediate subtidal zone, or that area just below the lowest tide level that never quite becomes exposed. These areas are often used by a number of terrestrial species as forage areas and serve as the link between the terrestrial and marine components of the ecosystem. They are in some ways easier for us to observe and study scientifically; but they are also areas that can be directly affected by land-based activities. Some coastal habitats are sensitive and some are simply limited in volume. They all add to the diversity of habitat and species found around the Minas Basin.

13.6.1 Subtidal Zone

The subtidal area of the Minas Basin and outer Cobequid Bay is comprised of gravel and sandy gravel (Pelletier, 1972) with outcrops of bedrock. At the seaward edge of the intertidal zone, there is a portion of seabed that is only exposed during lowest spring tides. This area extends subtidally as a large body of gravel lag. The fauna found here is limited to organisms such as Amphicteis (scale worm) and Sabellaria (Craig, 1976). Along with the more coarse gravel, there is reworked shell material.

13.6.2 Intertidal Habitats

The intertidal zone of the entire Minas Basin is mostly sandy mud overlying Carboniferous and Triassic sandstone. During the summer, when storms are infrequent, soft mud collects on the flats in depths of 20 cm to 30 cm (Bousfield and Leim, 1959). The Minas Basin mudflats vary greatly in substrate composition (McCurdy, 1979), from sand to fine silt. Based on the type of sediment accumulation, mudflats can be divided into two categories: vertical and lateral (Craig, 1976). Vertical accumulation is a result of sediment being deposited directly on the flat, building upwards. Lateral accumulation results from tidal streams eroding back and forth across the flat, reworking the original deposits and building laterally. Vertical sedimentation deposits are usually intensely bioturbated by *Corophium*, *Neanthes*, *Heteromastus*, *Polydora* and *Macoma* (Craig, 1976). Lateral sedimentation deposits, which are usually found on reworked shells and gravel, are usually more liquid in nature and hold fewer *Macoma*. *Corophium* and *Neanthes* are present, but are also usually fewer in numbers, thereby bioturbating the sediment far less (Craig, 1976).

Table 13.2 *Estimates of intertidal area and intertidal habitats by sub-watershed for the Minas Basin as calculated in 1973: Results for the Minas Channel were not identified*

Sub-watershed	Intertidal zone (ha)	Percentage intertidal	Total salt marsh (ha)	High salt marsh (ha)	Low salt marsh (ha)	Mudflats (ha)
Cobequid Bay	17,560	59%	373	226	147	17,187
Central Minas Basin	9710	15%	290	188	102	9420
Southern Bight	11,250	53%	2037	960	1077	9213

Source: Prouse et al (1984)

The intertidal area consists of tidal mudflats that become exposed at the low tide. As one moves towards land, the mudflats often merge into a low salt marsh where vegetation has become established, and then a high marsh that is periodically flooded by tidal waters but is predominantly dry. Within the Cornwallis River Estuary of the Southern Bight, the high marsh vegetation consists primarily of *Spartina patens*.

Between low and high marshes exists a transition area where *Juncus* spp (rushes) and *Spartina* spp (cordgrass) dominate. The low marsh is dominated by *Spartina alterniflora* before giving way to exposed mudflats (Perry-Giraud, 2005). This pattern can be seen in various locations around the Minas Basin.

Intertidal mudflats become exposed for several hours during each tidal cycle, particularly in the Cobequid Bay and Southern Bight of the Minas Basin. As shown in Table 13.2, much of the intertidal area of the Minas Basin occurs in these two areas, with a moderate amount within the Central Minas Basin along the Parrsboro shore, and very little in the Minas Channel. In the Southern Bight and Cobequid Bay, there are areas where the intertidal zone extends 1 km from shore (Hamilton et al, 2006) to as much as 2 km (Perry-Giraud, 2005). Figure 13.4 depicts the distribution of approximately 358 km^2 of intertidal flats that are exposed at low tide. This area accounts for close to 32% of the total area of the "estuary" east of the Minas Channel (Amos and Joice, 1977; Yeo and Risk, 1981, cited in Perry-Giraud, 2005).

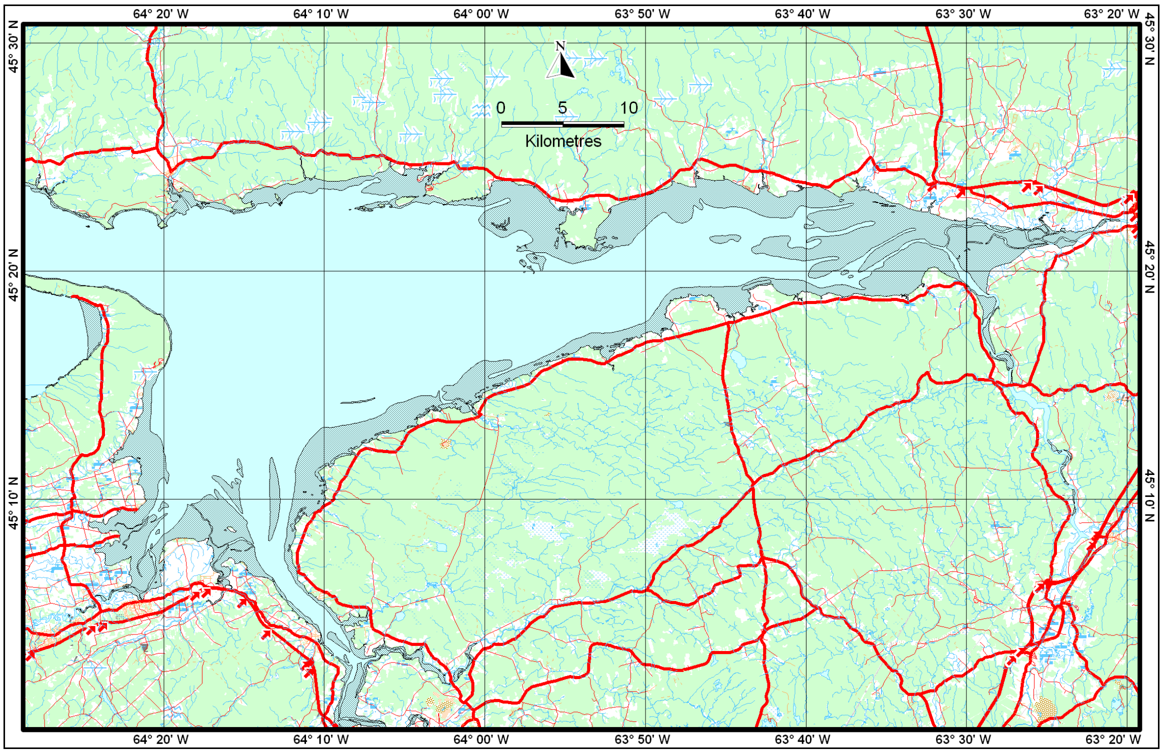


Figure 13.4 *This map of the Minas Basin details the extent of intertidal area (portions in grey) that is exposed at low tide*

Source: Stanley Johnson, Fisheries and Oceans Canada (adapted from Natural Resources Canada NTDB 1:50,000 digital map series)

To the untrained eye, the area seaward of any tidal marsh in the Minas Basin often appears as an expansive mudflat. However, a number of physical processes related to erosion, deposition, stream flow and tidal movements help to sort and shape the sediments in ways that have significant impacts on what marine creatures are likely to inhabit them. Fine silt and mud dominate the upper portions of the tidal flats and contain higher volumes of organic detritus from the nearby marshes. The content of sand within the tidal flat gradually increases as one travels from high water to the low water mark, with the latter typically becoming an area of rippled sands. In the transition area from upper tidal mudflat to the lower areas, *Macoma* and *Corophium* are still found, but in fewer numbers. Predatory burrowing moon snails (Polinices) area also found here. Once fully in the rippled sand area, tube-building polychaetes, particularly the Spionids, are dominant. Bamboo worms and *Clymenella* are also present (Craig, 1976).

In the still lower part of the tidal cycle, mega-rippled sands become exposed. These result from higher velocity tidal currents, and they become the dominant structure of the lower intertidal zone, replacing the biological structures associated closer to shore (Craig, 1976). Many large sand bars have developed in Cobequid Bay, with lengths of 1 km to 10 km and widths of 0.2 km to 4.25 km (Dalrymple, 1977) (see Figure 13.4). A large, partly intertidal, sand body that has developed in Cobequid Bay extends eastwards for over 25 km to the mouth of the Salmon River near Truro. This body is 10 km wide and has a thickness of almost 20 m. Mobile organisms such as *Crangon*, *Pagurus* and some polychaetes are found here (Craig, 1976).

13.6.3 Salt Marshes

For thousand of years now, the twice-daily tides have deposited tonnes of sediment along the tidal portions of the river valleys emptying into the bay. At the Windsor marsh, sediments settle during the slack water at an average of 7.8 mg/cm^2 (± 13.0) (Daborn et al, 2003). As a result, salt marshes exceeding 30 m in depth can be found around the bay (Davis and Browne, 1996a). Like most salt marshes, those around the Minas Basin play an important role in the stability, productivity and diversity of the marine waters. Even the relatively new 185 acres of salt marsh and tidal mudflat that have formed at the Avon causeway since about 1970 serve important ecological functions, such as the export of macro-detritus, feeding grounds for a range of waterfowl (van Proosdij, 2005) and as habitat for a number of fish within the tidal creeks (Daborn and Brylinsky, 2004).

Well over 300 years ago the Acadian settlers considered the salt marshes, which were clear of stones and trees, a rich resource for agricultural uses (Hilchey, 1981). It has been estimated that approximately 80% of the original Bay of Fundy salt marshes have been lost as a result of extensive dyking (Gordon and Cranford, 1994, cited in Daborn et al, 2003), much of which was carried out in the upper reaches of the bay by the original Acadian settlers. The present-day extent of salt marsh within the Minas Basin is about 2700 ha to 3800 ha, likely about <15% of what existed pre-contact (Daborn et al, 2003). A shown in Table 13.3, approximately 84% of the present day salt marshes found within the Minas Basin exist in the Southern Bight and Cobequid Bay.

Table 13.3 *Area (in hectares) of salt marsh found in the Minas Basin sub-watershed areas*

Region	Area (ha)	Description
Minas Channel	247.1	Cape Chignecto to Harbourville; Partridge Island to Blomidon
Southern Bight	1851.4	South of the line from Blomidon to Bramber (including the salt marshes along the Kennetcook River and the St. Croix River)
Cobequid Bay	1379.7	West of line from Economy to Cape Tenny (including salt marshes along the Shubenacadie River)
Central Minas Basin	376.6	Everything not covered above (south shore from Bramber to Cape Tenny, north shore from Economy Point to Partridge Island)
TOTAL	3854.8	Entire Minas Basin, from Cape Chignecto along the shoreline to Harbourville

Source: Calculations derived from the Nova Scotia Department of Natural Resources wetland database, which is based on aerial photography between 1992–1996; estimate provided by the Nova Scotia Department of Natural Resources Kentville office

Salt marshes need an area of low energy to become established, sheltered from all but the worst wave and storm action. Once they have taken root, however, they are extremely resistant to erosion and damage from storms. Within the Minas Basin, winter ice formation has been shown to be one of the significant means of salt marsh expansion. Spring tides with any wave action float ice blocks that, on occasion, freeze to the surface of the marsh. They then rip out marsh vegetation and their roots (van Proosdij, 2005) before drifting away. If an ice block melts, dropping the marsh vegetation on an aggrading portion of mudflat, the possibility of new colonization exists. This process has been visible to residents of the Minas Basin near the Windsor Causeway in the Southern Bight, where rapid mudflat formation has occurred since the 1970s, followed by colonization by marsh vegetation (Daborn et al, 2003).

Salt marshes are typically divided into two distinct zones. In the Minas Basin, the lower marsh spans the upper third of the intertidal area (Patriquin, 1981) and experiences flooding with the normal tidal cycle, while the upper marsh is found above the high tide line and experiences flooding only several times a season (during storms and extreme tidal events) (Bowron et al, 1999). In the Maritimes, salt marshes represent the climax community for coastal floodplains. The amount of exported nutrients, primarily in the form of dissolved organic nitrogen, is thought to be relatively high, supplying the main source of organic detritus (i.e. food) to the tidal flats (Craig, 1976). Yeo (1977) found refractory salt marsh organics to be in all Minas Basin intertidal sediments, verifying that salt marshes contribute substantially to the ecosystem as a whole.

13.6.4 Cliff Habitats

Significant cliff habitats are found on the north side of the Minas Channel at Cape d'Or and Cape Sharp, and on the southern side of the channel at Cape Split and the Sheffield Vault bluff near Halls Harbour. These comprise a very limited coastal habitat within the Minas Basin and are significant because of the historic nesting and current use of the peregrine falcon. The peregrine is listed under both federal and provincial species at risk legislation.

In the Minas Basin the peregrine has historically been found nesting along cliffs both north and south of the Minas Channel (Museum of Natural History, 2007) and in the Parrsboro area of the north Central Minas Channel.

14. TERRESTRIAL COMMUNITIES

This *Ecosystem Overview Report* (EOR) is based on watershed boundaries. Watersheds tend to have reasonably definable boundaries of study based on the height of land between neighbouring drainage systems. Terrestrial communities do not, of course, always recognize the hydrological boundaries of a watershed any more than they do some of our political ones. Instead, the flora and fauna of the land are more likely to be distributed based upon such variables as surficial geology and climate factors. It has not been within the scope of this report to evaluate the terrestrial components of the Minas Basin ecosystem. However, it is important to acknowledge that significant physical and biological linkages occur between terrestrial and marine communities. The strongest of these linkages is through the freshwater river systems that carry a chemical signature to the marine waters, and act as spawning and nursery habitat for a number of diadromous species, influencing coastal geomorphology by sculpting the vast tidal deposits of marine sediments. Chemistry has been briefly discussed in Section 8.1 “Freshwater Inputs”, and the use of several systems by diadromous fish is covered in Section 13.1 “Spawning and Reproduction Areas”.

14.1 FRESHWATER RIVER HABITATS

The long history of land use in Nova Scotia has altered many natural features, including streams and rivers. Only a small number of river sites around the Minas Basin remain bordered by mature or old growth forests, and recent study of freshwater habitats in these areas suggests that habitat features are likely altered from what would be expected in an undisturbed river. Even in river areas of the Minas Basin that have mature riparian vegetation, stream habitat features, such as the number of pools, pool spacing, depth of pools and cover, indicate impairment (ECA, 2006). This observation is critical given that the frequency of large woody debris (a major influence on channel-forming processes) within the channel adjacent to mature forests approximates that observed in other undisturbed areas of Canada (ECA, 2006). Degraded river habitat within the Minas Basin may have direct or indirect negative effects on a species of fish with a marine life-cycle component, may have undetermined effects (Lanteigne, 2006) or may have little apparent effect (Amiro, 2003). However, in general, little study has been conducted to examine how changes in quality or quantity of accessible freshwater habitat have affected diadromous populations within the Minas Basin.

15. Biological System Information Gaps

A number of biological system information gaps exist for the Minas Basin. Some are spatial in nature, such as areas where little study has been conducted. Others are temporal gaps, where we may have a moderate body of knowledge from a given period of time, but lack either complimentary seasonal or decadal information upon which to make informed decisions. As is often the case when we study biota and habitats, more questions are raised than answered. Therefore, the identification of gaps is not necessarily acknowledgement of minimal knowledge on a topic, but instead simply an understanding that there are further complexities to unravel. Many of the biological information gaps are very species specific and indicate an imbalance in our inventory of biota, spatially or temporally. Other gaps related to species biology exist, but they involve more detail linkages to the physical and biological components of the watershed and are therefore discussed under Section 17 "Ecosystem Relationships Data Gaps".

One of the biggest biological system gaps relates to the functions of the Minas Channel. The physical structure of the Minas Channel allows it to function as a "gateway" to the rest of the Minas Basin; yet, biologically we have not assessed it as such. It controls how much tidal exchange occurs, and inhibits or facilitates the movement and distribution of various species between the Bay of Fundy and the Minas Basin. Although in many ways it is vastly different than much of the Minas Basin in terms of chemical and physical oceanography, it is of great importance to biological processes of drift, dispersion and migration. Understanding the channel as a migration route for species into and out of the basin is critical because any current human activities such as fishing and shipping, or proposed activities such as tidal power generation, have the potential to interrupt the life cycle of a large number of species as they move through this area. Understanding seasonality of movements and species use of the water column by depth and life stage in the Minas Channel are critical gaps that need to be filled in order to manage our own impacts on the biota of the Minas Basin effectively. Species for which this knowledge is particularly important would include the Atlantic sturgeon, Atlantic salmon, striped bass, gaspereau, shad, dogfish, and herring, as well as various species of ground fish.

Without learning which factors are causing poor marine survival of Inner Bay of Fundy Atlantic salmon, the genetically distinct fish from the Minas Basin and Gaspereau River are unlikely to recover. Even with such knowledge, recovery may not be possible. At the spatial scale of the Minas Basin ecosystem, we need to understand the movements and migration routes of smolts and post-smolts through the Minas Basin, and their survival within the basin by life stage. This fills a current knowledge gap and will allow us to identify any critical concerns with the early stages of the salmon's marine survival within the basin. At an even larger spatial scale, insufficient data exists to evaluate the efficacy of marine habitat protection for the recovery of iBoF Atlantic salmon. Mortality rates of immature fish at sea are extremely high, and identification and mitigation of the cause(s) are critical if the salmon are to be recovered (Trzcinski et al, 2004).

Heavy metals can be toxic to living biota and have serious consequences for their survival and reproduction. However, comprehensive environmental quality guidelines that are linked to biological impairment do not currently exist. Elevated levels of dissolved metals, particularly copper, have been found in the Minas Basin, and a significant accumulation of this metal has been measured within the tissues of lobster in the basin. There is a need to determine if the copper levels observed are having a detrimental impact to that species. Similarly, slightly elevated mercury levels have been found in the COSEWIC listed striped bass that spawn in the Shubenacadie River. Assessment of the potential impact on that species, and examination of the time frame over which these metal concentrations are likely to have persisted, and the pathways by which they are accumulating in the biota, is necessary. The presence of elevated metals in these two species is an indicator that others should be examined and biological impacts to the flora and fauna of the marine component of the ecosystem assessed.

Atlantic sturgeon has been found in moderate numbers within the Minas Basin in recent surveys (Dadswell et al, 1984; Dyer et a,. 2005). Because of its longevity and slow aging to maturity, this bottom-dwelling species can be particularly susceptible to human impact. As a “Red” listed species within the province it is “known to be, or is thought to be, at risk” (NSDNR, 2007); yet, we know very little about it within the Minas Basin. Evaluation of its spatial and seasonal use of habitats within the Minas Basin by life stage is necessary to understanding the risks that it faces and to facilitating species at risk management.

Lanteigne (2006) identifies several uncertainties with regard to human activities that may be affecting the threatened Bay of Fundy striped bass population that spawns in the Shubenacadie River. These variables include the effects of illegal poaching; by-catches in recreational and aboriginal food fisheries; unintentional mortality at permitted tidal power stations; habitat impacts from municipal waste treatment, agriculture and pulp and paper facilities; ecotourism; and shipping noise. Addressing these uncertainties would allow for the development of a fact-based recovery strategy for the Shubenacadie River striped bass population.

