

THE SAINT JOHN RIVER: *A State of the Environment Report*



**A publication of the Canadian Rivers Institute
Celebrating 10 Years of Science
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Editors

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PREFACE

“Of the many rivers of Northeastern America, it would be difficult to find one which, in the diversity of its natural features, the facilities it affords for sportsmen, and the interesting history of its colonization, is more worthy of mention than the St. John; and yet this river, viewed in its entirety, has never formed the subject of any published work.”

Joseph W. Bailey, 1894.

All rivers that support human communities are each in their own way ecologically and socially important and unique. They provide habitat for numerous species and are sources of water for many purposes such as drinking water and irrigation. Rivers are used for navigation and energy production. They all support their own distinct assemblage of plant and animal communities and have their own history of human use. Despite the overwhelming importance of rivers, human activities have diminished, often significantly, the environmental quality and function of these same rivers that we depend upon. Our activities can negatively impact river ecosystems, such as by changing flow due to dams or diversions, degrading water quality from pollution, and diminishing natural biodiversity through over-fishing or the introduction of invasive species. The Saint John River in New Brunswick, Canada, is no exception. It has long been considered one of Canada’s more disrupted river systems, yet it is very representative of many rivers across southern Canada where the majority of people live today.

Called the *Wolastoq* or *W’alustuk*, meaning the “Bountiful Beautiful River”, by the Maliseet people of the Saint John River valley, the Saint John River is about 700 km

long. About 30% of the watershed is the headwaters in Maine and Quebec, and from here the river flows through the north-south length of eastern New Brunswick before emptying into the Bay of Fundy. Its large tidal estuary and significant tributaries, and the wide range of landscapes it passes through have resulted in the Saint John River supporting a high degree of biodiversity. The Saint John River is also culturally and historically important to First Nations peoples and European settlers alike as a food supplier, transportation and exploration route, and source of artistic inspiration.

Today, while still considered beautiful, many people are also concerned about the environmental state of the Saint John River. The river is subject to the impacts of industrial forestry in its headwaters and along many of its tributaries. In the middle stretch of the river, inputs from agriculture such as nutrients and sediments are important issues. This is where Canada’s third largest crop of potatoes is produced and poultry and hog farms are concentrated. Its large hydroelectric dams and reservoirs, and many smaller dams and reservoirs linked to flow controls (flood and hydroelectric production), can dramatically change the flow regime of the Saint John

Preface

River. Numerous industries are located along its shores. These generate electrical power, produce and process food, and process trees for lumber, paper products, and even rayon to be used in clothing. In total, the river basin supports a population of over 500,000 people. Most of them live in New Brunswick and in some form of municipality. Many of these municipalities discharge their wastewaters into the river or its tributaries. The cumulative impacts of these and other human activities have resulted in changes, some substantial, to the Saint John River ecosystem.

Finally, while this report is about the Saint John River, the story is the same for all rivers in southern Canada. While the land-use, developments, and effluent inputs are different in each watershed, all of these rivers have seen their environmental state altered by human activities, in some cases to a greater degree and others to a lesser one. As such, it is our belief that by improving our understanding of the state of the Saint John River, this report in turn should send a message across the nation about the need to improve our understanding of the state of all of Canada's rivers and to take action to protect and restore them for future generations.

SDK, RAC, KRM

Executive Summary

The Saint John River and its surrounding basin is a rich and important ecosystem biologically, socially, economically, and culturally. Many people living within the basin see or perceive that the Saint John River has been negatively impacted by both past and ongoing human activities. They would like actions to be taken to restore or maintain the environmental quality of this ecosystem and they want these efforts to be effective and efficient. Doing so requires an accurate and concise picture of exactly what is the environmental “state” of the Saint John River. The purpose of this *State of the Environment Report* is to provide this snapshot. The report is a synthesis of primarily recent and some historical data, information and studies regarding common indicators of freshwater environmental quality and describes trends in the condition of these indicators along the Saint John River.

In each chapter, the reader will find a brief introduction that explains the importance of the chapter’s topic for the river and the indicators used to assess the current state of the river, e.g., fish species diversity. As well, the methods used to collect the current (and past) information or data presented. Following this, trends in the state of the indicator are determined when possible by comparisons to historical data. For many of the indicators, the historical status was produced by the Saint John River Basin Board and their reports of the early 1970s. Comparisons were also made to reference sites or regulatory guidelines, and within, between, and among reaches of the Saint John River. To aid in the analysis and

presentation of trends, the report divides the river into a series of four reaches and twelve sub-reaches. Each chapter concludes with a summary and identification of issues of concern, data gaps, and suggested future research.

The six topics about the freshwater environment covered in this report are socioeconomic conditions, river habitats, water quality, primary production, fish, and traditional ecological knowledge. The findings consistently identify several sub-reaches along the main stem of the river that exhibit an altered environmental state or condition. The majority of findings suggest the cause of the diminished conditions in these reaches is the result of human activities in the basin such as flow regulation by dams, inputs of point-source pollutants, e.g., sewage wastewater, and altered river habitats, e.g., the creation of headpond reservoirs.

Expanding on the overall conclusions of this report, the socioeconomic chapter shows that the more ecologically altered reaches of the river also have, not surprisingly, higher population densities. The river habitats chapter details that dams have changed the river’s flow regime and gradient, submerged islands, and generally altered riverine habitat, including eliminating cold-water refuges for species like the Atlantic salmon, along most of its length. While there are limited benthic macroinvertebrate data for the river, what is available, when combined with results from other chapters, shows that wastewater and managed flows are

Executive Summary

impacting the community of animals that live on the riverbed.

The water quality and primary production chapters highlight that there have been improvements in the river's water quality since the 1970s, when the river was heavily impacted by gross levels of nutrient enriching pollution. Since that time municipalities and industries have installed wastewater treatment systems. As a result, the river's water typically meets Canada's guidelines for acceptable water quality. Not all is perfect though. Some stretches of the river regularly have water quality that is diminished by human activities and developments. Low levels of dissolved oxygen continue to be a problem in these stretches of the river because there is not enough water. The impacts of low water are and will be compounded by our changing climate.

Turning to fish, returns of Atlantic salmon at Mactaquac Dam continue to be low and there is little chance that the species will do more than continue to just persist without immediate actions being taken. There have also been changes in the river's fish community since the 1970s. The system increasingly favours warm-water fishes such as yellow perch. Several introduced species to the river, in particular smallmouth bass and muskellunge, have expanded their ranges and numbers. Wastewater inputs and other pollutants combined with flow changes are affecting the health of fish in some stretches of the river.

The report's scientific findings are supported by the traditional ecological knowledge of the river's Maliseet people. Recorded conversations with Elders detail historic and contemporary alterations to

the state of the Saint John River.

Finally, this report does not grade or provide conclusions on the "health" of the Saint John River. Health is in the eye of the beholder and determining whether a river is healthy often depends on what one values or believes is a crucial indicator of river health. For example, is the Saint John River healthy if its water quality is good, but the Atlantic salmon population is declining in numbers? Can the river be considered healthy if one or more stretches have poor water quality? By providing data on many of the indicators that are commonly used in determining river ecosystem health, this report can act as a common starting point for discussions amongst Saint John River communities and stakeholders about its current state and what actions would best meet their basin-wide goals for the river and its water.

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1. Introduction

Scott Kidd

1.1 Purpose of this Report

The purpose of this report is to provide, in one document, accurate information about the current status of key pieces of the Saint John River ecosystem. It is intended that this *“The Saint John River: A State of the Environment Report”* will improve our understanding of how and where human activities have impacted the river, leading in turn to discussions and decisions about how to address these impacts. By doing so, this report will meet the two main purposes of State of the Environment reports identified by Environment Canada, those being, “... to foster the use of science in policy- and decision-making and to report to Canadians on the condition of their environment.”

The last comprehensive report on the state of the Saint John River’s environment was released in 1975 by the Saint John River Basin Board (SJRBB). The SJRBB’s work highlighted several important issues of the day such as severe biological oxygen demand in parts of the river caused by poor wastewater treatment. It triggered actions by the regulators to correct some issues. The environmental and social complexity of the Saint John River makes assessing its “state of the environment” a challenge—one that calls for significant amounts of expertise, time, and financial and other resources. As a result, no similar broad-scale assessment of the Saint John River has been completed since the release of the last



SJRBB report in 1975. Instead, since that time, over 100 reports, publications, and theses have been written describing various individual elements of the Saint John River environment from water quality measures to fish community assessments.

Over 30 years later, the time has come for another state of the environment report for this important waterway. This report synthesizes key findings from these studies. In doing so, it:

- Evaluates the current status of common indicators or components of river ecosystem health;
- Describes trends in these indicators;
- Identifies problem areas in the Saint John River;
- Discusses links between the state of an indicator and human activities, e.g., discusses potential causes of the state or condition of an indicator; and
- Identifies data gaps and needs for future studies.