Very little discussion on the microalgae of the Minas Basin exists. Yet, intertidal sediments contain abundant benthic diatoms, and blue-green microalgae slicks are also commonly found. Many researchers have pointed to the importance of this community in the productivity of the ecosystem, suggesting that they may provide half of the primary production of the system (BoFEP, 2001). Researchnig contributions of microalgae on the mudflats, phytoplankton throughout the watershed and macrophytes in the Minas Channel and Central Minas Basin to the productivity of the Minas Basin is a biological systems gap that needs to be addressed. Gordon and Dadswell (1984, cited in Daborn, 2006) provided a description appropriate to the Minas Basin for a system with a production “pump” at each end: one based upon seaweeds and phytoplankton, and the other upon benthic diatoms and salt marshes. Not having clear understanding of the basic production from both ends of this “pump” of the Minas Basin ecosystem inhibits effective management of human activities and impacts in the watershed.

Although the freshwater systems of the Minas Basin support significant spawning populations of a number of diadromous species, including federally and provincially listed species at risk, virtually no study has been conducted on how habitat quality or quantity within the rivers has changed, or what are the implications of such changes. The Minas Basin has undergone hundreds of years of land alteration since the arrival of the first European settlers, and much of that alteration has affected river habitat quality. We have also installed a road crossing, splash dam, aboiteau, mill, hydro-dam or other structures on virtually every freshwater system. Many of these structures limit access of diadromous fish species to otherwise appropriate habitats. Therefore, understanding the implication of habitat quality and quantity changes in the freshwater portions of the watershed for the diadromous species that migrate to and from the marine waters of the Minas Basin remains a significant gap in the biological systems.

Spatially, the open water areas of the Central Minas Basin and Minas Channel are less well studied biologically. Since these areas are the interface between the Bay of Fundy and the remainder of the Minas Basin, a spatial examination of species use for the various life-cycle needs of reproduction, rearing, foraging and migration in these areas would help us to understand how changes may affect the biological system and how to prevent an “uncoupling” of the basin from the Bay of Fundy. Temporally, a “winter” gap in biological knowledge exists, as it does in most areas of the province. Less than favourable conditions discourage and inhibit research much outside of the spring and summer time frame. A broader temporal gap exists between the large number of studies that were conducted within the Minas Basin during the 1970s and the present time. Changing climates, sea-level rise and resource extraction are but a few of the factors that bring into question the relevance of older studies to today’s decision-making. There has been some spatially limited recent study in the Southern Bight of the watershed; but, overall, relatively little current research exists. Certainly, gaps in knowledge that existed after the 1970s have rarely been filled.

PART D – ECOSYSTEM RELATIONSHIPS

16. MARINE ECOSYSTEM RELATIONSHIPS

Without a doubt, one of the most recognized relationships of the Minas Basin ecosystem is the linkage between *Corophium volutator*, a small amphipod that lives within the tidal mudflats, and migrating shorebirds. As much as 70% of the world's semipalmated sandpiper population is dependent upon the Upper Bay of Fundy tidal flats (Hicklin, 1987), including those of the Minas Basin, as a forage area during their north south migration. The continued health of the mudflats is critical to the production of *Corophium*, the primary prey of the sandpipers. During recent years, there has been great concern about declining numbers of *Corophium* in some Southern Bight areas such as Starr's Point and Johnson's Mills that used to be major feeding grounds (Shepherd et al, 1995, cited in Daborn et al, 2003).

This example shows how ecosystem linkages work. The health of a mudflat and the processes that affect it create direct linkage between the physical habitat and the biology of a small marine organism living in the mud and silt of the tidal flat. This small organism then has a biological linkage with a larger predator bird species, providing it with the nourishment necessary to complete a long seasonal migration. Understanding the details of all three components and how they interact is ecosystem science. For a long time, science has focused on single species assessment, both in the Minas Basin and around the world. We have often created inventories of the species that inhabit an area, and sometimes evaluate one aspect of their life cycle in a particular area. However, it is a relatively recent approach to examine the complex ecosystem linkages of a species at all life stages. This approach is driven, in part, by the need to manage our own activities and to understand the implications of our actions. Some of the more recent works within the Minas Basin attempt to address these multiple relationships (Bradford and Iles, 1993; Daborn et al, 1993; Daborn et al, 2003; Hamilton et al, 2006) and serve as examples of how we should focus future study.

This section of the Minas Basin *Ecosystem Overview and Assessment Report* attempts to outline some examples of understood, or at least studied, ecosystem linkages. These linkages are categorized as biological linkages between living things, or physical–biological linkages between an organism and its habitat.

16.1 PHYSICAL–BIOLOGICAL LINKAGES

Sediments play a large role in the Minas Basin ecosystem and have significant influence on the biological communities present. In this way, the physical processes that break down the soft geological structures and create high turbidity throughout much of the basin, suspending the eroded materials in the water column, have a direct impact upon biological community composition and distribution. Turbidity limits light penetration into the water column, which, in turn, inhibits the amount of photosynthetic production and phytoplankton growth that can occur. Limited phytoplankton communities can reduce the presence of higher trophic-level organisms or affect their distribution. Within the Minas Basin, relatively few pelagic fish species inhabit the turbid waters of the Southern Bight and Cobequid Bay. However, several benthic species come to forage on the diversity of invertebrates that inhabit the intertidal mud. Although some organisms thrive, achieving high densities in the turbid conditions (Risk, 1976; Yeo, 1977; Westhead, 2002; Daborn et al, 2003), the overall effect of the high turbidity of the basin creates a low diversity community of biota (BoFEP, 2001).

The sediments of the Minas Basin are linked to its biota in other ways as well. The sediments and waters of the north shore of the Minas Basin and the Shubenacadie River have elevated levels of copper (Chou et al, 2000; Yeats and Westhead, 2002) and mercury, respectively (BoFEP, 2004). Concentrations of such metals within biota, through a process called bioaccumulation, can become toxic and impair life functions. Up to 800 ug/g of copper have been measured in lobster tissues from the Minas Basin (Chou et al, 2000), and trace amounts of mercury have been found in striped bass that spawn in the Shubenacadie. Such observations suggest that there has been direct or indirect biological uptake of heavy metal by biota of the basin. The potential impact on the health of these species is not known, but the linkage between the physical habitat and the biological organism is apparent.

A final example of the physical–biological linkages that exist within the Minas Basin watershed relates to tidal exchange and herring larvae. Herring spawn near the bottom of the basin in very shallow waters, typically < 5 m. As the eggs first hatch, the fish larvae are passively mobile, and will be distributed by the currents around them. Although the majority of the Minas Basin is believed to flush out to the Bay of Fundy within a week, and within the Cobequid Bay as much as 76% to 94% of the water is believed to mix with the next seaward segment and not return on the flood (Ketchum and Keen, 1953), herring larvae remain concentrated in the south Central Minas Basin for at least 60 days (Bradford and Iles, 1993). Although the observation of herring retention is not fully explained, the Minas Basin herring population appears to have found a location within the basin where they can successfully spawn, while ensuring that their young will remain stationary long enough to progress through the necessary stages of development. The physical processes and the biological organism are part of a functional ecosystem linkage in the Minas Basin.

16.2 BIOLOGICAL INTERACTIONS

Biological interactions are the relationships that exist between one living organism and another. These may be predator–prey relationship, symbiotic and asymbiotic relationships, a herbivorous forage relationship of an animal feeding on a plant, or any of a number of other relationships across all the trophic levels that exist in the food web and energy paths of an ecosystem. Many such biological interactions are readily apparent, while some are very complex and are not revealed until significant study identifies the relationship.

A key example of the biological interaction of species within the Minas Basin watershed is that between peregrine falcons and the hundreds of thousands of migrating shorebirds that pass through the area beginning in late July. The peregrine is currently a COSEWIC listed species of special concern under the federal Species at Risk Act (SARA) and is listed as threatened under the Nova Scotia Endangered Species Act (ESA). When Nova Scotia numbers of peregrines were low, migrating shorebirds shifted their staging to the mudflats of the Minas Basin from the New Brunswick side of the Bay of Fundy (Percy et al, 1996), probably because of the reduced likelihood of predation by peregrines (Elderkin, pers com, 2007). Record numbers of shorebirds began to congregate on the mudflats in the Southern Bight to feed on the small amphipod *Corophium* during the 1990s, and numbers of birds tripled to over 200,000 (NSDNR,1994). During more recent years, the peregrine has made a substantial recovery, and the nine territories on the Nova Scotia side of the Bay of Fundy have an exceptionally high density for this bird (Elderkin, pers com, 2007).

As the peregrine has recovered, a greater number of adult and fledged young can be seen hunting the semipalmated and least sandpiper on the Minas Basin mudflats. This requires the foraging shorebirds to spend more time avoiding peregrines and less time foraging. The mean weight of the shorebirds has shown a marked decline over the past two decades, suggesting that they must now spend more time in the area to gain sufficient weight for the migration to southern wintering grounds (Elderkin, pers com, 2007). Others suggest that declining numbers of *Corophium* in some areas of the Southern Bight could affect the shorebirds (Shepherd et al, 1995), although no link to the bird's weight has been discussed. From an ecosystem standpoint, the biological interactions of two or three of these species appear to be contributing to population fluctuations as a new balance is sought.

Another biological linkage example exists within the Minas Basin where the benthic invertebrate community is a significant foundation for some of the top trophic levels observed within the Minas Basin. Although flatfish and tomcod may not be top consumers in the Minas Basin food web, they are likely near the top, at least in the more turbid areas of the basin. There they feed on the amphipod *Corophium* and bivalve *Macoma*. Skates and rays forage for the shrimp *Crangon* and worms (Risk, 1976). In other Atlantic coast areas, Atlantic sturgeon are known to feed heavily on polychaete worms and crustaceans (Cameron and Mitchell, 1999) that are found in high numbers through the sediments of the Minas Basin. Copepods *Eurytemora* spp and the mysid shrimp *Neomysis americana* have been noted as among the most important pelagic food of fish in the Minas Basin (Redden, 1986; Redden and Daborn, 1991; and Stone and Daborn, 1987, cited in Daborn et al, 2003; Daborn and Brylinsky, 2004). Striped bass have been surveyed at the Avon River Estuary in the Southern Bight as recently as 2003, and their stomachs have been found to contain epibenthic animals, especially the shrimps *Crangon septemspinosa* and *Neomysis Americana* (Daborn and Brylinsky, 2004). Through these various examples we can see the biological linkage between two assemblages of organisms within the Minas Basin community: the invertebrates and the fish. It should therefore be apparent that any changes that affect the mudflats and the invertebrates within them are most likely to affect the fish community of the basin.

16.2.1 Marine Food Webs and Energy Flows

For many marine organisms, their true place within the food web of the Minas Basin is undefined. For a few species, such as Atlantic salmon, a general predator–prey model has been developed (Cairns, 2006); but localized models generally do not exist. Prey of some species, such as alewives, has been evaluated specifically within the Minas Basin (Stone and Daborn, 1987); but the predator components are generally detailed. The exception might be of juvenile salmon of the Inner Bay for which avian, mammalian and fish predators have been identified (Amirault et al, 1989). However, most knowledge of food webs comes from observations of what prey has been found in the stomach contents of individual fish (Daborn and Brylinsky, 2004) or waste pellets around nests (Elderkin, pers com, 2007, regarding peregrine falcon). Understanding the intricacies of food webs and how energy flows through the ecosystem are lofty goals, but worthy targets if our objective is to try to manage our impacts on ecosystems, instead of single species management.

The following example demonstrates a number of physical–biological linkages and biological interactions that ultimately affect the food web of the Minas Basin. Based on recent observations, in areas with highly dynamic mudflat morphology, such as the Avon River Estuary in the Southern Bight, local food web interactions are also expected to be dynamic. It appears that the Newport Bar of the estuary has recently stabilized to the extent that rafted pieces of *Spartina alterniflora* have established. It can be expected that this marsh grass vegetation will probably spread rapidly over the next few years as it has done on the Windsor mudflat next to the causeway. However, in terms of food web dynamics, the implications are that marsh areas do not produce the same high densities of invertebrates found on open mudflat areas (Daborn et al, 2003). Since invertebrates, such as *Corophium*, form the base of the estuary food chain, it is expected that the Newport Bar will eventually become a poor foraging area for migratory species (Daborn and Brylinsky, 2004). Currently, several shorebird species appear in large numbers on the flat during their annual migration through the Minas Basin area.

It is important for us to also note that tropic interactions within the Minas Basin are not always as clear as they may appear, and that a “web” is the best description of the related biological interactions. Through a biological cascade, Daborn et al (1993) suggested that the arrival of migratory shorebirds, which predate on an amphipod that densely populates mudflat areas of the Minas Basin, reduced amphipod numbers significantly enough that the diatoms upon which the amphipod grazed would increase in numbers. The diatoms are known to secrete a polysaccharide that increases sediment cohesion in the mudflats.

Therefore, it was felt that the arrival of migratory sandpipers created a top-down cascade effect through the food web that ultimately resulted in what was an observed increased stability of the intertidal sediments. The work by Daborn et al (1993) was one of the more comprehensive attempts to outline the physical and biological linkages of the Minas Basin watershed. However, more recent work by Hamilton et al (2006) shows us exactly how complex some of the linkages are and demonstrates the need for more ecosystem-based science.

Hamilton et al (2006) set about to examine some of the biological linkages in the Minas Basin between migrating shorebirds, the amphipod *Corophium* and diatoms/bacteria. They knew that sandpiper feed on the amphipod, which, in turn, feeds on the diatoms and bacteria. However, by using enclosures and fertilizers in a variety of combinations, it was determined that both top-down and bottom-up forces affected the populations, but never beyond a single trophic level. This is to say that when shorebird predation on amphipods was high, diatom abundance did not increase. Similarly, if diatoms were increased through fertilization, amphipod densities did not increase, nor did shorebird predation increase. Such results were not widely anticipated.

Hamilton et al (2003) had noted in an early study of the Minas Basin that there was a strong negative relationship between the numbers of mud snails (*Ilyanassa obsoleta*) counted on a mudflat prior to the arrival of the migrating shorebirds and the number of shorebirds that would forage on the mudflat a few weeks later. Interestingly, the density of the birds' primary prey, *Corophium*, was not a good predictor of where the birds would forage. This demonstrates the importance of indirect biological relationships in the ecology of the area, and led Hamilton et al (2006) to suggest that an observed indirect response by the mud snail was compensating for both bird exclusion and fertilizer addition experiments. The indirect response of the snails prevented the anticipated trophic cascade as predicted by Daborn et al (1993). As shown in Figure 16.1, following the interactions of biota through only three trophic levels quickly becomes a complicated task, and we often understand few of the linkages that exist.

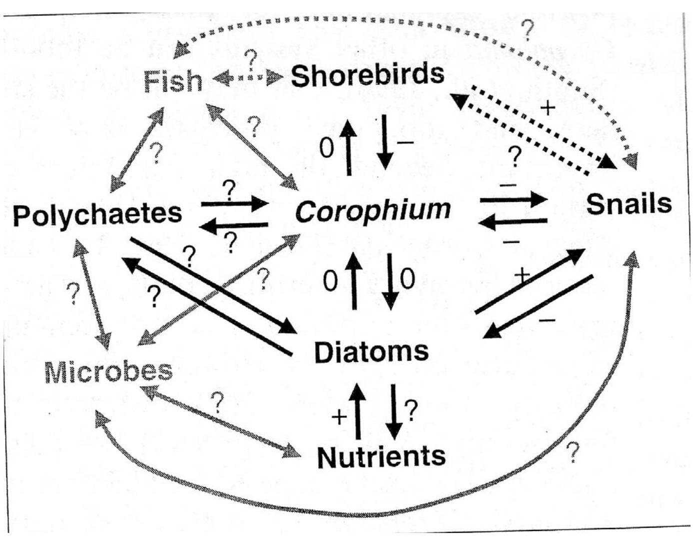


Figure 16.1 *Diagram of three levels of trophic interactions and potential effects based on Hamilton et al's (1999) studies of a mudflat near Avonport in the Southern Bight of the Minas Basin*

Source: Hamilton et al (2006)

All of these works discussed here highlight the need to understand the ecosystem linkages that exist. It is the complexities of these linkages that will challenge scientists as they undertake ecosystem science.

Very little is known about the energy flows through the Minas Basin ecosystem, and as noted in Section 15 “Biological Systems Information Gaps”, we have a poor understanding of the relative importance of various primary production mechanisms within the Minas Basin. Without clearly understanding production it is difficult to map relative energy flows through the ecosystem. Salt marshes are noted as important in nutrient supply and primary production within the turbid inner bays of the Southern Bight and Cobequid Bay (Walker et al, 1981; Prouse et al, 1984; Gordon et al, 1985; Gordon and Cranford, 1994; Daborn et al, 2003), and therefore, it would stand, initiate important energy flow through the ecosystem. However, the pathways of energy flow are not well defined within the Minas Basin.

17. ECOSYSTEM RELATIONSHIPS DATA GAPS

Using an ecosystem approach to science is a relatively new direction of study that is driven by our desire to manage at the ecosystem level. Because the approach is newly defined (although, certainly, some scientists have examined linkages in the past), relatively few existing works analyse the physical–biological linkages or biological interactions that drive the food webs and energy flows of the Minas Basin explicitly. This is further compounded by the fact that little funding has been available for research within the Minas Basin since the 1970s. The result is that ecosystem relationships within the Minas Basin are poorly defined.

Dyer et al (2005) carried out a number of interviews with fisheries organizations around the Minas Basin and Upper Bay of Fundy. They reported that people thought that ecosystem-based management would be a move in a positive direction. As managers and scientists consider ecosystem relationships, new terms are defined for old and new activities alike. Ecomorphodynamics refers to the study of the interactions and feedbacks that occur between topography, biota (e.g. vegetation and invertebrates), hydrodynamic (e.g. waves and currents) and sedimentary (e.g. suspended sediment concentration, deposition, erosion) processes and the resultant adjustment of morphology (van Proosdij et al, 2006). Individually, all of these areas of study have existed for decades. However, the term ecomorphodynamics brings them together in a way that encompasses ecosystem linkages and highlights the need to study them as one. Invasion ecology, or the study of the ecological effects of invasive species, is a similar term. Although invasion ecology remains a gap within the Minas Basin, its existence clearly highlights the need for knowledge on ecosystem linkages. Invasion ecology, like ecosystem science, allows us to better predict the ripple effects associated with introducing a new species (on purpose or by accident) or some other change to a system such as the Minas Basin. With invasion ecology the rate of change occurs over a very short period of time, and the opportunity to manage such change passes quickly.

As with most coastal ecosystems, local food webs and energy flows in the Minas Basin are not well defined and likely represent the largest gap in our knowledge of the ecosystem relationships of the Minas Basin. The high turbidity of the Southern Bight and the Minas Basin makes the use of more general energy and food web models inappropriate within the basin. The fact that the Central Minas Basin and Minas Channel are the interface between the Bay of Fundy and the rest of the Minas Basin adds unique complexities in terms of physical–biological linkages that are neither well studied nor understood. Many of the gaps are in our understanding of the oceanographic systems, particularly for the Central Minas Basin and Minas Channel. Addressing some of the gaps identified in Section 10 "Oceanographic Information Gaps" are necessary first steps in order for us to fill the more significant gaps regarding food webs and energy flows.

It is important to note that identification of keystone species or assemblages is critical to addressing gaps in our knowledge of ecosystem relationships. Otherwise the magnitude of the task would be beyond our capacity to perform in a timeframe supportive of the need for decision-making. As was shown by Hamilton et al (2006), understanding even three trophic levels within the Minas Basin (shorebirds, *Corophium* and diatoms) has proved a significant challenge. Focusing on keystone species would allow us to manage our activities around those species that support production and balance within the ecosystem. Yet, at the same time, we must heed the caution that a single species does not necessarily reflect ecosystem health. Monitoring ecosystem health is more likely to require a monitoring of ecosystem processes (such as rate of photosynthetic primary production by all plants) and/or a group of indicator species that represents endangered species, invasive species, keystone species and sensitive species found within an ecosystem (BoFEP, 2002), and in this way develops a suite of ecosystem indicators.