What this report *does not do* is grade or make conclusions regarding how “healthy” is the Saint John River. The authors of this report believe that determining the health

of a river is both a quantitative and qualitative exercise and one that requires input from the many communities and stakeholders along the river. For example, how healthy is the Saint John River if its overall water quality is good but if its population of Atlantic salmon is declining? Can the river be considered healthy if only one stretch of it has poor water quality? By providing data on many of the indicators that are commonly used in determining river ecosystem health, it is the hope of the Canadian Rivers Institute that this report will act as a catalyst for discussions amongst stakeholders about the state of the Saint John River and what actions are appropriate to maintain or restore its health.

1.2 What is the Canadian Rivers Institute?

The Canadian Rivers Institute (CRI) was created at the University of New Brunswick in 2001 with a mandate to become a national centre of excellence in water sciences research and education. Its focus has been on the development of the aquatic sciences needed to understand, protect, and sustain water resources for the region, Canada, and abroad. As a multi-disciplinary network of internationally respected researchers, the CRI carries out research and provides training and outreach focusing on rivers and the challenges of water resources conservation, protection, restoration, and sustainable use. Initially founded with two Canada Research Chairs and two additional professors, the CRI has grown to include an increasing network of >20 Science Directors (the principles), >50 Associates, 6 Canada

Research Chairs, 30+ staff, and over 100 graduate students with linkages to researchers across Canada and internationally. The CRI fosters a unique model of scientific interaction that strategically links academic, applied, policy, and management driven research across disciplines and sectors. This innovative model merges academic ideas-based and applied needs-based science and promotes the rapid transfer of new knowledge to regulatory agencies to create effective public policy for improving society and the quality of life in Canada and abroad.

1.3 General Description of the Saint John River

After the Saint Lawrence River, the Saint John River is the longest river in northeastern North America and has a basin area of over 55,000 km². It begins in northern Maine, travels northeast into northern New Brunswick, where it drains water from eastern Quebec, and then flows southeast through New Brunswick to the Bay of Fundy. Fifty-one percent of the Saint John River Basin is in New Brunswick, 36 percent is in Maine, and the remaining 13 percent is in Quebec (SJRBB 1975; Cunjak and Newbury 2005). Along its course it is fed by many significant tributaries, which include, beginning in the north, the Allagash River (Maine), Madawaska River (Quebec, NB), Green River (NB), Aroostook River (Maine, NB), Tobique River (NB), Meduxnekeag River (Maine, NB), and Nashwaak, Oromocto, and Kennebecasis Rivers (NB). The lower reaches also include major lacustrine sections; Grand Lake,

Washademoak Lake, Belleisle Bay, Long Reach, and Kennebecasis Bay. The major population centres on the river in New Brunswick are Edmundston, Fredericton, and Saint John; in Maine, Fort Kent and Presque Isle; and in Quebec, Cabano.

1.4 Physical Geography

The Saint John River Basin (**Figure 1.1**) overlays parts of New Brunswick's three physiographic sub-regions (SJRBB 1975; Cunjak and Newbury 2005): the Chaleur Uplands, which cross the Quebec–New Brunswick border; the Maritime Plain (or

New Brunswick Lowlands) which runs diagonally southwest through the province starting in Chaleur Bay; and the New Brunswick Highlands. The Highlands has two branches. One lies between the Chaleur Uplands and the Maritime Plain (Miramichi Highlands), while the other branch runs along the Bay of Fundy coastline (Caledonia Highlands). All three sub-regions are part of the larger Appalachian physiographic region (NRCAN undated). The bedrock of the three sub-regions is mostly sedimentary, with pockets of metamorphic and volcanic rocks. (For information on the geologic history of the Saint John River Basin, see Atlantic

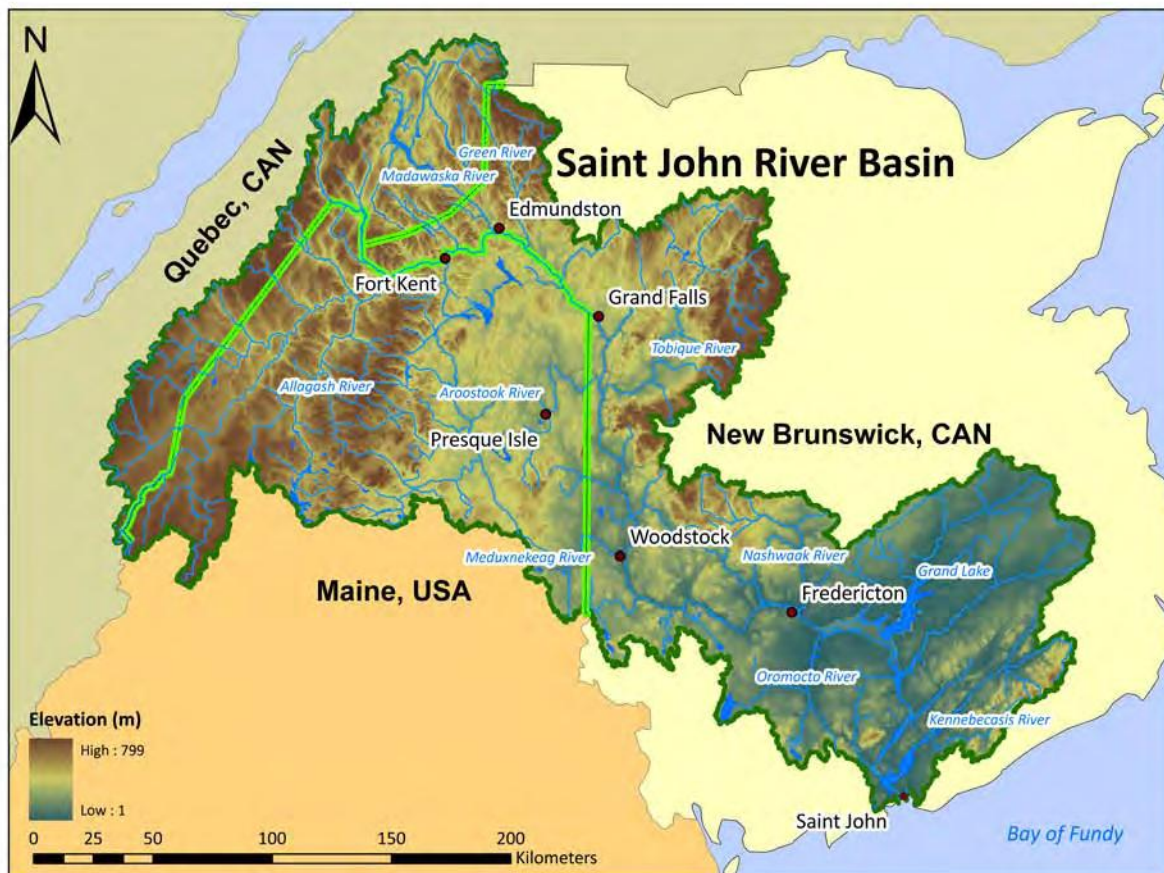


Figure 1.1 The Saint John River Basin.

Geoscience Society 2001).

The Chaleur Uplands is a peneplain of rolling hills and valleys 200 to 500 m above sea level, except for the eastern portion in the Tobique River watershed which has a steeper topography. The Saint John River passes from this region into the first branch of the New Brunswick Highlands near Woodstock. This region is characterized by steep slopes and fast flowing streams. The highest point in New Brunswick, Mount Carleton at 820 m above sea level, is found on the boundaries of the Chaleur Uplands and New Brunswick Highlands near Nictau Lake, which is the headwater of the Tobique River. The Saint John River traverses the Maritime Plain between Mactaquac and Hampstead. The flatness of this region has resulted in the formation of large lakes (Grand and Washademoak) and bogs. After Washademoak Lake, the river enters the second branch of the craggy New Brunswick Highlands which extends to the Bay of Fundy coast.

Most of the over-burden in the Saint John River Basin consists of morainal sediments (Rampton 1984) laid down at the end of the late Wisconsinan glacial event by the melting of the last glacier to cover New Brunswick, the Laurentide Ice Sheet, approximately 14,000 years ago. Scattered along the banks and flood plains of the Saint John River and its tributaries are pockets of more recent alluvial (sand, gravel, cobble) sediments. Significant areas of organic sediments forming bogs, fens and peat can also be found throughout the southern half of the basin. The areas of the basin with the most relief, such as along the Tobique River and the Kingston Peninsula, are typically underlain with older pre-Quaternary Period rocks.

The dominant soil-types in the Saint John River Basin are humo-ferric podzols and gray luvisols. Both of these are “forest soils” found throughout Canada (USask undated a). Humo-ferric podzols lie on sandy parent material, including the sandy glacio-fluvial deposits that underlie much of the Saint John River Basin (USask undated b). “Luvisolic soils are dominant in forested landscapes underlain by loamy tills derived from underlying sedimentary rocks...” (USask undated c). The organic soils—gleysols, fibrisols, and mesisols—can be found in the wetlands throughout the basin.

The Saint John River itself flows mostly through a confined valley. Upstream of Fredericton its substrate is typically cobble and sand with some boulders and bedrock outcroppings (Curry and Munkittrick 2005). Downstream of Fredericton the river shifts to primarily a shifting sand bottom. The course of the river despite flowing through some rugged upland regions drops just 481 m from its headwaters to its estuary (Cunjak and Newbury 2005). The highest waterfall is Grand Falls on the main river (23 m). The low slope, combined with the immense high tides of the Bay of Fundy (8 m), allows the head of tide to reach past Fredericton approximately 140 km upstream from the river’s mouth. The main stem of the Saint John River upstream of Edmundston averages 50 m wide and 2 m deep, and at Fredericton (135 km upstream) the river’s average width is 750 m while its depth is 3 m (Curry and Munkittrick 2005). Islands of alluvial deposits and sand and gravel bars are interspersed along its length (Bailey 1894).

1.5 Climate and Hydrology

The Saint John River Basin is considered to have a cold climate overall (based on Peel et al. 2007), with most of the watershed described as having a humid continental climate (SJRBB 1975) except near the Bay of Fundy coast, which has a maritime climate (GOVCAN undated). The climate becomes colder and drier the farther north one goes from the moderating and wet influence of the Bay of Fundy. The mean annual temperature and annual precipitation, respectively, for Saint John is 5°C and 140 cm, for Fredericton is 5.3°C and 114 cm, and for Edmundston is 3.2°C and 109 cm (ENVCAN undated).

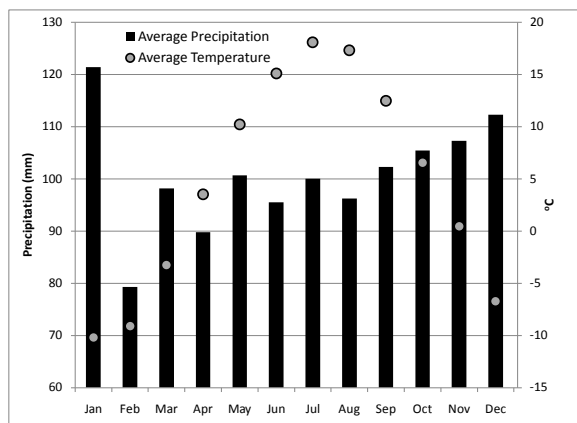


Figure 1.2 The average monthly temperature (°C) and precipitation (mm) for the Saint John River Basin (data from ENVCAN undated).

The mean annual discharge for the Saint John River is approximately 1100m³/s (Cunjak and Newbury 2005). Like most eastern Canadian rivers, its peak water levels and discharge occur in the late spring after the spring thaw (**Figure 1.3**). The river experiences a second, smaller pulse later in the fall. More detail regarding the Saint John River’s hydrology can be found in

Chapter 5 River Habitats, 5.2 Hydrologic Regime.

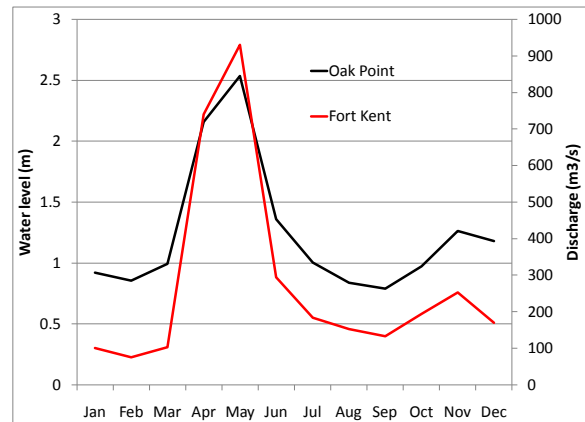


Figure 1.3 The mean monthly water levels (m) and discharge (m³/s) of the Saint John River at Fort Kent and Oak Point (data from Water Survey of Canada undated).

1.6 Landscape

Ecological land classification of the Saint John River Basin

Under the Canadian Ecological Land Classification System (CELCS), the Saint John River watershed lies within the Atlantic Maritime Ecozone (AME). The CELCS divides the AME into 15 ecoregions. Waters of the Saint John River run through 7 of these ecoregions: 117, Appalachians; 118, Northern New Brunswick Highlands; 119, New Brunswick Highlands; 120, Saint John River Valley; 121, Southern New Brunswick Uplands; 122, Maritime Lowlands; and 123, Fundy Coast (**Figure 1.4**).

For the purposes of describing and analyzing ecosystems within the province, New Brunswick has also developed its own system of ecological land classification (NBELC). Under this system, the province

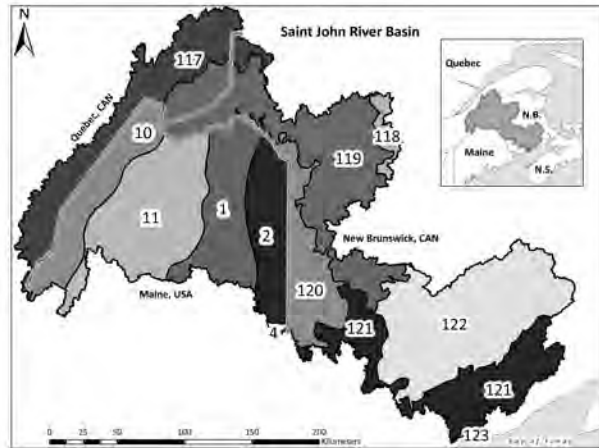


Figure 1.4 Ecoregions (parts or entire) of the CELCS Atlantic Maritime Ecozone and the Biophysical Regions of Maine within the SJRB. **CELCS Ecoregion** numbers are: 117, Appalachians; 118, Northern New Brunswick Highlands; 119, New Brunswick Highlands; 120, Saint John River Valley; 121, Southern New Brunswick Uplands; 122, Maritime Lowlands; and 123, Fundy Coast. **Maine biophysical regions** are: 1, Aroostook Hills; 2, Aroostook Lowlands; 4, Maine – New Brunswick Lowlands; 10, Boundary Plateau; 11, Saint John Uplands.

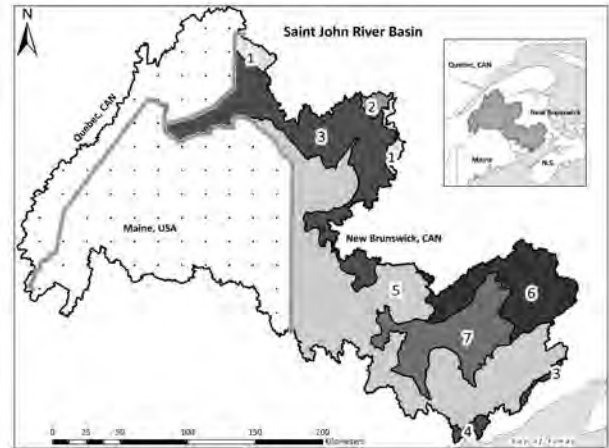


Figure 1.5 Ecoregions (parts or entire) of the NBELC within the SJRB. **NBELC Ecoregion** numbers are: 1, Highlands; 2, Northern Uplands; 3, Central Uplands; 4, Fundy Coast; 5, Valley Lowlands; 6, Eastern Lowlands; and 7, Grand Lake Lowlands.

has been divided into seven ecoregions (Zelazny 2007). Three of the NBELC ecoregions make up significant portions of the Saint John River Basin: Ecoregion 3, Central Uplands; Ecoregion 5, Valley Lowlands; and Ecoregion 7, Grand Lake Lowlands (**Figure 1.5**). As can be seen by comparing **Figures 1.4** and **1.5**, the boundaries of the CELCS and the NBELC are very similar.

Upper Saint John River Basin

Under the NBELC, most of the northern and north-eastern portions of the Saint John River Basin in New Brunswick are part of

the Central Uplands Ecoregion. This ecoregion is comprised of two separate upland areas—the Madawaska Uplands ecodistricts (Ecodistricts 3.1-3.5) and the Caledonia Uplands ecodistrict (Ecodistrict 3.6) (Zelazny 2007). All or portions of the Madawaska Uplands ecodistricts are within the boundaries of the Saint John River Basin. These ecodistricts tend to have warmer temperatures because of their predominant south- and west-facing slopes when compared to other ecodistricts of similar latitudes (Zelazny 2007). Upper slopes are typically covered in stands of hardwood trees—sugar maple, yellow birch, and beech (Zelazny 2007; Loo et al. 2010).

Mixed coniferous/tolerant hardwood forests cover most mid-slopes in the Madawaska Uplands. Balsam fir and white and red spruce dominant the lower slopes and valleys of the area, except where the ground is wet, where one finds mostly black spruce and cedar (Zelazny 2007; Loo et al. 2010).