Ecosystem indicators are primarily biological in nature, whereas environmental indicators are those of physical and chemical habitat character. An environmental indicator (i.e. metal concentration) does not necessarily mean that a biological effect will result. Measuring an ecosystem indicator (i.e. population or individual robustness of a species) determines if a change is occurring without immediately confirming the causal factor. Several Atlantic Canada documents outline how to select indicators, what characteristics an indicator should have and how an ecosystem framework might work (Vandermeulen, 1998; Strain and MacDonald, 2002; Parker and Rutherford, 2003; Vickers, 2005; Wells et al, 2005, cited in Vickers, 2005; Rice 2006). However, in order to put these documents to work in selecting indicators and creating an ecosystem framework, we return to the fundamental ecosystem relationship data gaps of understanding both the food web and energy flows of the ecosystem. These are the fundamental gaps in our ecosystem knowledge of the Minas Basin that currently prevent us from implementing the selection of indicators and developing a monitoring framework, as well as managing an ecosystem.

Brylinsky (1996) presented a series of conceptual models of the potential energy flows for a number of biological communities within the Bay of Fundy. Enhancement of these models for the specific spatial context of the Minas Basin with additional research on the various physical and biological linkages would provide an invaluable tool in carrying out ecosystem management within the Minas Basin. The models would undoubtedly be complex; but understanding how changes in one component are likely to affect linked components would allow for informed decision-making on coastal management issues.

In terms of energy flow through the Minas Basin ecosystem, there is a specific need to refine the energy flow model for salt marshes in the Southern Bight and Cobequid Bay, and a need to define the contributions from the Minas Channel and Central Basin to the ecosystem. Examination of these two components will then allow for the development of a functional model of energy flow within the Minas Basin. Understanding primary and secondary productivity as pillars upon which ecosystem diversity and abundance are built will help us to ensure that we do not disturb critical components of the larger system.

PART E – CONCLUSIONS AND RECOMMENDATIONS

At a large spatial scale, the Minas Basin ecosystem is composed of two distinct areas: the turbid inner bays of the Southern Bight and Cobequid Bay, and the transitional areas of the Central Minas Basin and the Minas Channel that connect the whole to the Bay of Fundy. Critical information gaps in our knowledge of ecosystem relationships of the Minas Basin inhibit the successful management of our own activities in a manner that will not significantly alter the functions and biota of the basin. These ecosystem information gaps can generally be classified as relating to food webs or energy flows.

Because the Minas Basin is spatially distinct from the larger Bay of Fundy, it is best served by study regarding the specific food web and energy flow at either the scale of the whole watershed or at a complete sub-watershed. Such gaps are complex and will be a challenge to address. Concurrent efforts to address specific system-related information gaps are also necessary.

A number of system information gaps have been presented under the headings of Geological Systems, Oceanographic Systems and Biological Systems. Carrying out study that addresses the identified gaps should be done in a manner where physical–biological linkages or the biological interactions are explored. This approach will facilitate ecosystem management objectives that may exist or be developed for the Minas Basin. Those information gaps that are specifically examined in a way that reveals the food webs and energy flow pathways of the basin are critical to the eventual selection of ecosystem health indicators.

It is not an appropriate exercise to prioritize the identified information gaps without identified end objectives. However, some gaps do appear to be significant no matter the future direction of management.

Within the geological system, further understanding of the sedimentology and biological linkages is necessary. The importance of this evaluation is derived from the sediment–biology links that impact upon both the base of the food web and energy flow though the system.

Within the oceanographic system of the Minas Basin, understanding the two energy “pumps” is critical. Here we refer to the manner in which nutrients move and in which primary production occurs in the salt marshes of the inner bays (Cobequid and Southern Bight) compared to the Central Minas Basin and the Minas Channel. We need to further understand how oceanographic processes link these two pumps.

Within the biological system we need to address knowledge gaps of spatial use of the Minas Basin by life stage for the pelagic and benthic fish assemblages. Such study should assess the functional use areas, such as migration, spawning and foraging. Particular attention in spatially and seasonally assessing the Minas Channel as a migration route is important because it is the biological “gateway” to the Bay of Fundy and beyond.

As we move towards filling the information gaps that exist for the Minas Basin, we should keep in mind “the scientific method”: frequently, study does not follow this method. Instead, we simply measure, sample, count or monitor something in order to define it. To truly learn about an ecosystem and its physical and biological linkages, we need to more rigorously apply the scientific method. As shown in Table 18.1, observation, hypothesis formulation, prediction and testing are the main components of the scientific method.

Table 18.2 *The four main components of the scientific method allow scientists to develop and test their hypotheses: This approach is much different than the simple inventorying of biota or habitat parameters that often takes place in a quest to learn about our environment.*

The scientific method is comprised of: characterizations (quantifications, observations and measurements); hypotheses (theoretical, hypothetical explanations of observations and measurements); predictions (reasoning, including logical deduction from hypothesis and theory); experiments (tests of all of the above). *Source:* Wikipedia, http://en.wikipedia.org/wiki/Scientific_method (2007)

By following the scientific method, we move away from an "inventory" approach to science and towards ecosystem science. The scientific method forces us to recognize and test the cause-and-effect relationships between living things and their environment. For example, collecting water chemistry samples around the Minas Basin might provide us with a good inventory of conditions. However, collecting water samples from the basin and each of the surrounding river systems, as well as bioaccumulation in a test organism, will allow us to examine ecosystem linkages. Through the latter study we might test a hypothesis that higher metal contents are within the bay at locations where higher metal content from freshwater rivers enters the basin, and that biota in those areas have higher uptake of elevated metals.

As noted in the closing summary of a recent Bay of Fundy Workshop:

> *We need to know what we have in order to know what to manage or what we stand to lose in the absence of appropriate management. Baseline studies, monitoring and ecological studies are all needed as part of the overall "management package" to protect the habitats, unique species, living resources and ecosystems of the Gulf of Maine and Bay of Fundy.* (Pohle, 2007)

Relating this statement to the gaps presented in this Ecosystem Overview Report of the Minas Basin: the geological, oceanographic and biological systems information gaps identified are primarily the baseline studies and monitoring. The ecosystem relationships gaps are the most lacking component at this point in time. They will require more study design in order to test hypotheses regarding the ecosystem relationships of the basin. All such study will play a role in the future management and decision-making processes for the Minas Basin.

REFERENCES

ACAP (Atlantic Coastal Action Program) (1996) *Caring for Our Coast: A Plan for Community: Management of the St. Croix Estuary Area*, ACAP, Nova Scotia, September

AGS (Atlantic Geoscience Society) (2001) *The Last Billion Years: A Geological History of the Maritime Provinces of Canada*, Nimbus, Halifax, NS

Amirault, D., Comeau, P. and Dadswell, M. (1989) *An Identification of Possible Causes for the Downturn of Salmon Stocks of the Inner Bay of Fundy*, Acadia Centre for Estuarine Research Publication No 10, Prepared for the Cobequid Salmon Association

Amiro, P. G. (1987) *Similarities in Annual Recruitment of Atlantic Salmon to Sprot Fisheries of Inner Bay of Fundy Rivers and Stock Forecasts for 1987*, CAFSAC Research Document 87/58

Amiro, P. G. (2003) *Population Status of Inner Bay of Fundy Atlantic Salmon (Salmo salar), to 1999*, Report 2488, Bedford Institute of Oceanography, Dartmouth, NS

Amos, C. L. (1976) "Effects of tidal power structures on sediment transport and loading in the Bay of Fundy-Gulf of Maine system", *Fundy Tidal Power and the Environment*, Acadia University, Wolfville, NS

Amos, C. L. (1978) "The postglacial evolution of the Minas Basin, NS: A sedimentological interpretation", *Journal of Sedimentary Petrology*, vol 48, pp965–982

Amos, C. L. (1984) "An overview of sedimentological research in the Bay of Fundy", in D. C. J. Gordon and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy*. Canadian Technical Report of Fisheries and Aquatic Sciences, Halifax, NS

Amos, C. L. and Joice, G. H. E. (1977) *The Sediment Budget of the Minas Basin, Bay of Fundy*, NS, Report BI-D-77-3, Bedford Institute of Oceanography, Dartmouth, NS

Amos, C. L. and Long, B. F. N. (1980) "The sedimentary character of the Minas Basin, Bay of Fundy", in in D. C. J. Gordon and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches on the Bay of Fundy*, Canadian Technical Report of Fisheries and Aquatic Sciences, No 1256, Halifax, NS

Amos, C. L. and Mosher, D. C. (1985) "Erosion and deposition of fine-grained sediments from the Bay of Fundy", Sedimentology, vol 32, pp815–832

Amos, C. L., Tee, K. T. and Zaitlin, B. A. (1991) "The post-glacial evolution of Chignecto Bay, Bay of Fundy, and its modern environment of deposition", in D. G. Smith, G. E. Reinson, B. A. Zaitlin and R. A. Rahmani (eds) *Clastic Tidal Sedimentology*, Canadian Society of Petroleum Geologists Memoir, pp59–90

Atlantic Salmon Federation (undated) *Fundy Rivers*, www.asf.ca/CommMedia.downld/fundyrivers.gif

Atlantic Tidal Power Programming Board (1969) *Feasibility of Tidal Power Development in the Bay of Fundy*, *Halifax*, Report to Atlantic Tidal Power Programming Board, Nova Scotia

Bader, R. G., Hood, D. and Smith, W. (1960) "Recovery of dissolved organic matter in sea-water and organic sorption by particulate material", *Geochim. Cosmoch. Acta*, vol 19, pp236–243

B a i l e y , W. B. (1954) *Seasonal V a r i a t i o n s in the Hydrographic C o n d i t i o n s of the Bay of Fundy*, Manuscript r e p o r t (Biological s e r i e s) , Fish, Res, Bd, Can, Ilo., vol 2

Baillie, W. H. T. (1946) "Polychaete from the Bay of Fundy 1911–1912", *Journal of the Fisheries Research Board of Canada*, vol 6, pp472–475

Barbeau, M. A. and Grecian, L. A. (2003) "Occurrence of intersexuality in the amphipod *Corophium volutator* (Pallas) in the Upper Bay of Fundy, Canada", *Crustaceana*, vol 76, pp665–679

Barlow, J. and Gentry, R. (2004) *Report of the NOAA Workshop on Anthropogenic Sound and Marine Mammals*, NOAA Technical Memorandum: NMFS SWFSC 361

Barnes, R. D. (1980) *Invertebrate Zoology*, Saunders College and Holt, Rinehart and Winston

Berkeley, E. and Berkeley, C. (1954) "Additions to the *Polychaete* fauna of Canada, with comments on some older records", *Journal of the Fisheries Research Board of Canada*, vol 11, pp454–471

Bay of Fundy Tidal Power Review Board (1977) *Reassessment of Fundy Tidal Power*, Reports of the Bay of Fundy Tidal Power Review Board and Management Committee, Bay of Fundy Tidal Power Review Board, NS

BoFEP (2001) "Fundy's Minas Basin: Multiplying the pluses of Minas", *Fundy Issues*, Bay of Fundy Ecosystem Partnership, Dartmouth, NS, issue 19, p12

BoFEP (2002) "Taking the Fundy's pulse: Monitoring the health of the Bay of Fundy", *Fundy Issues*, Bay of Fundy Ecosystem Partnership, Dartmouth, Nova Scotia, issue 22, autumn, p8

BoFEP (2003) "Alien invasions: Introduced species in the Bay of Fundy environs", Fundy Issues, Bay of Fundy Ecosystem Partnership. Dartmouth, Nova Scotia, issue 23, spring, p12

BoFEP (2004) "Contaminant concerns: Heavy metals and the Bay of Fundy", *Fundy Issues*, Bay of Fundy Ecosystem Partnership, Dartmouth, NS, issue 25, spring, p12

Bousfield, E. L. and Leim, A. H. (1959) "The fauna of Minas Basin and Minas Channel", *Bulletin of the National Museum of Canada*, vol 166, pp1–30

Bousfield, E. L. and Thomas, M. L. H. (1975) "Postglacial changes in the distribution of littoral marine invertebrates in the Canadian Atlantic region", Proceedings of the Nova Scotia Institute of Science, vol 27, pp47–60

Bowron, T. M., Graham, J. and Butler, M. (1999) *Community and Social Considerations in Salt Marsh Restoration Work in Nova Scotia*, Report 5, Ecology Action Centre, Halifax, NS

Bradford, R. G. and Iles, T. D. (1992) "Unique biological characteristics of spring-spawning herring (*Clupea harengus* L.) in Minas Basin, Nova Scotia, a tidally dynamic environment", Canadian Journal of Zoology, vol 70, pp641–648

Bradford, R. G. and Iles, T. D. (1993) "Retention of herring *Clupea harengus* larvae inside Minas Basin, inner Bay of Fundy", Canadian Journal of Zoology, vol 71, pp56–63

Braune, B. M. (1987) "Mercury accumulation in relation to size and age of the Atlantic Herring (*Clupea harengus harengus*) from the Southwestern Bay of Fundy, Canada", *Archives of Environmental Contamination and Toxicology*, vol 16, pp311–320

Bromley, J. E. G. (1979) "A preliminary checklist of the marine fauna of Minas Basin and Minas Channel", Proceedings of Nova Scotia Institute of Science, vol 29, pp517–541

Brown, D. E. and Grantham, R. G. (1992) *Fundy Basin Rift Tectonics and Sedimentation*, GAC/MAC Field Trip Guidebook A-3, NS

Brylinsky, M. J. (1996) "Appendix 1: Conceptual models for reference at the workshop", in Percy, J. A., Wells, P. G. and Evans, A. J. (eds) (1996) *Bay of Fundy Issues: A Scientific Overview*, Occasional Report No 8, Environment Canada, Atlantic Region, NS, pp173–183

Brylinsky, M., Gibson, J. and Gordon, D. C. J. (1994) "Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 51, pp650–661

Caddy, J. F. (1970) "Records of associated fauna in scallop dredge hauls from the Bay of Fundy", Canadian Technical Report of Fisheries and Aquatic Sciences, No 225, NS

Caddy, J. F. and Carter, J. A. (1984) *Macro-epifauna of the Lower Bay of Fundy: Observations from a Submersible and Analysis of Fauna Adjacencies*, Canadian Technical Report of Fisheries and Aquatic Sciences, No 1254, NS

Cairns, D. K. (2006) *A Review of Predator–Prey and Competitive Inter-specific Interactions in Atlantic Salmon (Salmo salar)*, Canadian Science Advisory Secretariat, Research Document 2006/19

Cameron, C. and Mitchell, S. (1999) St. Georges Bay Ecosystem Project (GBEP): Research Report II DIETS AND FEEDING, St. Francis Xavier University, Antigonish, NS, http://www.stfx.ca/research/gbayesp/DF_diet_benthic_b.htm, accessed 6 August 2007

Cameron, W. M. and Pritchard, D. W. (1963) "Estuaries", in M. N. Hill (ed) *The Sea*, vol 2, John Wiley and Sons, New York, pp306–324

Cammen, L. M. and Walker, J. A. (1986) "The relationship between bacteria and micro-algae in the sediment of a Bay of Fundy mudflat", Estuarine Coastal and Shelf Science, vol 22, pp91–99

Canadian Shark Research Laboratory (2007) Website, www.marinebiodiversity.ca/shark/english/index.htm, accessed 26 June 2007, Bedford Institute of Oceanography, Dartmouth, NS

CCME (Canadian Council of Ministers of the Environment) (2002) *Canadian Water Quality Guidelines for the Protection of Aquatic Life: Summary Table*

Chapman, C. J. and Hawkins, A. D. (1969) "The importance of sound in fish behaviour in relation to capture by trawls", in A. Ben-Tuvia and W. Dickson (eds) *Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics*, 19–27 October 1967, FAO Fisheries Report No 62, vol 3, Rome, pp717–729

Chapman, M. G. and Newell, G. E. (1947) "The role of body fluid in relation to movement in soft-bodied invertebrates: The burrowing of *Arenicola*", *Proceedings of the Royal Society of London*, p134, pp431–455

Chapman, V. J. (1937) "A note on salt marshes of Nova Scotia", *Rhodora*, vol 39, pp53–57

Chaput, G. and Bradford, R. G. (2003) *American Shad (Alosa sapidissima) in Atlantic Canada,* Report 2003/009, Fisheries and Oceans Canada, Dartmouth, NS

Chase, M., Hennigar, P., Sowles, J., Jones, S., Crawford, R., Harding, G., Pederson, J., Krahforst, C., Taylor, D. and Coombs, K. (1997) *Evaluation of Gulfwatch 1997: Sixth Year of the Gulf of Maine Environmental Monitoring Plan, Gulf of Maine Council on the Marine Environment*

Chase, M. E., Jones, S. H., Hennigar, P., Sowles, J., Harding, G. D. H., Freeman, K., Wells, P. G., Krahforst, C., Coombs, K., Crawford, R., Pederson, J. and Taylor, D. (2001) "Gulfwatch: Monitoring spatial and temporal patterns of trace metal and organic contaminants in the Gulf of Maine (1991–1997) with the blue mussel, *Mytilus edulis* L.", *Marine Pollution Bulletin*, vol 42, pp491–505

Chmura, G. L., Chase, P. and Bercovitch, J. (1997) "Climatic controls of the middle marsh zone in the Bay of Fundy", *Estuaries*, vol 20, pp689–699

Chmura, G. L., Coffey A. and Crago, R. (2001) "Variation in surface sediment deposition on salt marshes in the Bay of Fundy", *Journal of Coastal Research*, vol 17, pp221–227

Chou, C. L., Paon, L. A. and Moffatt., J. D. (2002) "Cadmium, copper, manganese, silver, and zinc in rock crab (*Cancer irroratus*) from highly copper contaminated sites in the Inner Bay of Fundy, Atlantic Canada", *Bulletin of Environmental Contamination and Toxicology*, vol 68, pp885–892

Chou, C. L., Paon, L. A., Moffatt, J. D. and King, T. (2003) "Selection of bioindicators for monitoring marine environmental quality in the Bay of Fundy, Atlantic Canada", *Marine Pollution Bulletin*, vol 46, pp756–762

Chou, C. L., Paon, L. A., Moffatt, J. D. and Zwicker, B. (2000) "Copper contamination and cadmium, silver, and zinc concentrations in the digestive glands of American lobster (*Homarus americanus*) from the Inner Bay of Fundy, Atlantic Canada", *Bulletin of Environmental Contamination and Toxicology*, vol 65, pp470–477

Collins, N. H. (1984) *Potential Fish Mortality Associated with Large Hydroelectric Turbines*

Colwell, J. A. (1980) *Zeolites in the North Mountain Basalt*, GAC/MAC Field Trip Guidebook, No 18, Department of Geology, Dalhousie University, Halifax, NS

Coon, D. (1999) *Overview of Tidal Barriers in the Inner Bay of Fundy: Tidal Barriers in the Inner Bay of Fundy – Ecosystem Impacts and Restoration Opportunities*, Moncton, NB,

COSEWIC (2004) *COSEWIC Assessment and Status Report on the Striped Bass Morone saxatilis in Canada*, Committee on the Status of Endangered Wildlife in Canada, Ottawa, www.sararegistry.gc.ca/status/status_e.cfm

COSEWIC (2007) *Species Search*, COSWEWIC website, www.cosewic.gc.ca, accessed 2 July 2007

Craig, H. D. (1976) *Intertidal Animal and Trace Zonations in a Macrotidal Environment, Minas Basin, Bay of Fundy, Nova Scotia*, MSc thesis, Biology, McMaster University, Hamilton, Ontario

Craig, H. D. and Risk, M. J. (1975) "Biofacies of Cobequid Bay, Bay of Fundy", *Geological Society of America Abstracts with Programs*, vol 6, no 9, p28

Cranford, P. J. (1988) "Behaviour and ecological importance of a mud snail (*Ilyanassa obsoleta*) population in a temperate macrotidal estuary", *Canadian Journal of Zoology*, vol 66, pp459–466

Crisp, D. J. (1964) "The effects of the severe winters of 1962–1963 on marine life in Britain", *Journal of Animal Ecology*, vol 33, pp55–74

Daborn, G. R. (1984) *Zooplankton Studies in the Upper Bay of Fundy Since 1976: Update on the Environmental Consequences of Tidal Power in the Upper Reaches of the Bay of Fundy*, University of Moncton, NB (Canada), 8 November 1982, Moncton, NB

Daborn, G. R. (ed) (1989) *Littoral Investigation of Sediment Properties: Minas Basin, Final Report*, Acadia Centre for Estuarine Research, ACER Publication No 17, NS

Daborn, G. R. (1997) *Fundy Marine Ecosystem Science Project: Science Overview*

Daborn, G. R. (2006) "Homage to Penelope: Unravelling the ecology of the Bay of Fundy system", in: G. W. Pohle, P. G. Wells, and S. J. Rolston (eds) *Challenges in Environmental Management in the Bay of Fundy–Gulf of Maine*, Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, New Brunswick, 24–27 October 2006, Bay of Fundy Ecosystem Partnership Technical Report No 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS

Daborn, G. R., Amos, C. L., Brylinsky, M., Christian, H., Drapeau, G., Faas, R. W., Grant, J., Long, B., Paterson, D. M., Perillo, G. and Piccolo, M. C. (1993) "An ecological cascade effect: Migratory birds affect stability of intertidal sediments", *Limnol. Oceanogr.*, vol 38, no 1, pp225–231

Daborn, G. R. and Bleakney, S. J. (1976) *Biological Considerations: Report from Discussion Group*, Fundy Tidal Power and the Environment, Acadia University, Wolfville, NS

Daborn, G. R. and Brylinsky, M. (2004) *Fish Population Studies of the Avon Estuary, Pesaquid Lake and Lower Avon River, 2003*, Acadia Centre for Estuarine Research Publication No 76, Prepared for Nova Scotia Department of Transportation and Public Works, NS

Daborn, G. R., Brylinsky, M. and van Proosdij, D. (2003) *Ecological Studies of the Windsor Causeway and Pesaquid Lake, 2002*, Acadia Centre for Estuarine Research Publication No 69, Prepared for Nova Scotia Department of Transportation and Public Works, NS

Daborn, G. R. and Dadswell, M. J. (1988) *Natural and Anthropogenic Changes in the Bay of Fundy*

Daborn, G. R. and Pennachetti, C. (1979) "Physical oceanographic and sedimentological studies in the Southern Bight of Minas Basin", *Proceedings of the Nova Scotia Institute of Science*, vol 29, pp315–333

Daborn, G., van Proosdij, D. and Spooner, I. (2004) *Intertidal Systems of the Minas Basin, Bay of Fundy,* Fieldtrip Guide Prepared for the AGU Chapman Conference, Halifax, NS

Dadswell, M. J., Bradford, R., Leim, A. H. and Scarratt, D. J. (1984) "A review of research on fish and fisheries in the Bay of Fundy between 1976 and 1983 with particular reference to its upper reaches", in D. C. Gordon Jr. and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in Upper Reaches of the Bay of Fundy*, Canadian Technical Report on Fisheries and Aquatic Science, vol 1256, pp163–294

Dadswell, M. J., Melvin, G. D. and Williams, P. J. (1983) "Effect of turbidity on the temporal and spatial utilization of the Inner Bay of Fundy by American Shad (*Alosa sapidissima*) (Pisces: Clupeidae) and its relationship to local fisheries", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 40 (Supplement 1), pp322–330

Dale, N. G. (1974) "Bacteria in intertidal sediments: Factors related to their distribution", *Limnology and Oceanography*, vol 19, pp509–518

Dalrymple, R. W. (1977) *Sediment Dynamics of Macrotidal Sand Bars, Bay of Fundy*, PhD thesis, Geology, McMaster University, Hamilton, Ontario

Dalrymple, R., Knight, R. J. and Lambiase, J. J. (1978) "Bedforms and their hydraulic stability relationships in a tidal environment, Bay of Fundy, Canada", *Nature*, vol 75, no 5676, pp100–104

Dalrymple, R., Knight, R. and Middleton, G. (1975) "Intertidal sand bars in Cobequid Bay (Bay of Fundy)", in L. Cronin (ed) *Estuarine Research*, vol 2, Geology and Engineering, Academic Press, New York, NY

Dauer, D. M. (1984) "High resilience to disturbance of an estuarine polychaete community", *Bulletin of Marine Science*, vol 34, pp170–174

Dauer, D. M., Ewing, R. M., Tourtellotte, G. H. and Barker, H. R. Jr. (1980) "Nocturnal swimming of Scolecolepides viridis (Polychaeta: Spionidae)", *Estuaries*, vol 3, pp148–149

Dauer, D. M. and Simon, J. L. (1976) "Repopulation of the polychaete fauna of an intertidal habitat following natural defaunation: Species equilibrium", *Oecologia*, vol 22, pp99–117

Davidson-Arnott, R. G. D., van Proosdij, D., Ollerhead, J. and Schostak, L. (2002) "Hydrodynamics and sedimentation in salt marshes: Examples from a macrotidal marsh, Bay of Fundy", *Geomorphology*, vol 48, pp209–231

Davis, D. and Browne, S. (eds) (1996a) *Natural History of Nova Scotia: Volume 1 – Topics and Habitats*, Nimbus, Halifax

Davis, D. and Browne, S. (eds) (1996b) The *Natural History of Nova Scotia: Volume 2 – Theme Regions*, Nimbus, Halifax

Dalziel, J. A., Yeats, P. A. and Amirault, B. P. (1998) *Inorganic Chemical Analysis of Major Rivers Flowing into the Bay of Fundy, Scotian Shelf and Bras d'Or Lakes*, Canadian Technical Report of Fisheries and Aquatic Sciences, NS

De Flaun, F. M. and Mayer, M. L. (1983) "Relationships between bacteria and grain surfaces in intertidal sediments", *Limnology and Oceanography*, vol 28, pp873–881

Denton, G. H. and Hughes, T. J. (1981) *The Last Great Ice Sheets*, John Wiley and Sons, Toronto, ON

Department of Fisheries and Oceans (1997a) *Bay of Fundy Soft-Shell Clams*, Report 96/127, DFO, NS

Department of Fisheries and Oceans (1997b) *Middle Shoal Channel Improvement Project – Scientific Advice Regarding the Reconsideration of the 15 July 1996 Screening Report Assessment Decision*, Department of Fisheries and Oceans Regional Habitat Status Report 97/1 E

Department of Fisheries and Oceans (1998a) *Atlantic Salmon, Inner Bay of Fundy*, SFA 22 & Part of SFA 23, Report D3-12(1998), DFO, NS

Department of Fisheries and Oceans (1998b) *Bay of Fundy Lobster (LFAs 35, 36 and 38)*, Report C3-61(1998), DFO, NS

Department of Fisheries and Oceans (1998c) *Shifts in Fishing Effort, Commercial Landings and Resource Distribution of Groundfish in NAFO Division 4X*, Report 98/4E, DFO, NS

Department of Fisheries and Oceans (1999) 1997 *State of the Ocean: Scotian Shelf, Bay of Fundy and Gulf of Maine*, Report G3-01(1998), DFO, NS

Department of Fisheries and Oceans (2001) *Update on Selected Scallop Production Areas (SPAs) in the Bay of Fundy, Report C3-63(2000)*, DFO, NS

Department of Fisheries and Oceans (2004) *Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals*, Canadian Science Advisory Secretariat, National Capital Region, Habitat Status Report, 2004/002

Desplanque, C. and Mossman, D. J. (1998) "A review of ice and tide observations in the Bay of Fundy", *Atlantic Geology*, vol 34, pp195–209

Desplanque, C. and Mossman, D. J. (2000) "Fundamentals of Fundy tides" in T. Chopin and P. G. Wells (eds) (2000) *Opportunities and Challenges for Protecting, Restoring and Enhancing Coastal Habitats of the Bay of Fundy*, Environment Canada, Occasional Report No 17

DeWolfe, D. L. (1981) *Atlas of Tidal Currents: Bay of Fundy and Gulf of Maine*

Douglas, S. G., Bradford R. G. and Chaput, G. (2003) A*ssessment of Striped Bass (Morone saxatillis) in the Maritime Provinces in the Context of Species at Risk*, Canadian Science Advisory Secretariate, Research Document 2003/08

Drinkwater, K. F., Smith, P. C. and Pettipas, R. (1992) *Spatial and Temporal Scales of Temperature Variability in the Bay of Fundy*, Report Serial No N2125, Northwest Atlantic Fisheries Organization, NS

Duncanson, J. V. (1965) *Falmouth: A New England Township in Nova Scotia*

Dupont, F., Hannah, C. G. and Greenberg, D. (2003) *Modelling the Sea Level in the Upper Bay of Fundy, Fisheries and Oceans Canada*, Bedford Institute of Oceanography, Dartmouth, NS

Dyer, C., Wehrell, S. and Daborn, G. R. (2005) *Fisheries Management Issues in the Upper Bay of Fundy, Acadia Centre for Estuarine Research Publication No 80*, Prepared for the ELJB Foundation

East Coast Aquatics Inc. (ECA) (2006) *A Descriptive Habitat Study of Low Impacted Streams of the Bay of Fundy*, Annapolis Fly Fishing Association, Middleton, NS

Elderkin, M. F. (2007) Personal communication, 3 July 2007, Species at risk biologist, Nova Scotia Department of Natural Resources, Kentville, NS

Environment Canada (2007a) S*pecies at Risk: Atlantic Salmon, Inner Bay of Fundy Population*, www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=672, accessed 2 July 2007

Environment Canada (2007b) *Climate Data Online*, http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html, accessed 26 July 2007

Environment Canada (2007c) *The National Air Pollution Surveillance (NAPS) Network*, http://www.etc-cte.ec.gc.ca/napsstations/main.aspx, accessed 26 July 2007

Environment Canada (2007d) What is the Air Quality Index?, http://www.atl.ec.gc.ca/airquality/whatis_index_e.html, accessed 30 July 2007

Environment Canada–Atlantic Region (undated) Occasional Report No 8, ISBN 0-662-25570-4

Environment Canada and the Government of Canada (1991) *Upper Bay of Fundy*, Section 20

Fader, G. B. (2003) *The Emerging Role of Marine Geology in Benthic Ecology*, Fisheries and Oceans Canada, http://www.mar.dfo-mpo.gc.ca/e/homepg.htm

Fader, G. B., King, L. H. and MacLean, B. (1977) *Surficial Geology of the Eastern Gulf of Maine and Bay of Fundy,* Report 76-17, Geological Survey of Canada

Fager, E. W. (1964) "Marine sediments: Effects of tube-building polychaete", *Science*, vol 143, pp356–358

Featherstone, R. P. and Risk, M. J. (1977) "Effect of tube-building polychaetes on intertidal sediments of the Minas Basin, Bay of Fundy", *Journal of Sedimentary Petrology*, vol 47, no 1, pp446–450

Fisheries and Environment Canada (1977) *Coastal Environments Oil Spills and Clean-up Programs in the Bay of Fundy*, Economic and Technical Review Report, EPS-3-EC-77-9

Fisheries and Oceans Canada (2003a) *Atlantic Salmon Maritime Provinces Overview for 2002: Gulf and Maritimes Regions*, Report 2003/026

Fisheries and Oceans Canada (2003b) *Underwater World: American Shad*

Fleituch, T., Starzecka, A. and Bednarz, T. (2001) "Spatial trends in sediment structure, bacteria, and periphyton communities across a freshwater ecotone", *Hydrobiologia*, vol 464, pp165–174

Forbes, D. L., Boyd, R. and Shaw, J. (1991) "Late Quaternary sedimentation and sea level changes on the inner Scotian shelf", *Continental Shelf Research*, vol 11, nos 8–10

Fundy Shore Ecotour (undated) *Fundy Shore Ecotour*, www.fundyshoreecotour.ns.ca

Ganong, W. F. (1903) "The vegetation of the Bay of Fundy salt and dyked marshes: An ecological study", *Botanical Gazette*, vol 36, pp161–186, 280–302, 349–367, 429–455

Garrett, C. J. S., Keeley, J. R. and Greenherg, D. A. (1978) "Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine", *Atmosphere–Ocean*, vol l6, pp403–423

Gibson, A. J. F. and Myers, R. A. (2001) *Gaspereau River Alewife Stock Status Report*, Candadian Scientific Advisory Research Document 2001/061

Godin, G. (1968) *The 1965 Current Survey of the Bay of Fundy: A New Analysis of the Data and an Interpretation of the Results*, Bedford Institute of Oceanography, Dartmouth, NS

Gordon, D. C. (1986) "A brief review of primary production in the Gulf of Maine and the Bay of Fundy", *Publ. Acadia Centre of Estuarine Research*, vol 1, pp35–54

Gordon, D.C., Jr. (1989) *Habitat Loss in the Gulf of Maine*

Gordon, D. C. J., Cranford, P. J. and Desplanque, C. (1985) "Observations on the ecological importance of salt marshes in the Cumberland Basin: A macrotidal estuary in the Bay of Fundy", *Estuarine Coastal and Shelf Science*, vol 20, pp205–227

Gordon, D.C. Jr. and Cranford, P. J. (1994) "Export of organic matter from macrotidal salt marshes in the upper Bay of Fundy, Canada" in W. J. Mitcsh (ed) *Global Wetlands: Old World and New*, Elsevier, NY, pp257–264

Gordon, D. C. J. and Dadswell, M. J. (eds) (1984) *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy*, vol 1256

Gordon, D. C. J. and Desplanque, C. (1983) "Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 40, pp1331–1342

Gordon, D. C. J., Keizer, P. D., Dale, J. and Cranford, P. J. (1980) *Pecks Cove Mudflat Ecosystem Study: Observations in 1978*, Report No 928, Marine Ecology Laboratory, Bedford Institute of Oceanography, Dartmouth, NS

Grant, D. R. (1970) "Recent coastal submergence of the Maritime provinces, Canada", *Canadian Journal of Earth Sciences*, vol 7, no 3, pp676–689

Grant, D. R. (1977) "Glacial style and ice limits, the Quaternary stratigraphic record and changes of land and ocean level in the Atlantic Provinces of Canada", *Geography Physics Quaternary*, vol 31, no 3, p4

Grant, D. R. (1980) "Quaternary sea-level change in Atlantic Canada as an indication of crustal delevelling", in N. A. Morner (ed) *Earth Rheology, Isostasy and Eustasy*, John Wiley and Sons, London

Grant, D. R. (1989) "Quaternary geology of the Atlantic Appalachian region of Canada", in R. J. Fulton (ed) *Quaternary Geology of Canada and Adjacent Greenland*, Geology of Canada No 1, Geological Survey of Canada

Grant, D. R. and King, L. H. (1984) "A stratigraphic framework for the Quaternary history of the Atlantic provinces", in R. J. Fulton (ed) *Quaternary Stratigraphy of Canada: A Canadian Contribution to IGCP Project 24*, Paper 84–10, Geological Survey of Canada

Gratto, G. (1978) *Some Aspects of the Flora and Fauna of the Western Minas Basin and Minas Channel*, National Research Council of Canada, Halifax, NS

Gratto, G. (1979) *Further Faunal and Ecological Surveys of the Intertidal Invertebrates of Scots Bay and the Western Minas Basin*, National Research Council, Halifax, NS

Gratto, G. W., Thomas, M. L. H. and Bleakney, J. S. (1983) "Growth and production of the intertidal amphipod Corophium volutator (Pallas) in the inner and outer Bay of Fundy", *Proceedings of Nova Scotia Institute of Science*, vol 33, pp47–55

Green, J. (1968) The Biology of Estuarine Animals, Sidgwick and Jackson, London

Greenberg, D. A. (1983) "Modelling the mean barotropic circulation in the Bay of Fundy and Gulf of Maine", *Journal of Physical Oceanography*, vol 13, pp886–904

Greenberg, D. A. (1984) "A review of the physical oceanography of the Bay of Fundy", in D. C. J. Gordon and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches on the Bay of Fundy*, Canadian Technical Report of Fisheries and Aquatic Sciences, No 1256

Greenberg, D. A., and C. L. Amos (1981) "Suspended sediment transport and deposition modeling in the Bay of Fundy, Nova Scotia – a region of potential tidal power development", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 40 (Supplement 1), pp20–34

Gregory, D. N. and Smith, P. C. (1988) *Current Statistics of the Scotian Shelf and Slope*, Fisheries and Oceans Canada, Canadian Technical Report of Hydrography and Ocean Science, No 106

Gulf of Maine Council on the Marine Environment (2003) *Gulfwatch: Monitoring Chemical Contaminants in Gulf of Maine Coastal Waters*, Gulf of Maine Council on the Marine Environment, Maine, US

Hachey, H. B. (1934) "The probable effect of tidal power development on Bay of Fundy tides", *Journal of the Franklin Institute*, vol 32, pp747–757

Hamilton, D., Barbeau, M. and Diamond, A. (2003) "Shorebirds, mud snails, and *Corphium volutator* in the upper Bay of Fundy, Canada: Predicting bird activity on intertidal mud flats", *Canadian Journal of Zoology*, vol 81, pp1358–1366

Hamilton, D., Diamond, A. and Wells, P. (2006) "Shorebirds, snails, and the amphipod (*Corophium volutator*) in the upper Bay of Fundy: Top-down vs bottom-up factors, and the influence of compensatory interactions on mudflat ecology", *Hydrobiologia*, vol 567, pp285–306

Hargrave, B. T. (1978) *Geochemical and Biological Observations in Intertidal Sediments from Cobequid Bay, Bay of Fundy, Nova Scotia*, Report 782, Bedford Institute of Oceanography, Dartmouth, NS

Hargrave, B. T., Prouse, N. J., Phillips, G. A. and Neame, P. A. (1983) "Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper Bay of Fundy", *Canadian Journal of Fisheries and Aquatic Sciences* (Supplement 1), pp229–243

Hart, J. L. (1958) "Fifty years of research in aquatic biology: 1908–1958", *Journal of the Fisheries Research Board of Canada*, vol 15, pp1127–1161

Hasselman, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K., Ewing, J. A., Gienapp, H., Hasselmann, D. E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D. J., Richter, K., Sell, W. and Walden, H. (1973) *Measurements of Wind-Wave Growth and Swell Decay During the Joint North Sea Wave Project (JONSWAP)*, DHI Zeitschrift (Special Issue)

Hennigar, T. W. (1968) Hydrogeology of the Salmon River and Adjacent Watersheds, Colchester County, Nova Scotia, MSc thesis, Dalhousie University, NS

Hennigar, T. W. (1972) *Hydrology of the Truro Area*, Nova Scotia, Department of Mines, Groundwater Section, Report 72-1

Hicklin, P. W., Linkletter, L. E. and Peer, D. L. (1980) "Distribution and abundance of *Corophium volutator* (Pallas) and *Heteromastus filiformis* (Claparede) in the intertidal zone of the Cumberland Basin and Shepody Bay, Bay of Fundy", *Canadian Technical Representative of Fisheries and Aquatic Science*, vol 965, pp1–56