Another small area of north-east Saint John River Basin in New Brunswick is part of the Ganong Ecodistrict (Ecodistrict 1.2) of the Highlands Ecoregion. Ecodistrict 1.2 is home to Mount Carleton, New Brunswick's highest point (820 m), and Nictau Lake which flows into the Tobique River. Zelazny (2007) describes the ecoregion as having the lowest annual temperatures in the province. This has resulted in the Ganong Ecodistrict having a boreal forest type dominated by balsam fir and black spruce interspersed with occasional stands of white birch and trembling aspen.

Middle Saint John River Basin

The majority of the Saint John River Basin in New Brunswick, and in particular the main river valley itself, lies in NBELC Ecoregion 5: Valley Lowlands, the largest ecoregion in New Brunswick. This ecoregion has a continental climate with warmer summers when compared to more northerly and coastal ecoregions, and cold winters. The southern portion of the ecoregion has a number of lakes and large, significant wetland areas.

The large geological and climactic diversity of the Valley Lowlands Ecoregion has resulted in a number of different plant species assemblages containing about 30 different tree species (Zelazny 2007). Some of these assemblages have species usually

connected to more southerly climates such as green and white ash, butternut, beech, and silver maple (Zelazny 2007). Lower slopes typically have coniferous forests, mid-slopes mixed wood communities, and upper slopes and ridges, stands of tolerant hardwoods (Cunjak and Newbury 2005; Zelazny 2007; Loo et al. 2010). Wetland areas support cedar and black spruce. One plant of particular interest found in this ecoregion is the Furbish's lousewort. "The populations from the upper Saint John River valley in New Brunswick and Maine are the world's only known populations of Furbish's lousewort" (Zelazny 2007: 205). Furbish's lousewort is listed as an endangered species under both Canada's *Species at Risk Act* and New Brunswick's *Endangered Species Act*.

Lower Saint John River Basin

A large amount of the Saint John River's floodplain is located in NBELC Ecoregion 7: Grand Lake Lowlands. In the low relief of the ecoregion, the river becomes broader with many alluvial islands. Fredericton, the provincial capital, and Grand Lake, New Brunswick's largest lake, are both located in Ecoregion 7. This part of the basin also has the longest and warmest growing season because of Grand Lake, which acts as a heat sink (Zelazny 2007). This warmer climate supports a number of "southern" trees such as basswood and white and green ash. Stands of silver oak are found in areas prone to regular flooding. This ecoregion also includes a number of provincially significant wetlands.

Finally, as the Saint John River reaches the City of Saint John and the Fundy Coast it enters into NBELC Ecoregion 4: Fundy Coast. While this ecoregion covers the

entire Bay of Fundy coastline, the Saint John River Basin's portion of it is confined to a small area around Saint John. This ecoregion has a moist, coastal climate. Around Saint John, red spruce, black spruce, white spruce, and balsam fir dominate the rugged uplands, while cedar is the predominant tree in lower areas (Zelazny 2007).

1.7 Biodiversity of the Saint John River Basin

A recent publication of the National Research Council of Canada, *Assessment of Species Diversity in the Atlantic Maritime Ecozone* (McAlpine and Smith, eds. 2010) details much of the biodiversity of Atlantic Canada. We address fish diversity in the Saint John River in Chapter 8, and the following section briefly discusses some additional biodiversity knowledge for the river. Ecoregion titles and boundaries are those of the Atlantic Maritime Ecozone (AME) established under the Canadian Ecological Land Classification System (CELCS) (see **Figure 1.4**).

Phytoplankton

Drawing upon the earlier work of Watt (1973) and the SJRBB (1974), Cunjak and Newbury (2005) describe the phytoplankton of the Saint John River along its length as being comprised of dinoflagellates, green algae, cyanobacteria, and diatoms. The diatom *Melosira* was common in the middle stretches of the Saint John River while the chrysophyte *Dinobryon serularia* was found mainly in the unpolluted headwaters of the Saint John River and its tributaries.

Aquatic fungi (hyphomycetes)

Bärlocher and Marvanová (2010) detail the regional diversity of aquatic fungi or hyphomycetes, which are the mitosporic states of ascomycetes and basidiomycetes fungi. While fungi are rarely discussed when reviewing the biodiversity of a river, they “perform a vital role [in these ecosystems] in conditioning plant detritus for consumption by stream invertebrates” (Bärlocher and Marvanová 2010: 71). They document 126 species and two varieties of aquatic fungi in the AME. Over 30 of these species were found in streams near Waterford, NB, the only area in the Saint John River watershed sampled by the authors. The actual diversity of aquatic hyphomycetes in the Saint John River likely much higher (Bärlocher and Marvanová 2010).

Zooplankton

Despite their importance to and prevalence throughout freshwater ecosystems, Cunjak and Newbury (2005) and Locke and Klassen (2010), respectively, note there is a shortage of information and data regarding the distribution, abundance and variety of zooplankton in the Saint John River. Locke and Klassen (2010) reported that there are at least 300 species or subspecies of zooplankton in the AME and the Saint John River watershed had the highest reported levels of zooplankton taxonomic richness in the AME. The number of zooplankton taxa in Ecoregion 121 (see **Figure 1.4**) is 21 species of copepoda, 40 species of cladocera, and 35 species of rotifera. For Ecoregion 122, there are 22 copepoda species, 36 cladocera species, and 34 rotifera species. Ecoregion 120 has 17 copepoda species and 27 cladocera species

(the authors were unable to accurately report on the number of rotifera species in this ecoregion). Common zooplankton throughout the lakes and impoundments of the Saint John River include the cladocerans *Bosmina longirostris*, *Bosmina coregoni*, and *Daphnia spp.*, and the copepod *Epischura lacustris* (Cunjak and Newbury 2005 citing SJRBB 1974; Locke and Klassen 2010).

Freshwater insects

Many flying insects have larva or nymphs that live in water for up to 2 years. The biodiversity of the Saint John River's benthic insect community has not been well studied and as a result there is limited data available. Cunjak and Newbury (2005) discuss the SJRBB sampling in the 1970s which revealed that tubificid worms and chironomid midges were the most common benthic invertebrates found in impoundments along the river. Relying on unpublished data for insects from R.A. Curry, Cunjak and Newbury (2005) noted that chironomid midges and blackflies are common along the entire length of the river. In the upper reaches, heptageniid and baetid mayflies, chloroperlid stoneflies, and philopotamid and hydropsychid caddisflies are the most common benthic insects to be found; in the lower reaches it is heptageniid and ephemereid mayflies, perlid stoneflies, and philopotamid and hydropsychid caddisflies (Cunjak and Newbury 2005).

Dragonflies and damselflies

The diversity of two groups of insect species in the Saint John River is relatively well studied; dragonflies and damselflies (Order Odonata). Brunelle (2010) reported 142 species of dragonflies and damselflies in the

AME which is 28% of all known North America species. There are 98 recorded species occurring in Ecoregion 120 (see **Figure 1.4**). Odonates can be found in both the still and running waters of the Saint John River.



Water mites

Smith (2010) explains there are about 400 species of water mites (Acarina: Hydrachnidiae) in the AME and that they are one of the dominant arthropods in its freshwater communities. Some species of water mites have distinct habitat preferences, while others are less selective and can be found in a variety of habitats e.g., springs, groundwater, streams, ponds, lakes, marshes, and temporary pools. Smith reported that the superfamily Arrenuroidea has 95 species in the AME and approximately 75 are found in the Saint John River watershed.

Freshwater mussels

The diversity of freshwater mussels in the AME is 19 or 20 species (Martel et al. 2010) of which 10 can be found in the Saint John River (D. Sabine, NB Department of Natural

Resources, pers. comm.). Species that are widespread through the river include *Elliptio complanata* (eastern elliptio) and *Pyganodon cataracta* (eastern floater). As discussed by Cunjak and Newbury (2005), because of their limited distribution in Canada, two species of freshwater mussel present in the Saint John River merit particular attention. The *Anodonta implicata* (alewife floater) is rare and *Lampsilis cariosa* (yellow lampmussel) is listed as a species at risk under Canada's *Species at Risk Act*.

Post-glacial influences on freshwater diversity

Across the AME, the Saint John River typically supports the greatest diversity of obligate, freshwater animals including fish as discussed in Chapter 8. This phenomenon relates to the post-glacial history of the region and the role of the Saint John River in the dispersal of freshwater animals (Curry 2007). The evidence from geology and current distributions of animals indicates that glaciers covered the present-day mainland and offshore islands of the AME until about 18,000 years ago. As the ice melted, fish and other obligate freshwater animals most probably recolonized the AME via the lower St. Lawrence River valley into the upper Saint John River in Maine. Ice and debris dams kept animals from dispersing farther east until 8,000 to 6,000 years ago, when a major blockage at Grand Falls released water into today's lower Saint John River valley.