Hicklin, P. W. and Smith, P. C. (1984a) "Studies of birds in the Bay of Fundy: A Review", in *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy*, Canadian Technical Report of Fisheries and Aquatic Sciences, No 1256

Hicklin, P. W. and Smith, P. C. (1984b) "Selection of foraging sites and invertebrate prey by migrant semipalmated sandpipers, *Calidris pusilla* (Pallas), in Minas Basin, Bay of Fundy", Canadian Journal of Zoology, vol 62, pp2201–2210

Hilchey, J. D. (1981) *The General Biology of Saltmarshes*, Publications Institute of Resource and Environmental Studies, Dalhousie University, Halifax, NS

Hind, H. Y. (1875) "The ice phenomena and the tides of the Bay of Fundy", *The Canadian Monthly and National Review*, vol 8, no 3, pp189–203

Hubert, J. F. and Mertz, K. A. (1980) "Eolian dune field of Late Triassic age, Fundy Basin, Nova Scotia", *Geology*, vol 8

Hubert, J. F. and Mertz, K. A. (1984) "Eolian sandstone in Upper Triassic–Lower Jurassic redbeds in the Fundy Basin, Nova Scotia", *Journal of Sedimentary Petrology*, vol 54

Hughson, W. B. (1976) *Fundy Avifauna: An Overview*, Fundy Tidal Power and the Environment., Acadia University, Wolfville, Nova Scotia

Huntsman, A. G. (1931) *The Maritime Salmon of Canada*, Biological Board of Canada, Bulletin no XXI

Huntsman, A. G. (1936) *Return of Salmon from the Sea*, Biological Board of Canada, Bulletin No LI

Huntsman, A. G. (1952) "The production of life in the Bay of Fundy", *Transactions of the Royal Society of Canada*, vol 46, pp15–38

Huntsman, A. G. and Rice, D. I. (1946) *Atlantic Salmon and Trout Investigations*, Reports of the Biological Stations, Fisheries Research Board of Canada., no 390, vol 34

Hustvedt, E. (1987) *Maritime Dykelands: The 350 Year Struggle*, Department of Environment, NS

Hutcheson, M. S. (1983) "Toxicological effects of potash brine on Bay of Fundy marine organisms", *Marine Environmental Research*, vol 9, pp237–255

Isaacman, L. and Beazley, K. (2005) "Historic characterization of changes to the fish community in the Avon River Nova Scotia", in J. A. Percy, A. J. Evans, P. G. Wells and S. J. Rolston (eds) *The Changing Bay of Fundy: Beyond 400 Years*. Proceedings of the Sixth Bay of Fundy Workshop, Cornwallis, Nova Scotia, 29 September–2 October, Environment Canada, Atlantic Region, Occasional Report No 23

Jermolajev, E. G. (1958) "Zooplankto of the Inner Bay of Fundy", *Journal of Fisheries Research Board*, vol 15, no 6, pp1219–1228

Jessop, B. M. (1999) *The Status (1960–1997) of Alewife and Blueback Herring Stocks in the Scotia–Fundy Area as Indicated by Catch–Effort Statistics*, CSAS Research Document 99/117

Kanwisher, J. W. (1955) "Freezing in intertidal animals", *Biological Bulletin*, vol 109, pp56–63

Keizer, P., Hargrave, B. and Gordon, D. (1989) "Sediment-water exchange of dissolved nutrients at an intertidal site in the upper reaches of the Bay of Fundy, Canada", *Estuaries*, vol 12, no 1, pp1–12

Ketchum, B. H. and Keen, D. J. (1953) "The exchanges of fresh and salt waters in the Bay of Fundy and in Passamoquoddy Bay", *Journal of the Fisheries Research Board of Canada*, 10, pp97–124

Kindle, E. M. (1917) "Notes on the bottom environment of the marine invertebrates of western Nova Scotia", *Ottawa Naturalist*, vol 30, pp149–154

King, L. H. and Fader, G. B. (1986) "Wisconsinan glaciation of the Atlantic continental shelf off southeast Canada", *Geological Survey of Canada Bulletin*, vol 363

King, L. H. and MacLean, B. (1976) *Geology of the Scotian Shelf and Adjacent Areas*

Kinne, O. (1963) "The effect of temperature and salinity on marine and brackish water animals", *Oceanography and Marine Biology: An Annual Review*, vol 1, pp301–340

Klein, G. de V. (1968) *Intertidal Zone Sedimentation, Minas Basin north shore, Bay of Fundy*

Knight, R. J. (1972) "Cobequid Bay sedimentology project: A progress report", *Maritime Sediments*, vol 8, pp45–60

Knight, R. J. (1977) *Sediments, Bedforms and Hydraulics in a Macrotidal Environment, Cobequid Bay (Bay of Fundy), Nova Scotia*, PhD thesis, McMaster University, Hamilton, ON

Knight, R. J. (1980) "Linear sand bar development and tidal current flow in Cobequid Bay, Bay of Fundy, Nova Scotia", in S. B. McCann (ed) *The Coastline of Canada: Littoral Processes and Shore Morphology*, Geological Survey Paper 80-10, Proceedings of a Conference Held in Halifax, 1–3 May 1978

Knight, R. J. and Dalrymple, R. W. (1976) "Winter conditions in a macrotidal environment, Cobequid Bay, Nova Scotia", *Revue di geographic de Montreal*, vol 30, pp65–85

Kosters, E., Butler, K., Fader, G., Milligan, T., Muschenheim K., Parrott, R. D. and van Proosdij, D. (2007) "Sedimentation in the Great Bay of Fundy: A research agenda", *Challenges in Environment Management in the Bay of Fundy–Gulf of Maine*, Proceedings of the Seventh Bay of Fundy Science Workshop, St. Andrews, New Brunswick, 24–27 October 2006, BoFEP

Kostylev, V. E., B. J. Todd, G. B. J. Fader, R. C. Courtney, G. D. M. Cameron, and R. A. Pickrill (2001) "Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs", Marine Ecology Progress Series vol 219, pp121–137

Lambiase, J. J. (1977) *Sediment Dynamics in the Macrotidal Avon River Estuary*, Nova Scotia, PhD thesis, McMaster University, Hamilton, ON

Lanteingne, M. (2006) *Recovery Potential assessment for the St. Lawrence Estuary, Southern Gulf of St. Lawrence and Bay of Fundy Striped Bass (Morone saxatillis) Populations*, Canadian Science Advisory Secretariate. Science Advisory Report 2006/053

Leggat, L., Merklinger, H. and Kennedy, J. (1981) *LNG Carrier Underwater Noise Study for Baffin Bay*, Department of National Defence, Research and Development Branch, Defence Research Establishment Atlantic. Dartmouth, Nova Scotia, DREA Report 81/3

LGL Ltd (2001) *Assessment of Noise Issues Relevant to Key Cetacean Species in the Sable Gully Area of Interest*, LGL report TA2446-2

Loring, D. H. (1979) "Baseline levels of transition and heavy metals in the bottom sediments of the Bay of Fundy", *Proceedings of the Nova Scotia Institute of Science*, vol 29, pp335–346

Loring, D. H. (1982) "Geochemical factors controlling the accumulation and dispersal of heavy metals in the Bay of Fundy sediments", *Canadian Journal of Earth Sciences*, vol 19, pp930–944

MacKinnon, M. and Walker, A. (1979) "Comparison of carbon content of the sediments in salt marshes at Kingsport and Grand Pre, Minas Basin, Bay of Fundy, Nova Scotia", *Proceedings of the Nova Scotia Institute of Science*, vol 29, pp373–379

MacMillan, J., Caissie, D., LeBlanc, J. and Crandlemere, T. (2005) "Characterization of summer water temperatures for 312 selected sites in Nova Scotia", *Canadian Technical Report of Fisheries and Aquatic Science,* No 2582

Magenheimer, J. F., Moore, R. R., Chmura, G. L. and Daoust, R. J. (1996) "Methane and carbon dioxide flux from a macrotidal salt marsh, Bay of Fundy, New Brunswick", Estuaries, vol 19, pp139–145

Majka, C. G. (1975) *The Ecology of a Tidal Mud-Fla*t, BSc thesis/dissertation, Biology, Mount Allison Univeristy, Sackville, NB

Martin, J. L., LeGresley, M. M. and Strain, P. M. (2001) *Phytoplankton Monitoring in the Western Isles Region of the Bay of Fundy During 1997–1989*, Report 243, Biological Station, St. Andrews, NB

Martin, J. L. and White, A. W. (1988) "Distribution and abundance of the toxic dinoflagellate *Gonyaulax excavata* in the Bay of Fundy", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 45, pp1968–1975

McCracken, F. D. (ed) *Fisheries and Marine Service*, Ottawa, ON

McCurdy, E. P. (1979) *Intertidal Invertebrates of Scots Bay and Western Minas Basin, Nova Scotia*, MSc thesis, Department of Biology, Acadia University, Wolfville, NS

McIntyre, T. M., Bradford, R. G., Davies, T. D. and Gibson, A. J. F. (2007) *Gaspereau River Alewife Stock Status Report*, Canadian Science Advisory Secretariate, Research Document 2007/nnn

Meadows, P. S. and Reid, A. (1966) "The behaviour of *Corophium volutator* (Crustacea, Amphipoda)", *Journal of Zoology*, London, vol 150, pp387–399

Mertz, K. A. and Hubert, J. F. (1990) "Cycles of sand-flat sandstone and playa-mudstone in the Triassic-Jurassic Blomidon redbeds, Fundy rift basin, Nova Scotia: Implications for tectonic and climatic controls", *Canadian Journal of Earth Science*, vol 27

Middleton, G. V. (1972) "Brief field guide to intertidal sediments, Minas Basin, Nova Scotia", *Maritime Sediments*, vol 8, pp114–122

Middleton, G. V. (1976) *The Sediment Regime of the Bay of Fundy: Fundy Tidal Power and the Environment*, Wolfville, NS

Middleton, G. V., Knight, R. J. and Dalrymple, R. W. (1976) "Facies model for macrotidal environments, Cobequid Bay, Nova Scotia", American Association of Petroleum Geology Bulletin, vol 60, pp697–704

Miller. C. K. and Milligan, G. C. (undated) *A Guide to the Geology, Landscapes and Mineral Resources of Nova Scotia*, Geology Department, Dalhousie University, Halifax, and Nova Scotia Department of Mines and Energy, Halifax, NS

Milton, R. (2003) Nova Scotia Department of Natural Resources, Kentville, NS

Misund, O. A. (1997) "Underwater acoustics in marine fisheries and fisheries research", *Review of Fish. Biol. Fisheries*, vol 7, pp1–34

Morrison, R. I. G. (1976a) *Maritimes Shorebird Survey 1974*, Contributors' Report, Canadian Wildlife Service, Ottawa, ON

Morrison, R. I. G. (1976b) *Maritimes Shorebird Survey 1975*, Preliminary Report, Canadian Wildlife Service, Ottawa, ON

Morrison, R. I. G. (1976c) *Use of the Bay of Fundy by Shorebirds,* Fundy Tidal Power and the Environment, Acadia University, Wolfville, NS

Moyse, C. M. (1978) *Bay of Fundy Environmental and Tidal Power Bibliography*, Report 822

Murdoch, M. H., Barlocher, F. and Laltoo, M. L. (1986) "Population dynamics and nutrition of *Corophium volutator* (Pallas) in the Cumberland Basin (Bay of Fundy)", *Journal of Marine Biology and Ecology*, vol 103, pp235–249

Murison, L. D. and Gaskin, D. E. (1988) "The distribution of right whales and zooplankton in the Bay of Fundy, Canada", *Canadian Journal of Zoology*, vol 67, pp1411–1420

Museum of Natural History (2007) *Peregrine Falcon*, museum.gov.ns.ca/mnh/nature/nsbirds/bns0100.htm, accessed on 2 July 2007

Myers, A, C. (1977) "Sediment processing in a marine subtidal sandy bottom community: I. Physical aspects", *Journal of Marine Research*, vol 35, pp609–623

Newell, R. C. (1970) Biology of Intertidal Animals, American Elsevier, New York, NY

Nicol, J. A. C. (1960) The Biology of Marine Animals, Sir Isaac Pitman & Sons, London, England

NOAA (1997) *NOAA's Estuarine Eutrophication Survey, vol 3: North Atlantic Region*, Office of Ocean Resources Conservation ad Assessment, Silver Spring, MD

Nova Scotia Salmon Association (undated) *News and Issues: Inner Bay of Fundy*, www.novascotiasalmon.ns.ca/newsandissues/innerbayoffundy.htm

NSDNR (1994) "Perigrine falcon recovery underway", *Conservation*, vol 18, no 3

NSDNR (2007) General Status Ranks of Species in Nova Scotia, http://www.gov.ns.ca/natr/wildlife/genstatus/ranks.asp, accessed 6 August 2007

Odum, E. P. (1971) *Fundamentals of Ecology*, W. B. Saunder Co, Toronto, ON

Ollerhead, J., Hicklin, P. W., Wells, P. G. and Ramsey, K. (eds) (1999) *Understanding Change in the Bay of Fundy Ecosystem*, Proceedings of the Third Bay of Fundy Science Workshop, Mount Allison University, Sackville, New Brunswick, 22–24 April, Environment Canada, Atlantic Region Occasional Report No 12, Environment Canada, Sackville, New Brunswick

Paramore, L. M. (1998) *Age, Growth, and Life History Characteristics of Striped Bass*, Morone saxatilis, *from the Shubenacadie–Stewiacke River, Nova Scotia, 1994*, MSc thesis, East Carolina University, Greenville, North Carolina

Parker, M. and Rutherford, R. J. (2005) "Development of a Musquash Ecosystem Framework", in, R. Singh and M.-I. Buzeta (eds) *Musquash Ecosystem Framework Development: Progress to Date*, Can. Manuscr. Rep. Fish. Aquat. Sci

Parrott, R. D., J. E. Hughes Clarke, B. J. Todd and G. Rockwell (2006) "Multibeam sonar mapping of the Bay of Fundy seafloor", in G. W. Pohle, P. G. Wells, and S. J. Rolston (eds) (2007) *Challenges in Environmental Management in the Bay of Fundy–Gulf of Maine*, Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, New Brunswick, 24–27 October 2006, Bay of Fundy Ecosystem Partnership Technical Report No 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS

Partridge, V. A. (2000) *Aspects of the Winter Ecology and Spring Recolonization of the Windsor Mudflat*, MSc thesis, Biology, Acadia University, Wolfville, NS

Patriquin, D. G. (1981) *The General Biology of Saltmarshes*, Publ. Inst. Resource and Environmental Studies, Dalhousie University, Halifax, NS

Peer, D. L. (1970) "Relation between biomass, productivity, and loss to predators in a population of a marine benthic polychaete, *Pectinaria hyperborean*", J. *Fish. Res. Bd. Canada*, vol 27, pp2143–2153

Peer, D. L., Linkletter, L. E. and Hicklin, P. W. (1986) "Life-history and reproductive biology of *Corophium volutator* (Crustacea, Amphipoda) and the influence of shorebird predation on population structure in Chignecto Bay, Bay of Fundy, Canada", *Netherlands Journal of Sea Research*, vol 20, pp359–373

Pelletier, B. R. (1974) *Sedimentary Textures and Relative Entropy and Their Relationship to the Hydrodynamic Environment*, Bay of Fundy System, Geological Survey of Canada, Paper 74–30, vol 1, pp77–95

Pelletier, B. R. and McMullen, R. M. (1972) "Sedimentation patterns in the Bay of Fundy and Minas Basin" in T. J. Gray and O. K. Gashus (eds) *Tidal Power*, Plenum Press, pp153–187

Pennachetti, C. (1978) *Plankton and Suspended Sediments in the Southern Bight of Minas Basin, Nova Scotia*, Canada Summer Job Corps Project

Percy, J. (1999) "Keystone *Corophium*: Master of the mudflats", *Fundy Issues*, BoFEP, no 13, Spring

Percy, J. A. (2001) *Fundy's Minas Basin: Multiplying the Pluses of Minas, Report 19*, Bay of Fundy Ecosystem Partnership, Granville Ferry, NS

Percy, J. A., Evans, A. J., Wells, P. G. and Rolston, S. J. (eds) (2005) *The Changing Bay of Fundy: Beyond 400 Years*, Proceedings of the Sixth Bayof Fundy Workshop, Cornwallis, Nova Scotia, 29 September–2 October 2004, Environment Canada, Atlantic Region, Occasional Report No 23

Percy, J. A., Perillo, G. M. E., Drapeau, G., Piccolo, M. C. and Chaouq, N. (1993) "Tidal circulation pattern on a tidal flat, Minas Basin, Canada", *Marine Geology*, vol 112, pp219–236

Percy, J. A. and Wells, P. G. (1996a) "Bay of Fundy ecosystem issues: A summary", in Percy, J. A., P. G. Wells and A. J. Evans (eds) *Bay of Fundy Issues: A Scientific Overview*, Occasional Report No 8, Environment Canada, Atlantic Region, pp139–150

Percy, J. A., Wells, P. G. and Evans, A. J. (eds) (1996b) *Bay of Fundy Issues: A Scientific Overview*, Occasional Report No 8, Environment Canada, Atlantic Region

Percy, J.A., Wells, P. G. and Evans, A. J. (1997) (eds) *Bay of Fundy Issues: A Scientific Overview*

Perillo, G. M. E., Drapeau, G., Piccolo, M. C. and Chaouq, N. (1993) "Tidal circulation pattern on a tidal flat, Minas Basin, Canada", *Marine Geology*, vol 112, pp219–236

Perley, M. H. (1852) *Reports on the Sea and River Fisheries of New Brunswick*, Fredericton, NB

Perry-Giraud, C. (2005) *Thirty Year Assessment of the Cornwallis Estuary Evolution: Aerial Photo and GIS Analysis*, MSc in Environment, Ground and Water, University of Rouen, France

Petrie, B. (1987) "Undulations of the Nova Scotia Current." *Atmosphere*-Ocean, vol 25, no 1

Pohle, G. W., Wells, P. G. and Rolston, S. J. (eds) (2007) *Challenges in Environmental Management in the Bay of Fundy-Gulf of Maine*, Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, New Brunswick, 24–27 October 200, Bay of Fundy Ecosystem Partnership Technical Report No 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS

Pol, R. A. (1996) *Chemical Loadings (Exports) to the Bay of Fundy: A Framework for Concentrations and Exports from Atlantic Canada Rivers*, Draft Report, Environment Canada, Moncton, NB, January

Pritchard, D. (1955) "Estuarine circulation patterns", *Proceedings of the American Society of Civil Engineering*, vol 81, pp717-1–717-11

Prouse, N. J., Gordon, D. C., Hargrave, B. T., Bird, C. J., McLachlan, J., Lakshminarayana, J. S. S., Devi, S. J. and Thomas, M. L. H. (1984) "Primary production: Organic matter supply to ecosystems in the Bay of Fundy", in D. C. Gordon Jr. and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in Upper Reaches of the Bay of Fundy*, Can. Tech. Rept. Fish. Aquat. Sci., Report 1256, pp65–95

Redden, A. M. (1986) Habitat Utilization by the Atlantic silverside (*Menidia menidia* L.) in *Stratified and Vertically Mixed Estuaries*, MSc thesis, Acadia University, NS

Redden, A. M. and Daborn, G. R. (1991) "Viability of subitaneous copepod eggs following fish predation on egg-carrying calanoids", *Marine Ecology – Progress Series*, vol 77, pp307–310

Redfield, A. C. and Deevy, E. S. (1952) *Marine Fouling and its Prevention*

Reid, P. R. (1982) *Aspects of Tile Winter Ecology and Behaviour of Bald Eagles (Haliaectus leucocephalus alaseanus Townsend) on the Shubenacadie River, Nova Scotia*, MSc thesis, Acadia University, NS

Rhoads, D. C., and Young, D. K. (1970) "The influence of deposit feeding organisms on sediment stability and community trophic structure", Journal of Marine Research, vol 28, pp150–178

Rice, J. (2006) *Background Scientific Information for Candidate Criteria and Community Properties to be Ecologically Significant*, Canadian Science Advisory Secretariat, Research Document 2006/089

Risk, M. J. and Craig, H. D. (1976) "Flatfish feeding traces in the Minas Basin", *Journal of Sedimentary Petrology*, vol 46, pp411–413

Risk, M. J. and Moffat, J. S. (1977) "Sedimentological significance of fecal pellets of *Macoma baltica* in the Minas Basin, Bay of Fundy", *J. Sed. Petrol*, vol 48, pp1425–1436

Risk, M. J., Moffat, J. S., Yeo, R. K., Craig, H. D. and Tunnicliffe, V. J. (1976) "Animal–sediment relationships in the Minas Basin, Bay of Fundy", *Geological Association of Canada, Program with Abstracts*, vol 1, p84

Risk, M. J., Yeo, R. K. and Craig, H. D. (1976) *Aspects of the Marine Ecology of the Minas Basin Relevant to Tidal Power Development*, Fundy Tidal Power and the Environment, Acadia University, Wolfville, NS

Roland, A. E. (1982) *Geological Background and Physiography of Nova Scotia*, Nova Scotia Institute of Science, Halifax, NS

Russel et al (2005) *BoFEP Multibeam Sonar Mapping of the Bay of Fundy Sea Floor*, BoFEP

SARA (2003) *Species at Risk Act, Canada Gazette Part III*, Chapter 29, vol 25, no 3

SARA (2007) SARA Public Registry, Reports on Critical Habitat Protection, http://www.sararegistry.gc.ca/plans/reports_e.cfm, accessed 26 July 2007

Saunders, H. L. (1958) "Benthic studies in Buzzards Bay – animal–sediment relationships", *Limnology and Oceanography*, vol 3, pp245–258

Scarratt, D. J. (1976) *Biological Resources of the Bay of Fundy–Gulf of Maine System*, Fundy Tidal Power, Acadia University, Wolfville, NS

Schwarz, A.L. and Greer, G. L. (1984) "Responses of Pacific herring *Clupea harengus pallasi* to some underwater sounds", *Can. J. Fish. Aquat. Sci*., vol 41, pp1183–1192

Schwinghamer, P. (1981) *Size Distributions of Benthic Organisms in the Bay of Fundy, Canada*, PhD thesis, Biology Department, Dalhousie University, Halifax, NS

Schwinghamer, P., Tan, F. C. and Gordon, D. C. J. (1983) "Stable carbon isotope studies on the Pecks Cove mudflat ecosystem in the Cumberland Basin, Bay of Fundy", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 40, pp262–272

Scott, D. B., Boyd, R. and Medioli, F. S. (1987) *Relative Sea-Level Changes in Atlantic Canada: Observed Level and Sedimentological Changes vs Theoretical Models*, Society of Economic Paleontologists and Mineralogists Special Publication, no 41

Scott, D. B. and Greenberg, D. A. (1983) "Relative sea-level rise and tidal developments in the Fundy tidal system", *Canadian Journal of Earth Science*, vol 20, no 10

Scott, D. B. and Medioli, F. S. (1980) "Post-glacial emergence curves in the Maritimes determined from marine sediments in raised basins", in *Proceedings of the Canadian Coastal Conference*, Burlington, ON

Scott, F. W. and A. J. Hebda (2004) "Annotated list of the mammals of Nova Scotia", *Proc. N.S. Inst. Sci.*, vol 42, part 2, pp189–208

Shaw, J., Taylor, R. B. and Forbes, D. L. (1991) "Impact of accelerated sea level rise on the coast of Nova Scotia, Canada", in *The Climate of Nova Scotia*, Symposium, 19 November 1991, Nova Scotia Climate Advisory Committee, Atmospheric Environment Service, NS

Shepherd, P. C. F. (1993) *Effects of Baitworm Harvesting on the Prey and Feeding Behaviour of Shorebirds in the Minas Basin Hemispheric Shorebird Reserve*, MSc thesis, Biology, Acadia University, Wolfville, NS

Shepherd, P. C. F. and Boates, S. J. (1999) "Effects of a commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy Hemispheric Shorebird Reserve", *Conservation Biology*, vol 13, pp347–356

Shepherd, P. C. F., Partridge, V. A. and Hicklin, P. W. (1995) *Changes in Sediment Types and Invertebrate Fauna in the Intertidal Mudflats of the Bay of Fundy between 1977 and 1994*, Can. Wildl. Serv. Technical Report No 237

Simon, J. E. and Campana, S. E. (1987) *Species Composition and Distribution in Inshore Waters of Southern Nova Scotia: Results of Exploratory Trawl Surveys*, Can. Tech. Rep. Fish. Aquat. Sci., No 1582

Smith, P. C. (1983) "The mean and seasonal circulation off southwest Nova Scotia", *Journal of Physics*

Spooner, I. S. and Yeo, G. (2003) *Tidal Sedimentation in the Cornwallis River – Avon River Estuaries, Bay of Fundy, Nova Scotia: Sedimentology, Morphology and Natural History*, Atlantic Geoscience Society, Halifax, NS

Stea, R. (2003) *A Virtual Fieldtrip of the Landscapes of Nova Scotia*, Nova Scotia Department of Natural Resources, NS

Stea, R. R. and Brown, Y. (1989) "Variation in drumlin orientation form and stratigraphy relating to successive ice flows in southern and central Nova Scotia", *Sedimentary Geology*, vol 62

Stea, R. R., Conley, H. and Briwn, Y. (1992b) *Surficial Geology of the Province of Nova Scotia*, Nova Scotia Department of Natural Resources, NS

Stea, R. R., Mott, R. J., Belknap, D. F. and Radtke, U. (1992a) "The pre-Late Wisconsin chronology of Nova Scotia, Canada", in P. U. Clark and P. D. Lea (eds) *Interglaciation/Glaciation Transition in North America*, Special Paper, 270, Geological Society of America

Stevens, G. R. (1980) *Mesozoic Vulcanism and Structure: Northern Bay of Fundy Region, Nova Scotia*, GAC/MAC Field Trip Guidebook No 8, Department of Geology, Dalhousie University, Halifax, NS

Stewart, P. L. and Arnold, S. H. (1994) *Environmental Requirements of Atlantic Herring (Clupea harengus harengus) in Eastern Canada and Its Response to Human Impacts*, Can. Tech. Rep. Fish. Aquat. Sci.

Stone, H. H. and Daborn, G. R. (1987) "Diet of alewives, *Alosa pseudoharengus*, and blueback herring, *A. aestivalis*, (Pisces : Clupeidae) in Minas Basin, Nova Scotia, a macrotidal, turbid estuary, *Env. Biol. Fish*, vol 19, pp55–67

Strain, P. M. and Macdonald, R. W. (2002) "Design and implementation of a program to monitor ocean health", *Ocean and Coastal Management*, vol 45, pp325–355

Strain, P. M., Wildish, D. J. and Yeats. P. A. (1995) "The application of simple models of nutrient loading and oxygen demand to the management of a marine tidal inlet", *Marine Pollution Bulletin*, vol 30, pp253–264

Swift, D. J. P. and Borns, H. W. (1967) "A raised fluvial outwash terrace, north shore of the Minas Basin, Nova Scotia", *Journal of Geology*, vol 75, pp693–710

Swift, D. J. P., Cok, A. E. and Lyall, A. K. (1966) "A subtidal sandbody in the Minas Channel, Eastern Bay of Fundy", *Maritime Sediments*, vol 2, pp175–180

Swift, D. J. P., Jagodits, F. L., Mannon, B. L. and Paterson, N. R. (1968) “Structure of the Minas Passage, Bay of Fundy: A preliminary report”, *Marine Sediments*, vol 3

Swift, D. J. P. and McMullen, R. M. (1968) “Preliminary studies of intertidal sand bodies in the Minas Basin, Bay of Fundy, Nova Scotia”, *Canadian Journal of Earth Sciences*, vol 5, pp175–183

Swift, D. J. P., Pelletier, B. R., Lyall, A. K. and Miller, J. A. (1971) *Quaternary Sedimentation in the Bay of Fundy*, Earth Science Symposium on Offshore Eastern Canada, Ottawa, ON

TEC Ltd. (Thaumas Environmental Consultants Ltd) (2005) *Gulf of St. Lawrence Integrated Management Ecosystem Assessment*, Department of Fisheries and Oceans, Chapters 11, 12, 13

Tee, K. T. (1976) “Tide induced residual current: A two-dimensional non-linear numerical tidal model”, J. Mar, Res, vol 34, pp6C3–628

Tee, K. T. (1977) “Tide induced r e s i d u a l c u r r e n t – v e r i f i c a t i o n of a numerical Model”, J. Phy, Oceanog, vol 7, pp396–402

Thomas, M. L. H. (1976) *Intertidal Resources of the Bay of Fundy*, Fundy Tidal Power and the Environment, Acadia University, Wolfville, NS

Thurston, H. (1990) *Tidal Life: A Natural History of the Bay of Fundy*, Camden House Publishing, Camden, ON

Thurston, H. (1994) *Dawing of the Dinosaurs: The Story of Canada’s Oldest Dinosaurs*, Nimbus Publishing and Davis and Browne, Halifax

Trzcinski, M. K., Gibson, A. J. F., Amiro, P. G. and Randall, R. G. (2004) *Inner Bay of Fundy Atlantic salmon (Salmo salar) Critical Habitat Case Study*, Canadian Science Advisory Secretariat, Research Document. 2004/114

Tserhoglou, D. and Anthony, E. H. (1971) “Particle size, water stable aggregates and bacterial population in lake sediments”, *Canadian Journal of Microbiology*, vol 117, pp217–227

Tunnicliffe, V. J. and Risk, M. J. (1977) “Relationships between the bivalve *Macoma balthica* and bacteria in intertidal sediments: Minas Basin, Bay of Fundy”, *Journal of Marine Research*, vol 35, pp499–507

Turk, T. R., Risk, M. J., Hirtle, R. W. M. and Yeo, R. K. (1980) “Sedimentological and biological changes in the Windsor mudflat, an area of induced siltation”, *Canadian Journal of Fisheries and Aquatic Sciences*, vol 37, pp1387–1397

Turnpenny, A. W. H. and Nedwell, J. R. (1994) *The Effects on Marine Fish, Diving Mammals and Birds of Underwater Sound Generated by Seismic Surveys*, Report by Fawley Aquatic Research Laboratories Ltd. for United Kingdom Offshore Operators Association Limited, London, UK

van Proosdij, D. (2005) *Monitoring Seasonal Changes in Surface Elevation of Intertidal Environments near the Windsor Causeway*, Department of Geography, St. Mary’s University, Prepared for, Nova Scotia Department of Transportation and Public Works, Halifax, NS

van Proosdij, D., Bambrick, J. and Baker, G. (2006) *Spatial and Temporal Variations in the Intertidal Geomorphology of the Avon River Estuary*, Saint Mary’s University, Prepared for, Nova Scotia Department of Transportation and Public Works, Halifax, NS van Proosdij, D. and Dobek, P. (2005) *Bay of Fundy Tidal Barriers GIS Database Development*, Department of Geography, St Mary's University, BoFEP and Environmental Conservation Branch, Ecosystem Science and Information Division, Environment Canada Atlantic Region, NS

Vandermeulen, H. (1998) "The development of marine indicators for coastal zone management", *Ocean and Coastal Management*, vol 39, pp63–71

Veith, F. (1884) *Report upon the Condition of the Rivers in Nova Scotia in Connection with the Fisheries in that Province*, Canadian Department of the Secretary of State, Sessional Papers No 134

Verspoor, E., O'Sullivan, M., Arnold, A. L., Knox, D. and Amiro, P. G. (2002) "Restricted matrilineal gene flor and regional differentiation among Atlantic salmon (*Salmo salar L.*) populations within the Bay of Fundy, eastern Canada", *Heredity*, vol 89, pp465–472

Vickers, J. A. (2005) *Environmental and Resource Management in Minas Basin, Bay of Fundy – The Role of Appropriate Indicators and Indices to Assess Marine Ecosystem Health*, MSc thesis, Marine Management, Dalhousie University, Halifax, NS

Volkaert, F. (1987) "Spatial pattern of soft-bottom *Polychaeta* off Nova Scotia, Canada", *Marine Biology*, vol 93, pp627–639

Wade, J. A. and Maclean, B. C. (1990) "The geology of the southeastern margin of Canada", in M. J. Keen and G. L. Williams (eds) Geology of the Continental Margin of Eastern Canada, Geology of Canada No 2, Geological Survey of Canada

Wagner, F. J. E. (1979) "Distribution of pelecypods and gastropods in the Bay of Fundy and eastern Gulf of Maine", *Proc. N. S. Inst. Sci.,* vol 29, no 4

Walker, A., Ackles, T., Perkyns, J., Mackinnon, M., Keiszer, P. and McLachlan, J. (1981) *The Chemistry of Tidal Waters of a Salt Marsh of Minas Basin (Bay of Fundy) Kings County, Nova Scotia*, National Research Council of Canada, Atlantic Research Laboratory Technical Report, No 29

Wark, J. M. and Clarke (1980) "Geochemical discriminators and paleotectonic environment of the North Mountain basalts, Nova Scotia", *Canadian Journal of Earth Science*, vol 17

Watson, E. E. (1936) "Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy", *Journal of the Biological Board of Canada*, vol 2, pp141–197

Webb and Hall (1958) "The ecology of Lagos Lagoon", *Philosophical Transcripts of the Royal Society of London*, vol 241, pp307–419

Webster, T. (2000) *Applied Geomatics Research Group Research Activities Related to the Coastal Zone 2000–2002*, Applied Geomatics Research Group (AGRG), Centre of Geographic Sciences, NSCC, NS

Wells, P. G. (1998) *A Selected Bibliography on Corophium spp, with Special Emphasis on Corophium volutator and the Wildlife Ecology of Mudflats in the Upper Bay of Fundy*, Draft 2, Environmental Conservation Branch, Environment Canada, Dartmouth, NS

Wells, P. G. (1999) *Environmental Impact of Barriers on Rivers Entering the Bay of Fundy: Report of an ad hoc Environment Canada Working Group*, Technical Report Series No 334, Canadian Wildlife Service, Ottawa, ON

Wells, P. G. (2003) "Assessing health of the Bay of Fundy – concepts and framework", *Marine Pollution Bulletin*, vol 46, pp1059–1077

Wells, P. G., Daborn, G. R., Percy, J., Harvey, J. and Rolston, S. J. (2004) *Health of the Bay of Fundy: Assessing Key Issues*, Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum, Taking the Pulse of the Bay, Wolfville, Nova Scotia, 13–16 May 2002, Environment Canada – Atlantic Region, Occasional Report No 21, March

Wells, P. G., Harvey, J., Percy, J. A., Daborn, G. R. and Rolston, S. J. (eds) (2005) *The Bay of Fundy Coastal Forum: Taking the Pulse of the Bay*, A GPAC–BoFEP Coastal Forum, held 15–16 May 2002 as part of the 5th BoFEP Bay of Fundy Science Workshop, Wolfville, NS, Environment Canada–Atlantic Region, Occasional Report No 25, Environment Canada, Dartmouth, NS, and Sackville, NB

Wells, P. G. and Rolston, S. J. (1991) (eds) *Health of Our Oceans: A Status Report on Canadian Oceans*

Welsted, J. W. (1974) "Morphological maps of the Fundy coast", *Maritime Sediments*, vol 10, pp46–51

Westgate, A. J., Muir, D. C. G., Gaskin, D. E. and Kingsley, M. C. S. (1997) "Concentrations and Accumulation Patterns of Organochlorine Contaminants in the Blubber of Harbour Porpoises, Phocoena phocoena, from the Coast of Newfoundland, the Gulf of St. Lawrence and the Bay of Fundy/Gulf of Maine", *Environmental Pollution*, vol 95, pp105–119

Westhead, M. (2002) Unpublished data, Department of Fisheries and Oceans/Acadia University, Bedford Institute of Oceanography, NS

Westhead, M. C. (2005) *Investigations of the Reference Condition Approach and Intertidal Ecology of the Minas Basin, Bay of Fundy, with Reference to the Impacts of Intertidal Harvesting*, MSc thesis, Acadia University, http://www.bofep.org/PDFfiles/westhead_MSc_thesis.pdf

Whiteaves, J. F. (1901) *Catalogue of the Marine Invertebrates of Eastern Canada, Geological Survey of Canada*, Ottawa, ON

Wildish, D. J. (1976) *The Marine and Estuarine Sublittoral Benthos of the Bay of Fundy and Gulf of Maine*, Fundy Tidal Power and the Environment, Acadia University, Wolfville, NS

Wildish, D. J. (1984) "A review of the sublittoral benthic ecological research in the Bay of Fundy: 1976–1982", in D. C. Gordon and M. J. Dadswell (eds) *Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy*, Canadian Technical Report of Fisheries and Aquatic Sciences No 1256

Wildish, D. J. and Peer, D. (1983) "Tidal current speed and production of benthic macrofauna in the lower Bay of Fumdy", *Canadian Journal of Fisheries and Aquatic Sciences*, vol 40 (Supplement 1), pp309–321

Wildish, D. J., Peer, D., Wilson, A. J., Hines, J., Linkletter, L. and Dadswell, M. J. (1983) *Sublittoral Macro-infauna of the Upper Bay of Fundy*, Canadian Technical Report of Fisheries and Aquatic Sciences, No 1194

Willcocks-Musselman, R. (2003) *Minas Basin Watershed Profile, Report 2*, Bay of Fundy Ecosystem Partnership, Acadia University, Wolfville, NS

Willison, M. and Butler, M. (1998) "Ecosystem management of fisheries", *Ecology Action Centre Publication*, winter, vol 16, no 1, pp8–11

Wilson, W. J. (1988) "Shifting zones in a Bay of Fundy soft-sediment community: Patterns and processes", *Ophelia*, vol 29, pp227–245

Wilson, W. J. (1989) "Predation and the mediation of intraspecific competition in an infaunal community in the Bay of Fundy", *Journal of Experimental Marine Biology and Ecology*, vol 132, pp221–245

Wilson, W. H. Jr. (1991) "The importance of epibenthic predation and ice disturbance in a Bay of Fundy mudflat", *Ophelia Supplement*, vol 5, pp507–514

Windom, H.L. (1996) "Riverine contributions to heavy metal inputs to the Northeast Shelf ecosystem", in K. Sherman, N. A.Jaworski and T. J. Smayda (eds) *The Northeast Shelf Ecosystem: Assessment, Sustainability and Management*, Blackwell Science, Cambridge, MA

Woodley, T. H. and Gaskin, D. E. (1996) "Environmental characteristics of North Atlantic right and fin whale habitat in the lower Bay of Fundy, Canada", *Canadian Journal of Zoology*, vol 74, pp75–84

Yeats, P. A. (2007) Personal communication, 12 July 2007, Department of Fisheries and Oceans, Dartmouth, NS

Yeats, P. A. and Westhead, M. (2007) *Heavy Metals in the Bay of Fundy Water and Sediments and MEQ*, Department of Fisheries and Oceans, Dartmouth, NS