Reptiles and Amphibians

There are 27 reported species of non-marine reptiles and amphibians in the AME

(McAlpine 2010), of which 23 can be found in New Brunswick. All of these species except the four-toed salamander (*Hemidactylium scutatum*) occur in the Saint John River Basin—15 amphibians and 7 reptiles (D. McAlpine, pers. comm.) Eighteen (18) and twenty-one (21) of these species of amphibians and reptiles occur in Ecoregion 120, Saint John River Valley, and Ecoregion 121, Southern New Brunswick Uplands, respectively. Populations of *Glyptemys insculpta* (wood turtle) in the Saint John River Basin deserve increased attention as this species has been listed as threatened under Canada's *Species at Risk Act*. McAlpine (2010: 624) describes wood turtle populations as being vulnerable to habitat loss, road kill, and collecting for the pet trade.

Birds

Sabine (2010) reported that at least 480 species of birds have been recorded in the AME. He notes that 287 bird species presently use the AME for some significant portion of the year. There are 211 bird species confirmed as breeding in New Brunswick, and approximately 189 breed in the basin (D. Sabine, NB Department of Natural Resources, pers. comm.).

Mammals

Excluding *Homo sapiens*, Forbes et al. (2010) report 58 species of mammals native to the AME. This total includes species that are now extirpated, such as the wolverine (*Gulo gulo*). They list 38 species as presently occurring in Ecoregion 120, Saint John River Valley, and another 6 as possibly occurring. Most of the mammals in the basin, such as beaver (*Castor canadensis*), mink (*Neovison vison*), otter (*Lontra canadensis*), and

moose (*Alces alces*), are common throughout eastern Canada. One exception to this is the Maritime shrew (*Sorex maritimensis*) which is endemic to the AME and in the Saint John River Basin is found in Ecoregion 121, Southern New Brunswick Uplands, and Ecoregion 123, Fundy Coast (Forbes et al. 2010).

1.8 Species at Risk

Like all river ecosystems where humans live, the Saint John River Basin is home to an increasing number of species at risk. **Table 1.1** provides details of species and/or populations that are particularly dependent upon the Saint John River watershed.

Table 1.1 Partial list of species at risk in the Saint John River Basin. (Information from Govt. of Canada, Species at Risk Public Registry, www.sararegistry.gc.ca, and NB Natural Resources, www.gnb.ca/0078/speciesatrisk/).

Species	Taxon	Status	Source for status	Importance of Saint John River Basin to species at risk
Atlantic salmon <i>Salmo salar</i> (Inner Bay of Fundy population)	Fishes	Endangered	SARA ¹	Spawning, rearing of young
Striped bass <i>Morone saxatilis</i> (Bay of Fundy population)	Fishes	Threatened No status	COSEWIC ² SARA	Feeding
American eel <i>Anguilla rostrata</i>	Fishes	Threatened No status	COSEWIC SARA	Juvenile and adult, feeding and growth
Shortnose sturgeon <i>Acipenser brevirostrum</i>	Fishes	Special concern	SARA	Complete lifecycle
Wood turtle <i>Glyptemys insculpta</i>	Reptiles	Threatened	SARA	Complete lifecycle
Yellow lampmussel <i>Lampsilis cariosa</i>	Molluscs	Special concern	SARA	Complete lifecycle
Cobblestone tiger beetle <i>Cicindela marginipennis</i>	Arthropods	Endangered	SARA	Found on treed islands with infrequently flooded beaches
Skillet clubtail <i>Gomphus ventricosus</i>	Arthropods	Endangered No status	COSEWIC SARA	Complete lifecycle
Pygmy snaketail <i>Ophiogomphus howei</i>	Arthropods	Special concern	SARA	Complete lifecycle, clean rivers with gravel or sand bottoms
Butternut <i>Juglans cinerea</i>	Vascular Plants	Endangered	SARA	Saint John River and other floodplains
Furbish's lousewort <i>Pedicularis furbishiae</i>	Vascular Plants	Endangered	SARA	Saint John River bank
Pinedrops <i>Pterospora andromedea</i>	Vascular Plants	Endangered	NB ESA ³	Old white pine stands/rich soils
Anticosti aster <i>Symphotrichum anticostense</i>	Vascular Plants	Threatened	SARA	Banks of fast flowing rivers in boreal forest
Prototype quillwort <i>Isoetes prototypus</i>	Vascular Plants	Special concern	SARA	Cold, nutrient-poor, spring-fed lakes

¹ Species at Risk Act. ² Committee on Endangered Wildlife in Canada. ³ NB Endangered Species Act.

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2. Report Methodology

The main objectives of this state of the environment report are to provide a synthesis of recent data, information and studies regarding common indicators of freshwater environmental quality in the Saint John River Basin and to describe trends in the condition of these indicators.



2.1 Information Provided in Chapters

In each chapter, the reader will find a brief introduction that explains the importance of that chapter's topic, e.g., primary production, to the Saint John River, and the indicators used to assess the current state of the ecosystem in that reach and why. For each indicator, e.g., total phosphorous, the report discusses the current environmental state of the indicator. Trends in the state of the indicator are determined when possible by comparing its current state to historical data, a reference site or guideline, and differences between and within reaches along the river. Each chapter concludes with a summary of comparisons, and identification of issues of concern, data gaps, and suggested future research. A copy of the final report can be downloaded from www.unb.ca/cri.

2.2 River Reaches

The Saint John River is often described as having three basins—upper, middle, and lower (see for example Cunjak and Newbury

2005; Curry and Munkittrick 2005). The upper basin flows from the Saint John River's headwaters to Grand Falls, NB (located 360 km upstream from the Bay of Fundy). Grand Falls has a vertical drop of 23 m and is the only natural barrier to upstream fish movement on the main stem of the river. The middle basin lies between Grand Falls and Mactaquac Dam (140 km upstream), which now acts as a barrier to fish movement. Mactaquac Dam is also located at the head of tide, or upstream limit of the Bay of Fundy's very extreme tide's influence on the river ecosystem. The lower basin flows from here to the Saint John Harbour at the Bay of Fundy.

It was impossible to examine all the countless catchments, i.e., the tributaries that make up the sub-basins: there was simply not enough information for these areas. We used the smallest scale details wherever possible, but focused the report on the main stem reaches of the Saint John River where the best spatial and long-term coverage of information existed. Each of the three sub-basins is divided into a series of reaches and then shorter sub-reaches based upon natural and created biophysical characteristics of the river.

Table 2.1 Description of reaches and sub-reaches used in the Saint John River State of the Environment Report.

Reach	Sub-reach
<p>1 – Headwaters to Grand Falls, NB</p> <ul style="list-style-type: none"> Isolated by natural barrier of Grand Falls 	<p>1A – Headwaters to upstream of Baker Brook River</p> <ul style="list-style-type: none"> Little human influence other than forestry <p>1B – Baker Brook River to upstream of Green River</p> <ul style="list-style-type: none"> Captures inputs from multiple municipalities and industries <p>1C – Green River to Grand Falls</p> <ul style="list-style-type: none"> Municipalities and main stem’s first reservoir
<p>2 – Grand Falls to Mactaquac Dam</p> <ul style="list-style-type: none"> Isolated by Grand Falls and Mactaquac Dam 	<p>2A – Little River to upstream of Aroostook River</p> <ul style="list-style-type: none"> Captures inputs from agriculture <p>2B – Aroostook River to upstream of Tobique River</p> <ul style="list-style-type: none"> Flow controlled <p>2C – Tobique River upstream to Beechwood Dam</p> <ul style="list-style-type: none"> 2nd reservoir <p>2D – Beechwood to upstream of Becaquimec Stream</p> <ul style="list-style-type: none"> Flow regulation, food processing, municipalities (e.g., Florenceville) <p>2E – Becaquimec Stream (Hartland) to Mactaquac Dam</p> <ul style="list-style-type: none"> Municipalities and 3rd and largest reservoir
<p>3 – Mactaquac Dam to Long Reach (Oak Point)</p> <ul style="list-style-type: none"> Long Reach represents upper limits of Saint John River estuary as defined by salt water intrusion 	<p>3A – Mactaquac Dam to Jemseg River</p> <ul style="list-style-type: none"> Municipalities of Fredericton and Oromocto <p>3B – Jemseg River to Oak Point</p> <ul style="list-style-type: none"> Grand Lake, Canaan-Washademoak watershed, and Long Reach
<p>4 – Long Reach (Oak Point) to Saint John Harbour</p> <ul style="list-style-type: none"> Saint John River Estuary 	<p>4A – Oak Point to Reversing Falls (estuarial)</p> <ul style="list-style-type: none"> Reversing Falls (switches fresh to saltwater and flow direction reversals) <p>4B – Saint John Harbour*</p> <ul style="list-style-type: none"> Captures inputs from City of Saint John

*Because of the significant physico-chemical differences between fresh and saltwater ecosystems, only Chapter 8 Fishes of the Saint John River includes Reach 4B in its analyses.

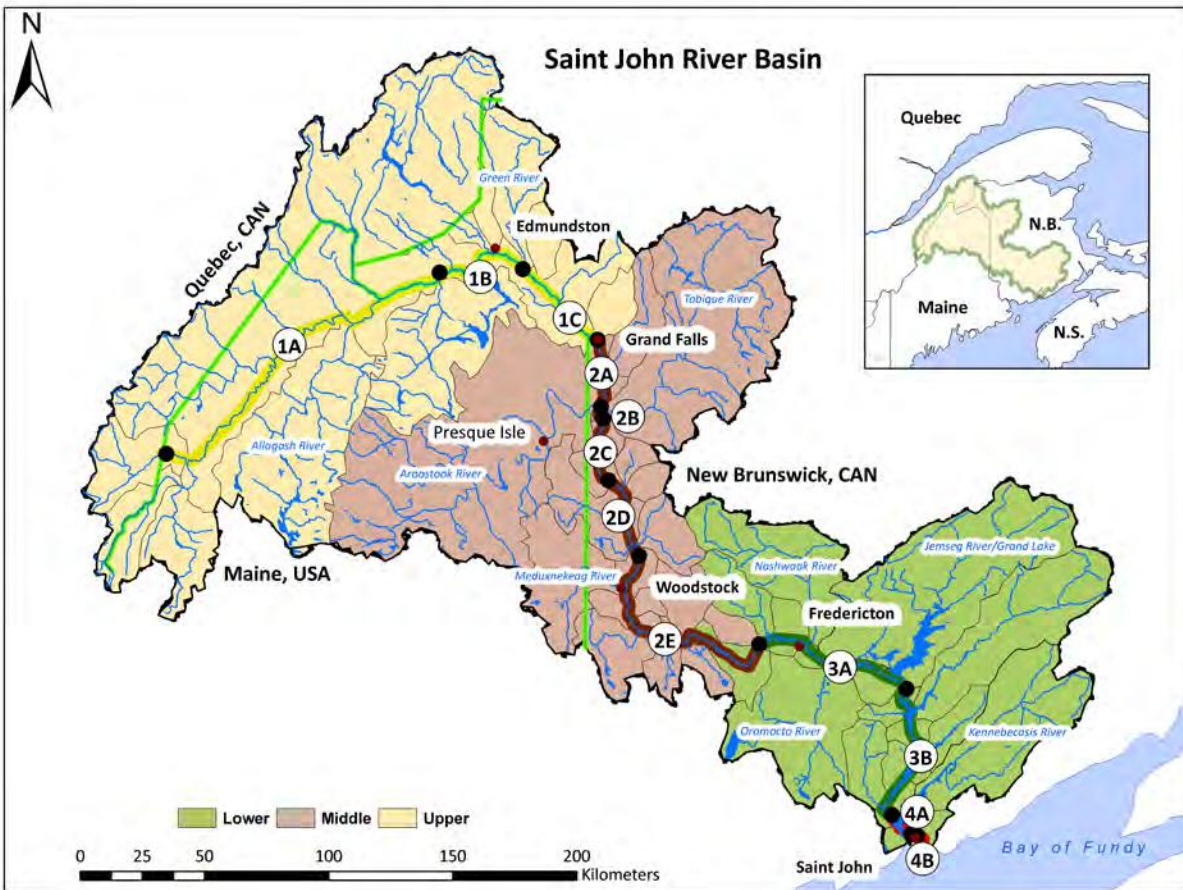


Figure 2.1 Reaches and sub-reaches of the Saint John River.

2.3 Historical Data from the Saint John River Basin Board

The historic data for the Saint John River aquatic ecosystem is sparsely dispersed in federal and provincial government reports before the 1950's. The first in-depth studies and thus much of the historical data regarding the river's ecosystem that we could use was generated for the work of the Saint John River Basin Board (SJRBB). The SJRBB was created after the 1969 Maritime Provinces Water Resources Study identified serious water quality and management problems for the Saint John River (Montreal Engineering 1969). To address these

problems, the federal government and the Province of New Brunswick signed the Saint John River Basin Agreement on June 30, 1970. The agreement was to "[P]rovide for optimum management of water resources of the River Basin for the social betterment and economic improvement of the region with due consideration to the maintenance of a proper ecological balance." The agreement also created the SJRBB which was tasked with preparing a "plan for the development and management of the water resources in the Saint John River Basin." The SJRBB delivered its final report and "A Plan for Water Management in the Saint John River Basin" in April 1975 (SJRBB 1975a). The SJRBB identified five main

water management problems in the basin (SJRBB 1975b):

1. Abating and preventing pollution. The four components of this problem are:
 - a. Large loads of organic pollution from forest and agricultural product industries render a large part of the main stem and some tributary waters unfit for domestic use or recreation and uninhabitable by the more valuable fish species.
 - b. Untreated domestic pollution creates a health hazard.
 - c. The loading of nitrogenous nutrients from the pulp industry and agricultural run-off is excessive, so that if phosphate loading were to increase there would be a serious risk of eutrophication.
 - d. Toxic chemical input to the water resource, although not high at present, needs to be carefully controlled.
2. Reducing flood and erosion damage.
3. Providing and maintaining adequate water supplies and liquid waste disposal services.
4. Obtaining the peaking power required to satisfy demands for electrical energy without causing major ecological change or adverse effects on other water users.
5. Preserving adequate public access to water bodies for recreation.

Beginning in 1972, the SJRBB had 30 background research reports prepared (Cardy 1981) that addressed various water management issues, such as use of the basin for forestry and tourism. These reports in turn provided the data and information necessary for the SJRBB to write its final report in support of their

recommendations. In addition to the final report, other SJRBB reports used herein for historic reference include:

- Water use and aquatic ecology in the Saint John River Basin (SJRBB 1974);
- Aquatic ecology of the Saint John River Basin (Watt 1973); and
- Fishes of the upper and middle Saint John River (Meth 1973).

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3. Development in the Saint John River Basin

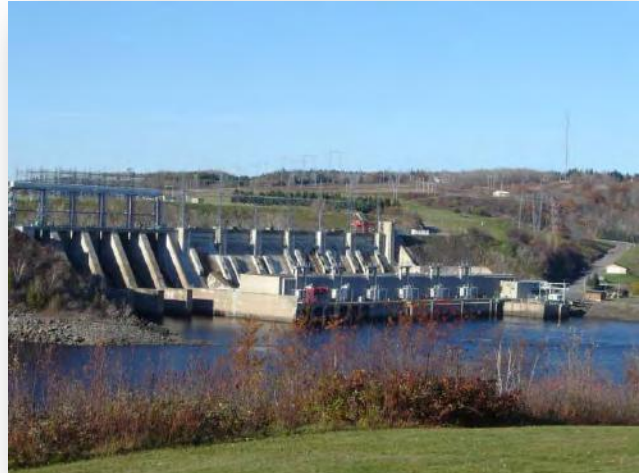
Scott Kidd
Eric Luiker

3.1 History of Development

Before 1650: Maliseet Nation and first European contacts

Prior to European contact at the beginning of the 17th century, the Saint John River Basin was inhabited for centuries by people of the Wolastoqiyik (Maliseet) nation, providing them with water, food, a transportation route and access to natural resources. It also provided a link between the St. Lawrence River region and Nova Scotia for the Wolastoqiyik (Frink 1999). Archaeological sites have been found from the mouth of the Saint John River up to its headwaters.

The first recorded European exploration of the river was conducted by the French explorers Sieur de Monts and Samuel de Champlain, who entered it on Saint John the Baptist Day, June 24, 1604 (Raymond 1910; SJRBB 1975). Shortly thereafter a colony was established at its mouth (Raymond 1910). Activities on the river during this period related primarily to trading and exploration. Settlement upstream remained primarily by aboriginal peoples, generally at confluences of major tributaries and on the main channel of the river.



1650-1783: European settlement

Acadians were the first European settlers to permanently reside along the river. Between 1672 and 1700, sixteen land grants had been granted by France to prominent citizens, with the provision of clearing and inhabiting the land, thus the first agricultural based homesteads were established on the river (Raymond 1910).

The first large scale European migration to the Saint John River occurred in 1756 when Britain expelled Acadians from Nova Scotia. Many of them moved to New Brunswick and after the Treaty of Paris (1763), traveled north along the Saint John River where some settled in the Madawaska region upstream of Grand Falls.