Yeo, R. K. (1977) *Animal–Sediment Relationships and the Ecology of the Intertidal Mudflat Environment, Minas Basin, Bay of Fundy, Nova Scotia*, MSc thesis, Department of Geology, McMaster University, Hamilton, ON

Yeo, R. K.,and Risk, M. J. (1981) "The sedimentology, stratigraphy, and preservation of intertidal deposits in the Minas Basin System, Bay of Fundy", *Journal of Sedimentary Petrology*, vol 51, pp245–260

Zobell, C. E. (1946) *Marine Microbiology: A Monograph on Hydro Bacteriology*, Chromica Botanica Co., MA

APPENDIX A: SUMMARY OF SPECIES AT RISK IN THE MINAS BASIN WATERSHED

Table A1 *Summary of species assessed and reported through the Atlantic Canada Conservation Data Centre for the Minas Basin watershed sub-basins and sorted first by provincial (SPROT) and national (NPROT) protected species, followed by provincial ranking (SRANK); further explanation of ranks follows this table*

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Alces americanus	Moose	G5		S1	**Endangered**
Falco peregrinus anatum	American Peregrine Falcon	G4T3	**Special Concern**	S1B	**Threatened**
Isoetes prototypus	Prototype Quillwort	G1?	**Special Concern**	S2	**Vulnerable**
Glyptemys insculpta	Wood Turtle	G4	**Special Concern**	S3	**Vulnerable**
Thuja occidentalis	Northern White Cedar	G5		S1S2	**Vulnerable**
Salmo salar	Atlantic Salmon (iBoF)	G5	**Endangered**	S2	
Danaus plexippus	Monarch Butterfly	G5	**Special Concern**	S2B	
Euphagus carolinus	Rusty Blackbird	G4	**Special Concern**	S3B	
Asio flammeus	Short-eared Owl	G5	**Special Concern**	S1S2B	
Glaucomys volans	Southern Flying Squirrel	G5	**Special Concern**	S2S3	
Morone saxatillis	Striped Bass (BoF)	G5	**Threatend**	S1	
Desmatodon obtusifolius	a Moss	G5		S1	
Timmia megapolitana	a Moss	G5		S1	
Antennaria parlinii	a Pussytoes	G4G5		S1	
Antennaria rosea ssp. arida	a Rosy Pussy-Toes	G5T3T5		S1	
Sanicula odorata	Black Snake-Root	G5		S1	
Osmorhiza depauperata	Blunt-Fruited Sweet-Cicely	G5		S1	
Elymus hystrix var. bigeloviana	Bottlebrush Grass	G5T5?		S1	
Lycaena hyllus	Bronze Copper	G5		S1	
Ophiogomphus aspersus	Brook Snaketail	G3G4		S1	
Pilea pumila	Canada Clearweed	G5		S1	
Viola canadensis	Canada Violet	G5		S1	
Spiranthes casei var. casei	Case's Ladies'-Tresses	G4T4		S1	
Gratiola neglecta	Clammy Hedge-Hyssop	G5		S1	
Carex haydenii	Cloud Sedge	G5		S1	
Somatochlora franklini	Delicate Emerald	G5		S1	
Goodyera pubescens	Downy Rattlesnake-Plantain	G5		S1	
Dirca palustris	Eastern Leatherwood	G4		S1	
Carex garberi	Elk Sedge	G5		S1	
Montia fontana	Fountain Miner's-Lettuce	G5		S1	
Cryptogramma stelleri	Fragile Rockbrake	G5		S1	
Fraxinus pennsylvanica	Green Ash	G5		S1	
Gomphaeschna furcillata	Harlequin Darner	G5		S1	
Polygonia gracilis	Hoary Comma	G5		S1	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Oeneis jutta	Jutta Arctic	G5		S1	
Cardamine maxima	Large Toothwort	G5		S1	
Carex livida var. radicaulis	Livid Sedge	G5T5		S1	
Sorex dispar	Long-tailed Shrew	G4		S1	
Carex laxiflora var. laxiflora	Loose-Flowered Sedge	G5T5		S1	
Equisetum palustre	Marsh Horsetail	G5		S1	
Amelanchier nantucketensis	Nantucket Shadbush	G3Q		S1	
Adiantum pedatum	Northern Maidenhair-Fern	G5		S1	
Cynoglossum virginianum var. boreale	Northern Wild Comfrey	G5T4T5		S1	
Carex plantaginea	Plantain-Leaved Sedge	G5		S1	
Carex prairea	Prairie Sedge	G5?		S1	
Cypripedium arietinum	Ram's-Head Lady's-Slipper	G3		S1	
Astragalus robbinsii var. minor	Robbins' Milk-Vetch	G5T5		S1	
Hepatica nobilis var. obtusa	Round-Leaved Liverleaf	G5T5		S1	
Hepatica nobilis var. obtusa	Round-Leaved Liverleaf	G5T5		S1	
Ophiogomphus rupinsulensis	Rusty Snaketail	G5		S1	
Juncus secundus	Secund Rush	G5?		S1	
Desmodium canadense	Showy Tick-Trefoil	G5		S1	
Gomphus ventricosus	Skillet Clubtail	G3		S1	
Allium tricoccum	Small White Leek	G5		S1	
Listera australis	Southern Twayblade	G4		S1	
Potamogeton pulcher	Spotted Pondweed	G5		S1	
Oxytropis campestris var. johannensis	St. John's Oxytrope	G5T4		S1	
Scirpus pedicellatus	Stalked Bulrush	G4		S1	
Coenagrion resolutum	Taiga Bluet	G5		S1	
Leptodea ochracea	Tidewater Mucket	G4		S1	
Carex tuckermanii	Tuckerman Sedge	G4		S1	
Enallagma carunculatum	Tule Bluet	G5		S1	
Malaxis brachypoda	White Adder's-Mouth	G4Q		S1	
Ageratina altissima	White Snakeroot	G5		S1	
Stylurus scudderi	Zebra Clubtail	G4		S1	
Crataegus robinsonii	A Hawthorn	G2G4Q		S1?	
Pipistrellus subflavus	Eastern Pipistrelle	G5		S1?	
Atriplex acadiensis	Maritime Saltbush	G2G4		S1?	
Dichanthelium acuminatum var. lindheimeri	Panic Grass	G5T5		S1?	
Suaeda rolandii	Roland's Sea-Blite	G1G2Q		S1?	
Vireo gilvus	Warbling Vireo	G5		S1?B	
Caprimulgus vociferus	Whip-Poor-Will	G5		S1?B	
Gallinula chloropus	Common Moorhen	G5		S1B	
Sturnella magna	Eastern Meadowlark	G5		S1B	
Progne subis	Purple Martin	G5		S1B	
Carex bebbii	Bebb's Sedge	G5		S1S2	
Callophrys lanoraieensis	Bog Elfin	G3G4		S1S2	
Alasmidonta varicosa	Brook Floater	G3		S1S2	
Zizia aurea	Common Alexanders	G5		S1S2	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Nymphalis vaualbum	Compton Tortoiseshell	G5		S1S2	
Arabis hirsuta var. pycnocarpa	Hairy Rock-Cress	G5T5		S1S2	
Asio otus	Long-eared Owl	G5		S1S2	
Festuca subverticillata	Nodding Fescue	G5		S1S2	
Platanthera flava var. herbiola	Pale Green Orchid	G4T4Q		S1S2	
Carex pensylvanica	Pennsylvania Sedge	G5		S1S2	
Carex hystericina	Porcupine Sedge	G5		S1S2	
Carex tenera	Slender Sedge	G5		S1S2	
Conopholis americana	Squaw-Root	G5		S1S2	
Najas gracillima	Thread-Like Naiad	G5?		S1S2	
Anemone virginiana	Virginia Anemone	G5		S1S2	
Lobelia spicata	Pale-Spiked Lobelia	G5		S1S2SE	
Huperzia selago	Fir Clubmoss	G5		S1S3	
Plantago rugelii	Black-Seed Plantain	G5		S1SE	
Cuscuta pentagona	Field Dodder	G5		S1SE	
Trillium grandiflorum	Large-Flower Trillium	G5		S1SE	
Alisma gramineum	Narrow-Leaf Water-Plantain	G5		S1SE	
Puccinellia fasciculata	Salt Marsh Goosegrass	G3G5		S1SE	
Ribes americanum	Wild Black Currant	G5		S1SE	
Saxifraga paniculata ssp. neogaea	a White Mountain Saxifrage	G5T5?		S2	
Lestes eurinus	Amber-Winged Spreadwing	G4		S2	
Boloria chariclea	Arctic Fritillary	G5		S2	
Enallagma aspersum	Azure Bluet	G5		S2	
Satyrium calanus	Banded Hairstreak	G5		S2	
Gomphus borealis	Beaverpond Clubtail	G4		S2	
Carex atratiformis	Black Sedge	G5		S2	
Dromogomphus spinosus	Black-Shouldered Spinyleg	G5		S2	
Caulophyllum thalictroides	Blue Cohosh	G4G5		S2	
Salix pedicellaris	Bog Willow	G5		S2	
Carex comosa	Bristly Sedge	G5		S2	
Celithemis elisa	Calico Pennant	G5		S2	
Anemone canadensis	Canada Anemone	G5		S2	
Shepherdia canadensis	Canada Buffalo-Berry	G5		S2	
Piptatherum canadense	Canada Mountain-Ricegrass	G5		S2	
Carex castanea	Chestnut-Colored Sedge	G5		S2	
Somatochlora tenebrosa	Clamp-Tipped Emerald	G5		S2	
Polygonum scandens	Climbing False-Buckwheat	G5		S2	
Triosteum aurantiacum	Coffee Tinker's-Weed	G5		S2	
Amblyscirtes vialis	Common Roadside-Skipper	G5		S2	
Stellaria humifusa	Creeping Sandwort	G5?		S2	
Arabis drummondii	Drummond Rockcress	G5		S2	
Gomphus spicatus	Dusky Clubtail	G5		S2	
Vaccinium caespitosum	Dwarf Blueberry	G5		S2	
Polygonia comma	Eastern Comma	G5		S2	
Lampsilis radiata	Eastern Lampmussel	G5		S2	
Callophrys niphon	Eastern Pine Elfin	G5		S2	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Amphiagrion saucium	Eastern Red Damsel	G5		S2	
Vallisneria americana	Eel-Grass	G5		S2	
Nannothemis bella	Elfin Skimmer	G4		S2	
Myriophyllum farwellii	Farwell's Water-Milfoil	G5		S2	
Dryopteris fragrans var. remotiuscula	Fragrant Fern	G5T3T5		S2	
Potamogeton friesii	Fries' Pondweed	G4		S2	
Hudsonia ericoides	Golden-Heather	G4		S2	
Ranunculus flammula var. flammula	Greater Creeping Spearwort	G5T4T5		S2	
Asplenium trichomanes-ramosum	Green Spleenwort	G4		S2	
Aeshna verticalis	Green-Striped Darner	G5		S2	
Carex capillaris	Hair-Like Sedge	G5		S2	
Lactuca hirsuta var. sanguinea	Hairy Wild Lettuce	G5?T5?		S2	
Polygonum arifolium	Halberd-Leaf Tearthumb	G5		S2	
Tiarella cordifolia	Heart-Leaved Foam-Flower	G5		S2	
Callophrys henrici	Henry's Elfin	G5		S2	
Utricularia gibba	Humped Bladderwort	G5		S2	
Somatochlora cingulata	Lake Emerald	G5		S2	
Botrychium lanceolatum var. angustisegmentum	Lance-Leaf Grape-Fern	G5T4		S2	
Aeshna constricta	Lance-Tipped Darner	G5		S2	
Desmodium glutinosum	Large Tick-Trefoil	G5		S2	
Cypripedium parviflorum var. pubescens	Large Yellow Lady's-Slipper	G5T5		S2	
Pyrola minor	Lesser Wintergreen	G5		S2	
Enallagma minusculum	Little Bluet	G3G4		S2	
Coeloglossum viride var. virescens	Long-Bract Green Orchis	G5T5		S2	
Lestes unguiculatus	Lyre-Tipped Spreadwing	G5		S2	
Asplenium trichomanes	Maidenhair Spleenwort	G5		S2	
Celithemis martha	Martha's Pennant	G4		S2	
Equisetum pratense	Meadow Horsetail	G5		S2	
Aglais milberti	Milbert's Tortoiseshell	G5		S2	
Aeshna clepsydra	Mottled Darner	G4		S2	
Minuartia groenlandica	Mountain Sandwort	G5		S2	
Gomphus adelphus	Moustached Clubtail	G4		S2	
Pieris oleracea	Mustard White	G4G5		S2	
Galium boreale	Northern Bedstraw	G5		S2	
Viola nephrophylla	Northern Bog Violet	G5		S2	
Thorybes pylades	Northern Cloudywing	G5		S2	
Boyeria grafiana	Ocellated Darner	G5		S2	
Somatochlora minor	Ocellated Emerald	G5		S2	
Impatiens pallida	Pale Jewel-Weed	G5		S2	
Amblyscirtes hegon	Pepper and Salt Skipper	G5		S2	
Erigeron philadelphicus	Philadelphia Fleabane	G5		S2	
Epitheca princeps	Prince Baskettail	G5		S2	
Dorocordulia libera	Racket-Tailed Emerald	G5		S2	
Anemone virginiana var. virginiana	River Anemone	G5T5		S2	
Hieracium robinsonii	Robinson's Hawkweed	G2G3		S2	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Draba arabisans	Rock Whitlow-Grass	G4		S2	
Sympetrum rubicundulum	Ruby Meadowhawk	G5		S2	
Senecio pseudoarnica	Seabeach Groundsel	G5		S2	
Spiranthes lucida	Shining Ladies'-Tresses	G5		S2	
Cypripedium reginae	Showy Lady's-Slipper	G4		S2	
Salix sericea	Silky Willow	G5		S2	
Eriophorum gracile	Slender Cotton-Grass	G5		S2	
Cypripedium parviflorum var. makasin	Small Yellow Lady's-Slipper	G5T4Q		S2	
Cardamine parviflora var. arenicola	Small-Flower Bitter-Cress	G5T5		S2	
Woodsia glabella	Smooth Woodsia	G5		S2	
Osmorhiza longistylis	Smoother Sweet-Cicely	G5		S2	
Platanthera flava	Southern Rein-Orchid	G4		S2	
Nehalennia gracilis	Sphagnum Sprite	G5		S2	
Enallagma cyathigerum vernale	Springtime Bluet	G4		S2	
Enallagma exsulans	Stream Bluet	G5		S2	
Lestes vigilax	Swamp Spreadwing	G5		S2	
Lestes forcipatus	Sweetflag Spreadwing	G5		S2	
Libellula pulchella	Twelve-Spotted Skimmer	G5		S2	
Symphyotrichum undulatum	Wavy-leaf American-Aster	G5		S2	
Myriophyllum verticillatum	Whorled Water-Milfoil	G5		S2	
Allium schoenoprasum var. sibiricum	Wild Chives	G5T5		S2	
Rumex salicifolius var. mexicanus	Willow Dock	G5T5		S2	
Anemone quinquefolia	Wood Anemone	G5		S2	
Spiranthes ochroleuca	Yellow Nodding Ladies'-Tresses	G4		S2	
Carex houghtoniana	A Sedge	G5		S2?	
Symphyotrichum boreale	Boreal American-Aster	G5		S2?	
Juncus dudleyi	Dudley's Rush	G5		S2?	
Lycopodium hickeyi	Hickey's Clubmoss	G5		S2?	
Hieracium kalmii var. kalmii	Kalm's Hawkweed	G5T5?		S2?	
Eleocharis ovata	Ovate Spikerush	G5		S2?	
Epilobium coloratum	Purple-Leaf Willow-Herb	G5		S2?	
Dichanthelium linearifolium	Slim-Leaf Witchgrass	G5		S2?	
Hieracium umbellatum	Umbellate Hawkweed	G5		S2?	
Carex peckii	White-Tinged Sedge	G4G5		S2?	
Cardinalis cardinalis	Northern Cardinal	G5		S2B	
Anas acuta	Northern Pintail	G5		S2B	
Anas clypeata	Northern Shoveler	G5		S2B	
Piranga olivacea	Scarlet Tanager	G5		S2B	
Rallus limicola	Virginia Rail	G5		S2B	
Hylocichla mustelina	Wood Thrush	G5		S2B	
Eremophila alpestris	Horned Lark	G5		S2B,S4N	
Calidris maritima	Purple Sandpiper	G5		S2N	
Ophioglossum pusillum	Adder's Tongue	G5		S2S3	
Hedeoma pulegioides	American Pennyroyal	G5		S2S3	
Suaeda calceoliformis	American Sea-Blite	G5		S2S3	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Lilium canadense	Canada Lily	G5		S2S3	
Carex adusta	Crowded Sedge	G5		S2S3	
Rudbeckia laciniata	Cut-Leaved Coneflower	G5		S2S3	
Rudbeckia laciniata var. gaspereauensis	Cut-Leaved Coneflower	G5TNR		S2S3	
Erigeron hyssopifolius	Daisy Fleabane	G5		S2S3	
Hypericum dissimulatum	Disguised St. John's-Wort	G5		S2S3	
Goodyera repens	Dwarf Rattlesnake-Plantain	G5		S2S3	
Floerkea proserpinacoides	False Mermaid-Weed	G5	NAR	S2S3	
Polygala sanguinea	Field Milkwort	G5		S2S3	
Potamogeton zosteriformis	Flatstem Pondweed	G5		S2S3	
Juncus marginatus	Grassleaf Rush	G5		S2S3	
Conioselinum chinense	Hemlock Parsley	G5		S2S3	
Erynnis juvenalis	Juvenal's Duskywing	G5		S2S3	
Botrychium simplex	Least Grape-Fern	G5		S2S3	
Symphyotrichum ciliolatum	Lindley's Aster	G5		S2S3	
Carex hirtifolia	Pubescent Sedge	G5		S2S3	
Alopecurus aequalis	Short-Awn Foxtail	G5		S2S3	
Cypripedium parviflorum	Small Yellow Lady's-Slipper	G5		S2S3	
Asclepias incarnata ssp. pulchra	Swamp Milkweed	G5T5		S2S3	
Alasmidonta undulata	Triangle Floater	G4		S2S3	
Poa glauca	White Bluegrass	G5		S2S3	
Sialia sialis	Eastern Bluebird	G5	NAR	S2S3B	
Sayornis phoebe	Eastern Phoebe	G5		S2S3B	
Myiarchus crinitus	Great Crested Flycatcher	G5		S2S3B	
Passerina cyanea	Indigo Bunting	G5		S2S3B	
Pooecetes gramineus	Vesper Sparrow	G5		S2S3B	
Panicum philadelphicum	Philadelphia Panic Grass	G5		S2S3SE	
Polygonum buxiforme	Small's Knotweed	G5		S2S3SE	
Iva frutescens ssp. oraria	Marsh Elder	G5T5		S2SE	
Oenothera fruticosa ssp. glauca	Shrubby Sundrops	G5T5		S2SE	
Isoetes acadiensis	Acadian Quillwort	G2G3		S3	
Rhamnus alnifolia	Alderleaf Buckthorn	G5		S3	
Cordulia shurtleffii	American Emerald	G5		S3	
Chromagrion conditum	Aurora Damsel	G5		S3	
Packera paupercula	Balsam Groundsel	G5		S3	
Euphydryas phaeton	Baltimore Checkerspot	G4		S3	
Sympetrum semicinctum	Band-Winged Meadowhawk	G5		S3	
Epitheca canis	Beaverpond Baskettail	G5		S3	
Megalodonta beckii	Beck Water-Marigold	G4G5		S3	
Primula laurentiana	Bird's-Eye Primrose	G5		S3	
Fraxinus nigra	Black Ash	G5		S3	
Cepphus grylle	Black Guillemot	G5		S3	
Aeshna tuberculifera	Black-Tipped Darner	G4		S3	
Verbena hastata	Blue Vervain	G5		S3	
Enallagma boreale	Boreal Bluet	G5		S3	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Listera convallarioides	Broad-Leaved Twayblade	G5		S3	
Carex bromoides	Brome-Like Sedge	G5		S3	
Somatochlora walshii	Brush-Tipped Emerald	G5		S3	
Aeshna canadensis	Canada Darner	G5		S3	
Libellula julia	Chalk-Fronted Corporal	G5		S3	
Goodyera tesselata	Checkered Rattlesnake-Plantain	G5		S3	
Proserpinaca pectinata	Comb-Leaved Mermaid-Weed	G5		S3	
Epitheca cynosura	Common Baskettail	G5		S3	
Hesperia comma	Common Branded Skipper	G5		S3	
Anax junius	Common Green Darner	G5		S3	
Plathemis lydia	Common Whitetail	G5		S3	
Leucorrhinia glacialis	Crimson-Ringed Whiteface	G5		S3	
Botrychium dissectum	Cutleaf Grape-Fern	G5		S3	
Dichanthelium clandestinum	Deer-Tongue Witchgrass	G5?		S3	
Cordulegaster diastatops	Delta-Spotted Spiketail	G5		S3	
Leucorrhinia intacta	Dot-Tailed Whiteface	G5		S3	
Epilobium strictum	Downy Willow-Herb	G5?		S3	
Hagenius brevistylus	Dragonhunter	G5		S3	
Panax trifolius	Dwarf Ginseng	G5		S3	
Corallorhiza trifida	Early Coralroot	G5		S3	
Carex eburnea	Ebony Sedge	G5		S3	
Lestes dryas	Emerald Spreadwing	G5		S3	
Enallagma civile	Familiar Bluet	G5		S3	
Boyeria vinosa	Fawn Darner	G5		S3	
Hemidactylium scutatum	Four-toed Salamander	G5	**NAR**	S3	
Ischnura posita	Fragile Forktail	G5		S3	
Leucorrhinia frigida	Frosted Whiteface	G5		S3	
Euthamia caroliniana	Grass-Leaved Goldenrod	G5		S3	
Polygonia faunus	Green Comma	G5		S3	
Enallagma hageni	Hagen's Bluet	G5		S3	
Platanthera hookeri	Hooker Orchis	G4		S3	
Carex lupulina	Hop Sedge	G5		S3	
Leucorrhinia hudsonica	Hudsonian Whiteface	G5		S3	
Macromia illinoiensis	Illinois River Cruiser	G5		S3	
Trillium erectum	Ill-Scent Trillium	G5		S3	
Somatochlora incurvata	Incurvate Emerald	G4		S3	
Aeshna eremita	Lake Darner	G5		S3	
Gomphus exilis	Lancet Clubtail	G5		S3	
Platanthera grandiflora	Large Purple-Fringe Orchis	G5		S3	
Platanthera orbiculata	Large Roundleaf Orchid	G5		S3	
Hesperia comma laurentina	Laurentian Skipper	G5T5		S3	
Stylogomphus albistylus	Least Clubtail	G5		S3	
Stellaria longifolia	Longleaf Stitchwort	G5		S3	
Enallagma ebrium	Marsh Bluet	G5		S3	
Salix petiolaris	Meadow Willow	G5		S3	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Trisetum spicatum	Narrow False Oats	G5		S3	
Enodia anthedon	Northern Pearly-Eye	G5		S3	
Hieracium paniculatum	Panicled Hawkweed	G5		S3	
Polygonum pensylvanicum	Pennsylvania Smartweed	G5		S3	
Dorocordulia lepida	Petite Emerald	G5		S3	
Pyrola asarifolia	Pink Wintergreen	G5		S3	
Argia moesta	Powdered Dancer	G5		S3	
Leucorrhinia proxima	Red-Waisted Whiteface	G5		S3	
Ophiogomphus carolus	Riffle Snaketail	G5		S3	
Calopteryx aequabilis	River Jewelwing	G5		S3	
Carex rosea	Rosy Sedge	G5		S3	
Sympetrum costiferum	Saffron-Winged Meadowhawk	G5		S3	
Nehalennia irene	Sedge Sprite	G5		S3	
Somatochlora elongata	Ski-Tailed Emerald	G5		S3	
Libellula incesta	Slaty Skimmer	G5		S3	
Eleocharis nitida	Slender Spike-Rush	G3G4		S3	
Lestes rectangularis	Slender Spreadwing	G5		S3	
Sparganium natans	Small Bur-Reed	G5		S3	
Utricularia radiata	Small Swollen Bladderwort	G4		S3	
Luzula parviflora	Small-Flowered Wood-Rush	G5		S3	
Lycopodiella appressa	Southern Bog Clubmoss	G5		S3	
Epitheca spinigera	Spiny Baskettail	G5		S3	
Lestes congener	Spotted Spreadwing	G5		S3	
Basiaeschna janata	Springtime Darner	G5		S3	
Didymops transversa	Stream Cruiser	G5		S3	
Satyrium liparops	Striped Hairstreak	G5		S3	
Aeshna subarctica	Subarctic Darner	G5		S3	
Calopteryx amata	Superb Jewelwing	G4		S3	
Asclepias incarnata	Swamp Milkweed	G5		S3	
Milium effusum var. cisatlanticum	Tall Millet-Grass	G5TNR		S3	
Cordulegaster maculata	Twin-Spotted Spiketail	G5		S3	
Helocordulia uhleri	Uhler's Sundragon	G5		S3	
Argia fumipennis violacea	Variable Dancer	G5T5		S3	
Equisetum variegatum	Variegated Horsetail	G5		S3	
Ladona exusta	White Corporal	G4		S3	
Sympetrum obtrusum	White-Faced Meadowhawk	G5		S3	
Laportea canadensis	Wood Nettle	G5		S3	
Juncus subcaudatus	Woods-Rush	G5		S3	
Bartonia virginica	Yellow Screwstem	G5		S3	
Sympetrum vicinum	Yellow-Legged Meadowhawk	G5		S3	
Cystopteris tenuis	A Bladderfern	G4G5		S3?	
Lycopodium sitchense	Alaskan Clubmoss	G5		S3?	
Polypodium appalachianum	Appalachian Polypody	G4G5		S3?	
Carex foenea	Dry-Spike Sedge	G5		S3?	
Sparganium fluctuans	Floating Bur-Reed	G5		S3?	
Lycopodium sabinifolium	Ground-Fir	G4		S3?	

GNAME	GCOMNAME	GRANK	NPROT	SRANK	SPROT
Isoetes lacustris	Lake Quillwort	GNR		S3?	
Campanula aparinoides	Marsh Bellflower	G5		S3?	
Rubus pensilvanicus	Pennsylvania Blackberry	G5		S3?	
Bidens connata	Purple-Stem Swamp Beggar-Ticks	G5		S3?	
Potamogeton richardsonii	Redhead Grass	G5		S3?	
Ranunculus gmelinii	Small Yellow Water-Crowfoot	G5		S3?	
Agrimonia gryposepala	Tall Hairy Groovebur	G5		S3?	
Lycopodium complanatum	Trailing Clubmoss	G5		S3?	
Potamogeton praelongus	White-Stem Pondweed	G5		S3?	
Icterus galbula	Baltimore Oriole	G5		S3B	
Coccyzus erythropthalmus	Black-billed Cuckoo	G5		S3B	
Dolichonyx oryzivorus	Bobolink	G5		S3B	
Sterna hirundo	Common Tern	G5	**NAR**	S3B	
Ammodramus nelsoni	Nelson's Sharp-tailed Sparrow	G5	**NAR**	S3B	
Accipiter gentilis	Northern Goshawk	G5	**NAR**	S3B	
Mimus polyglottos	Northern Mockingbird	G5		S3B	
Polygonia interrogationis	Question Mark	G5		S3B	
Mergus serrator	Red-breasted Merganser	G5		S3B	
Potamogeton confervoides	Algae-Like Pondweed	G4		S3S4	
Speyeria aphrodite	Aphrodite Fritillary	G5		S3S4	
Viola sagittata var. ovata	Arrow-Leaved Violet	G5T5		S3S4	
Sanguinaria canadensis	Bloodroot	G5		S3S4	
Carex tribuloides	Blunt Broom Sedge	G5		S3S4	
Polystichum braunii	Braun's Holly-Fern	G5		S3S4	
Cystopteris bulbifera	Bulblet Fern	G5		S3S4	
Equisetum scirpoides	Dwarf Scouring Rush	G5		S3S4	
Carex albicans var. emmonsii	Emmons Sedge	G5T5		S3S4	
Polygonia progne	Gray Comma	G5		S3S4	
Feniseca tarquinius	Harvester	G4		S3S4	
Carex argyrantha	Hay Sedge	G5		S3S4	
Callophrys polios	Hoary Elfin	G5		S3S4	
Spiranthes romanzoffiana	Hooded Ladies'-Tresses	G5		S3S4	
Liparis loeselii	Loesel's Twayblade	G5		S3S4	
Proserpinaca palustris var. crebra	Marsh Mermaid-Weed	G5T5		S3S4	
Euthamia galetorum	Narrow-Leaf Fragrant Golden-Rod	G3		S3S4	
Loxia curvirostra	Red Crossbill	G5		S3S4	
Sphenopholis intermedia	Slender Wedge Grass	G5		S3S4	
Lysimachia thyrsiflora	Water Loosestrife	G5		S3S4	
Lindernia dubia	Yellow-Seed False-Pimpernel	G5		S3S4	
Libellula luctuosa	Widow Skimmer	G5		SH	

Atlantic Canada CDC Canada Atlantique

2004 Edition

Part I. Conservation Data Centre Subnational Rarity Ranks

Biological diversity or biodiversity can be described at a number of levels, from molecules to ecosystems. Biodiversity is a combination of species diversity (the variety of species), genetic diversity (the genetic variability among individuals of that species), and ecological diversity (the variety of ecosystems/habitats in which they live). Conservation Data Centres (CDCs), as part of The NatureServe* international network, track biodiversity at two levels: species and ecological communities. Species and ecological communities are referred to as **elements** of biodiversity. Elements are ranked in each jurisdiction (province or state) and at global and national levels in order to help prioritise conservation efforts.

NatureServe and all CDCs (called Heritage Programs in the US) use a standardised element ranking system that has evolved over some 30 years, with input from hundreds of scientists, managers and conservationists. The following material describes this element ranking system at the subnational (S) or provincial level and explains how ranks are assigned for species elements of biodiversity. (The community ranking process is slightly different.)

* Formerly known as The Nature Conservancy (TNC)

Definitions of Provincial (subnational) ranks - SRANKS

S1 Extremely rare throughout its range in the province (typically 5 or fewer occurrences or very few remaining individuals). May be especially vulnerable to extirpation.

S2 Rare throughout its range in the province (6 to 20 occurrences or few remaining individuals). May be vulnerable to extirpation due to rarity or other factors.

S3 Uncommon throughout its range in the province, or found only in a restricted range, even if abundant in at some locations. (21 to 100 occurrences).

S4 Usually widespread, fairly common throughout its range in the province, and apparently secure with many occurrences, but the Element is of long-term concern (e.g. watch list). (100+ occurrences).

S5 Demonstrably widespread, abundant, and secure throughout its range in the province, and essentially ineradicable under present conditions.

S#S# Numeric range rank: A range between two consecutive numeric ranks. Denotes range of uncertainty about the exact rarity of the Element (e.g., S1S2).

SH Historical: Element occurred historically throughout its range in the province (with expectation that it may be rediscovered), perhaps having not been verified in the past 20 - 70 years (depending on the species), and suspected to be still extant.

SU Unrankable: Possibly in peril throughout its range in the province, but status uncertain; need more information.

SX Extinct/Extirpated: Element is believed to be extirpated within the province.

S? Unranked: Element is not yet ranked.

SA Accidental: Accidental or casual in the province (i.e., infrequent and far outside usual range). Includes species (usually birds or butterflies) recorded once or twice or only at very great intervals, hundreds or even thousands of miles outside their usual range; a few of these species may even have bred on the one or two occasions they were recorded.

SE Exotic: An exotic established in the province (e.g., Purple Loosestrife or Coltsfoot); may be native in nearby regions.

SE# Exotic numeric: An exotic established in the province that has been assigned a numeric rank.

SP Potential: Potential that Element occurs in the province, but no occurrences reported.

SR Reported: Element reported in the province but without persuasive documentation which would provide a basis for either accepting or rejecting (e.g., misidentified specimen) the report.

SRF Reported falsely: Element erroneously reported in the province and the error has persisted in the literature.

SZ Zero occurrences: Not of practical conservation concern in the province, because there are no definable occurrences, although the species is native and appears regularly. An NZ rank will generally be used for long distance migrants whose occurrences during their migrations are too irregular (in terms of repeated visitation to the same locations) or transitory. In other words, the migrant regularly passes through the province, but enduring, mappable Element Occurrences cannot be defined.

Qualifiers

Breeding Status

B Breeding: Basic rank refers to the breeding population of the element in the province.

N Non-breeding: Basic rank refers to the non-breeding (usually wintering) population of the element in the province.

M Migratory: Basic rank refers to the migratory stopover population in the province.

Other Qualifiers:

? Inexact or uncertain: for numeric ranks, denotes inexactness, e.g., SE? denotes uncertainty of exotic status. (The "?" qualifies the character immediately preceding it in the SRANK)

C Captive or cultivated: Element is presently extant in the country or province only in captivity or cultivation.

Part II. The Ranking Process

To rank species elements, eight different biological criteria are assessed for each species. A letter value from A to D is assigned to each biological factor for which there is enough information. A species with all **A**s will likely be ranked S1 whereas a species with all **D**s would likely receive a S5. Where there is a mixture of letter ranks, the person doing the ranking must use their judgment to decide how much weight should be given to certain factors, depending on the biology of the species in question. The eight factors considered in assigning status ranks are described below. Following this there is a matrix (Table 1) summarising the guidelines for scoring (A-D) the eight criteria.

Ranking Matrix Eight ranking criteria and value of letter scores for each criterion.

	MATRIX SCORE			
	A	**B**	**C**	**D**
CRITERIA				
Population size	<1000	1000-3000	3000-10,000	> 10,000
Geographic Distribution	<4% of province	4-10% of province	11-50% of province	>50% of province
Population Trend	Rapid decline (>50% in 10 yrs)	Decline (>20% in 10 yrs)	Stable (natural fluctuation)	Increasing
Distribution Trend	Rapid Decline	Decline	Stable	Increasing
Number of Element Occurrences	0-5	6-20	21-100	>100
Number of protected EOs	Believed to be none	At least one	Several	Many
Threats to population	Extreme	Moderate	Limited	None
Threats to habitat	Extreme	Moderate	Limited	None

1. Provincial Abundance

A single letter code represents the estimated provincial abundance of the species. Abundance is measured in different ways depending on the biology of the species. For animal populations it is usually measured by the number of individuals, for plants it may be measured by the area occupied by a distinct population, and for aquatic invertebrates it may be measured by the stream length that the species occupies:

A = Fewer than 1,000 individuals <u>or</u>
Fewer than 10 miles of stream length <u>or</u>
fewer than 800 ha

B = 1,000 - 3,000 individuals <u>or</u>
10 - 50 miles of stream length <u>or</u>
800 - 4000 ha

C = 3,000 - 10,000 individuals *or*
50 - 250 miles of stream length *or*
4,000 to 20,000 ha

D = over 10,000 individuals *or*
over 250 miles of stream length *or*
over 20,000 ha

2. Provincial Range

This denotes the approximate range of the species as a percentage of the province's area. It is defined as the current area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of occurrence, but, *excluding* significant areas where the species does not occur due to unsuitable habitat. Thus the estimate of range for a species exhibiting a linear use of coastal forests or riverine habitats would not consider tracts of unsuitable habitat in the interior of the polygon.

A = Very small range, less than 3% of province
B = Narrow range, less than 10% of province
C = Moderately widespread, less than half of province
D = Widespread, more than half of province

3. Population Abundance Trend

Population Abundance Trend is an estimate of the change in the number of mature individuals over time, from long term monitoring data and historical accounts, where available. Natural fluctuations will not normally count as part of a decline. An observed decline should not be considered as part of a natural fluctuation unless there is evidence for this.

A = Declining rapidly (decrease of 50 % in the last 10 years or 3 generations, whichever is longer)
B = Declining (decrease of 20 % in the last 10 years…)
C = Stable
D = Increasing

4. Distribution Trend

A single-letter code which best characterizes the trend in the species' distribution over its provincial range:

A = Declining rapidly (decrease of 50 % in the last 20 years or 6 generations, whichever is longer)
B = Declining (decrease of 20 % in the last 20 years…)
C = Stable
D = Increasing

5. Number of Element Occurrences (EOs)

An “element occurrence” is the mapping unit of CDC methodology. It is generally defined as an area of land or water on which an “element of biodiversity” (plant and animal species or natural community) is or was present. It is a physical location important to the conservation of a species or community, an area worth preserving to insure the survival of a community or species at risk. For a species it is generally the habitat occupied by a local population, for a community it is the area containing a stand or patch. What constitutes an occurrence also varies between species (e.g. hibernacula, den sites, breeding ponds where adults, egg masses and/or larvae have been identified, breeding colonies, etc.). Some species can have more than one type of occurrence, for example breeding and wintering occurrences.

A single letter code (below) represents the number of estimated occurrences believed extant for the species in the province. When a species' distribution is extremely limited and there are very few site occurrences, it is very susceptible to any number of ecological disturbances, both predictable and unpredictable. This criteria is therefore an important factor influencing SRANK when the number of occurrences is few. If the letter code for this field is A or B, the species usually qualifies for a rank of S1 or S2.

A = 0 - 5 occurrences
B = 6 - 20 occurrences
C = 21 - 100 occurrences
D = 101+ occurrences

6. Number of Protected Element Occurrences

The estimated number of adequately protected occurrences of the species in the province.

A = Believed to be none protected.
B = At least one protected occurrence.
C = Several protected occurrences.
D = Many protected occurrences.
U = Unknown whether any occurrence protected.

7. Threats to Population

Threats to population include observed, inferred or projected 1) direct exploitation, 2) harassment, or 3) ecological interactions with predators, competitors, pathogens or parasites - which may result in population declines. Threats may arise from natural or man-made forces.

A = Very threatened in the province; threats are of high magnitude (affect more than half the population) and imminent; unmitigated.
B = Moderately threatened province-wide (less than half the population); threats imminent; mitigated by some level of human protection.
C = Not very threatened province-wide; threats not so imminent; threat is less significant to population viability; threats are being mitigated through protective measures.
D = Unthreatened on a province-wide basis, although it may be threatened in minor portions of the province.

8. Threats to Habitat

Threats to habitat include observed, inferred or projected habitat alterations (loss, conversion, degradation or fragmentation) which may result in population declines or loss of element occurrences.

A = Very threatened in the province (affects more than half the provincial range); threats are of high magnitude and imminent; unmitigated.

B = Moderately threatened province-wide (affects less than half the provincial range); threats imminent; mitigated by some level of human protection.

C = Not very threatened province-wide; threats not so imminent; threat is less significant to population viability; threats are being mitigated through protective measures.

D = Unthreatened on a province-wide basis, although it may be threatened in minor portions of the province.

9. Other Considerations

Other considerations in determining the rank that are not apparent from the letter codes selected for the above criteria. Generally, these considerations will raise rather than lower the rank, e.g., "Never sexually reproduces" or "All occurrences are in