After the American Revolutionary War, ~14,000 Loyalists moved from the United States to New Brunswick in 1783. Many of these people who were farmers were granted prime lands along the Saint John River by the British government. Some of this land was already occupied by other settlers, primarily Acadians, who were in turn forced to find new areas to settle,

again typically upstream of Grand Falls. Prior to 1783, there were ~1400 English and ~400 Acadians in the Saint John River Basin (Raymond 1910; SJRBB 1975; McLeod 1984; Washburn 1985). The number of Wolastoqiyik people in the basin at this time was 10,000 (Cecelia Brooks, pers. comm.).

1779-1900: Period of land clearing and wood harvesting

Commercial lumbering began in earnest along the Saint John River in 1779 after William Davidson received a contract from the British Government to provide the Royal Navy with mast timber (McLeod 1984; Frink 1999). By the end of that year “gangs of loggers were at work along the Nashwaak and Oromocto Rivers cutting trees with reckless abandon” (McLeod 1984: 61). Following this, further requests were made by Britain for ship masts, with a premium price paid for the longest and widest white pine logs. The British began logging the forests of New Brunswick for ship masts and other timber because Britain was cut off from its traditional lumber supplies in the United States and the Baltic due to the Revolutionary War and the Napoleonic Wars (Wright 1966; McLeod 1984). By 1850, nearly all of the valleys of the major tributaries of the Saint John River had seen logging. For example, “Between 1818 and 1824, timber yields from [the Tobique River area] jumped from 7,850 to 43,460 tons, and the Wapskehegan Valley became one of most heavily felled sites in the province” (Zelazny 2007: 200).

Trees closest to river banks were selected, and hauled to the river side by oxen, and then floated down the river in log drives or towed by sloops to Fort Howe/Saint John

(Raymond 1910). The wood harvesting industry expanded quickly, with 300 sawmills located in New Brunswick between 1810 and 1840. In 1824, 114,116 tons of pine and birch timber, 1918 masts and other wood products had been shipped to Britain (Raymond 1910). During the 1850s, shipbuilding was at its peak, and 80% of the New Brunswick economy was linked to forestry.

Land was also being cleared for agriculture throughout this period, so much so that “by the 1890s, there were already reminiscences about the region’s former appearance. By that time, cleared agricultural land extended almost completely from Grand Falls to Meductic, a stretch of river that was described only 90 years earlier as “dark wilderness”” (MacDougall and Loo 1998: 19, citing Bailey 1894; see also Zelazny 2007).

Between 1850 and 1900 there was a period of rapid growth and industrialization in the City of Saint John. This was accompanied by increasing immigration from England, Scotland and Ireland (SJRBB 1975). With an expanding population, and the development of the railway system in New Brunswick, human impacts were reaching further into the Saint John River Basin.

1900-1960: Industrialization

In the late 19th century, with the invention of the steamship, the demand for ship masts and ship building supplies diminished. In the early 1900s, New Brunswick’s forests began to be cut for the expanding pulp and paper industry rather than just for lumber. “The first sulphite pulp mill in New Brunswick was opened by Donald Fraser in Edmundston in 1917. This

was the beginning of large volume point source effluent into the Saint John River” (from Chapter 7). The rise of pulp and paper as the dominant forest industry in New Brunswick with its accompanying mills is evidenced by the reduction to fewer than 150 sawmills in the province in 1971 versus more than 600 in the early 1900s (Washburn 1985).

New Brunswick’s agricultural activities also became more industrialized during this period. Favourable growing conditions and increased mechanization resulted in the growth of potato farming in the basin, so much so that Statistics Canada (2009a) reports that New Brunswick is the third largest producer of potatoes in Canada. Coinciding with this increase in potato production was the opening of the first McCains potato processing plant in Florenceville, NB in 1957.

Also during this period, several large hydroelectric dams were constructed in the basin. These include dams at Grand Falls (1925) and Beechwood (1957). As will be discussed throughout this report, these dams, along with Mactaquac Dam (1968-69), have had an impact on the Saint John River (Kenny and Secord 2010).

Finally, the majority of population growth within the basin was adjacent to the main channel of the river in various villages, towns and cities. As these urban areas increased in size, there was a need to consolidate household and industrial waste discharges, and in the early years, usually directed straight to the nearest river. “Prior to the 1950s, none of these communities had effluent treatment, and raw sewage entered untreated into the Saint John River” (from Chapter 7).

By the end of this period of industrialization, the state of the Saint John River had greatly deteriorated, so much so that some stretches of it were grossly polluted (Department of National Health and Welfare Canada 1961; Sprague 1964).

3.2 Population

As reported below in Chapter 4 Socioeconomic Conditions of the Saint John River Basin, the total population of the Saint John River Basin in 2001 was approximately 513,000. The population of the New Brunswick portion of the basin was approximately 314,000 (S. Dalton, pers. comm.), while in 1971 it was 299,000 (SJRBB 1975). In 1971, the New Brunswick portion of the basin accounted for 47% of the province’s total population, in 2001, 43%.

The population of the basin continues to be fairly evenly split between rural and urban residents. The Saint John River Basin Board (SJRBB) reported in 1975 that 53% of the New Brunswick portion of the basin lived in cities and towns and 47% lived in villages and unincorporated areas. In 2001, the total population of the municipalities of over 10,000 residents in the basin (Quispamsis, Rothesay, Edmundston, Fredericton, and Saint John) was 159,876 or 51% of the New Brunswick’s portion of the basin. Adding other towns such as Grand Bay-Westfield brings the number of urban residents in the basin closer to 55%. Interestingly, this was well below the 2001 national average of 80% of Canadians being urban residents, although in New Brunswick, the rural-urban split was 50-50 (all 2001 data from Statistics Canada 2007; 2009b).

3.3 Land Use

Most of the land in the Saint John River Basin continues to be covered by forest (**Figure 3.1**). However, little of this can be considered old growth forest, because as discussed earlier, significant areas of the basin have been subject to logging for timber and pulp for several hundred years (Frink 1999). These activities have changed the forest ecology of the Saint John River Basin. For example, MacDougall and Loo (1998) reported that the Saint John River Valley Hardwood Forest (SJRHF) once covered much of the Saint John River Valley (NB Ecological Land Classification Ecoregion 5, Valley Lowlands; see Chapter 1.6), but it has been much reduced by logging, settlements, agriculture, and dam reservoirs. Today, the “SJRHF now covers less than 1% of the land base within this region and only occurs in small-sized and usually highly isolated patches [primarily from Meductic to Beechwood]. On-going clearing and cutting jeopardize the remaining stands, as well as the many rare plant species associated with this forest type” (MacDougall and Loo 1998: 7).

About 6% of the land in the basin is used for agriculture today (**Figure 3.1**). Zelazny (2007) reports that around the towns of St. Leonard and Grand Falls (Reaches 1C and 2A) and up- and downstream of Florenceville (Reaches 2C, 2D, 2E; see **Figure 2.1**), 25% of the land is used for agriculture (see also **Figure 3.2**). Much of this agricultural land is in intensive potato production (Brasfield 2007). Around Sussex (Reach 4A), 15% of the land base is agricultural.

There are also pockets of intense urban development in and around the cities of Fredericton and Saint John. Thirteen percent (13%) or 18 km² of Fredericton’s total area (138 km²) is impervious cover (FAWA 2005), which is “the amount of land cover in roads, buildings and parking lots, and turf grass cover in a watershed and can seriously impact biotic integrity in associated streams” (i.e., groundwater can’t be replenished and runoff is direct and rapid to surface waters; USEPA 2011). The catchments within Fredericton that have the greatest impervious cover, up to 38%, are those along the banks of the Saint John River (FAWA 2005).

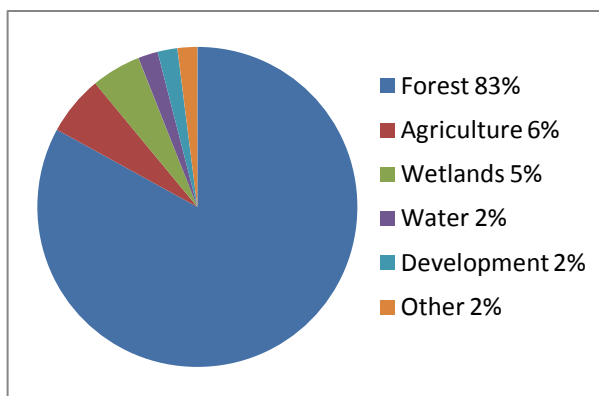


Figure 3.1 Land use in the Saint John River Basin – New Brunswick portion (data from NBDOE 2007).

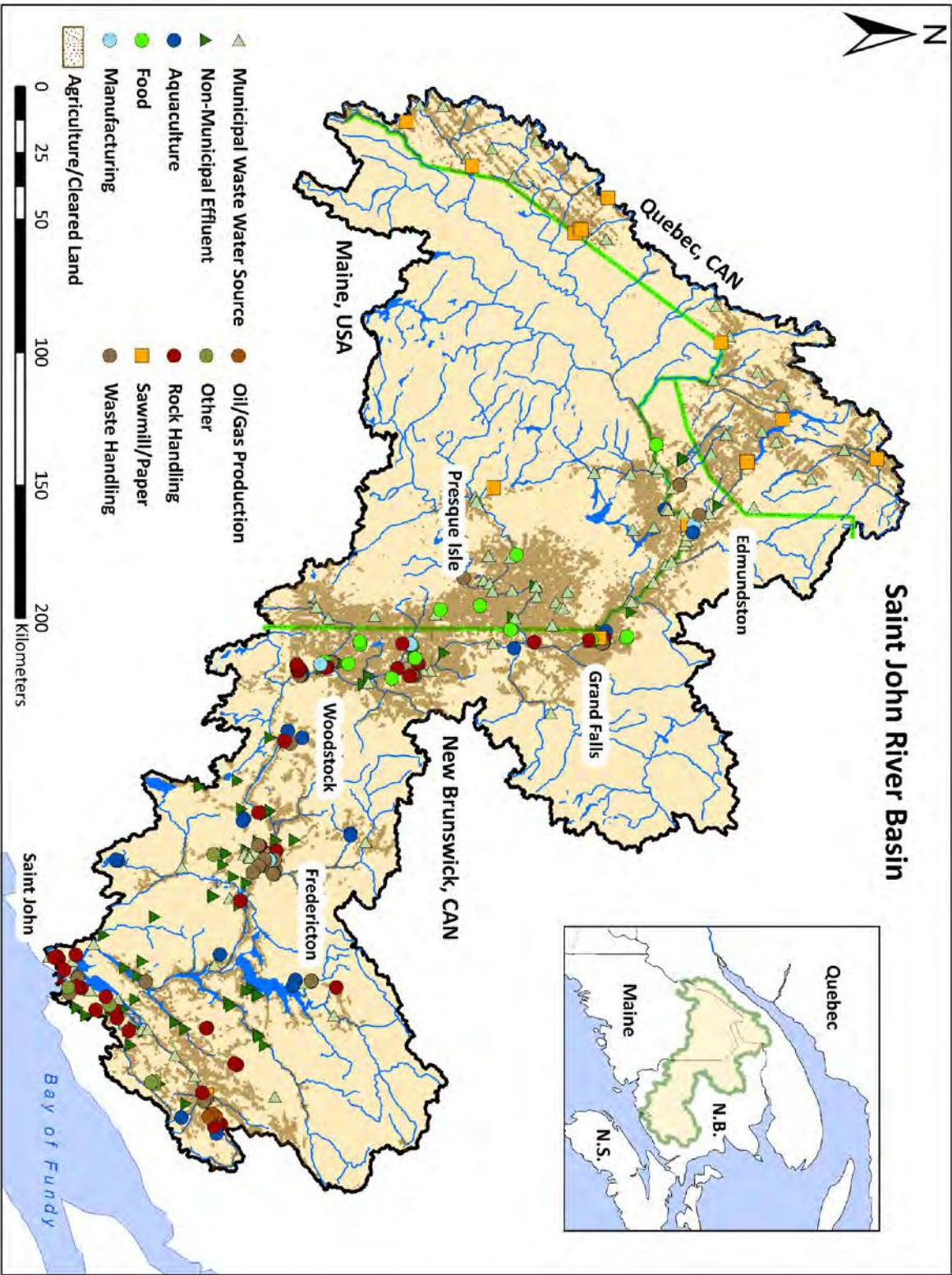


Figure 3.2 Locations of activities known to impact river environments in the Saint John River Basin.

3.4 Development in Focus: Dams and Wastewater

Present situation

Within the Saint John River Basin there are over 200 dams or water control structures. There are also more than 100 sources of municipal wastewater and another 70 or more non-municipal effluent sources. The basin is home to 15 sawmills and pulp and paper mills and another 21 food processing facilities. There is a myriad of other developments in the basin, including 19 aquaculture facilities and ~40 waste handling and rock handling facilities each

(see **Figures 3.2** and **3.3**; see 3.7 References for data sources). As this report will demonstrate, the two largest human influences on the present state of the Saint John River are human built dams and inputs of wastewater effluents.

Dams

There have been dams constructed on tributaries of the Saint John River since the early 1800s. Many of these were used to drive mills or aid in log driving. Although small, these dams had an impact on the state of the Saint John River, particularly fish populations because of a lack of fish

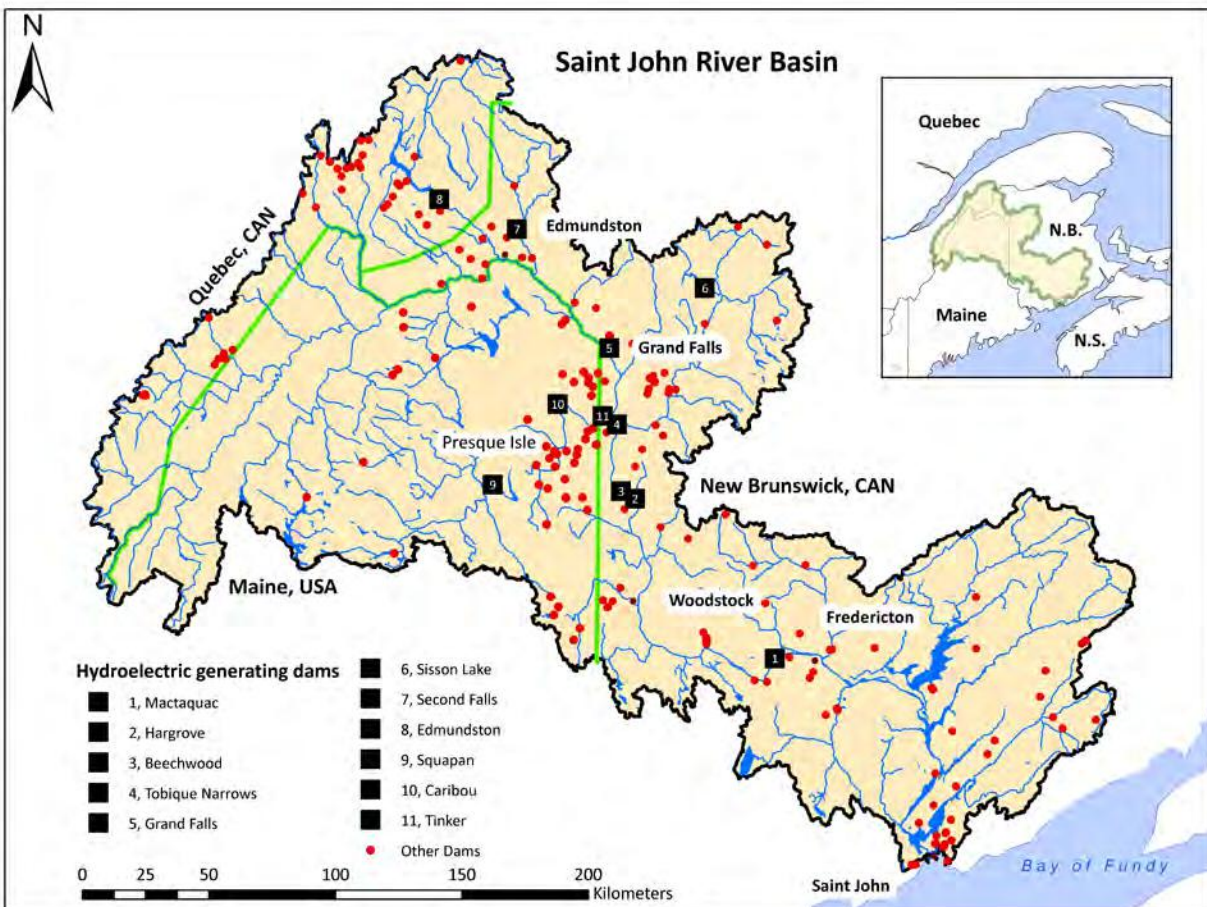


Figure 3.3 Hydroelectric and other dams in the Saint John River Basin.

passage over the dams. Regarding this situation, Wynn (1984: 94) wrote, “As the number of mills in the province increased during the second quarter of the century [1825-50], so an increasing number of the province’s streams were barricaded by mill dams at, or near, the head of tide and spawning grounds were cut off” (see also Perley 1852; Thomas 2001). One dam built around 1840 on the Nashwaak River near Marysville received particular condemnation for its impact on trout fishing and salmon spawning (Bailey 1894; Thomas 2001).

While the many smaller dams located throughout the basin still are affecting the state of the Saint John River, today much of the concern focuses on the ecological impacts of the hydroelectric dams located on the main stem of the river (**Table 3.1; Figure 3.3**). For example, impacts of the Mactaquac Dam include no fishway and therefore preventing upstream fish

passage, impeding flow, and increasing erosion and sedimentation (Wells 1999; WWF 2011). Each chapter describing the biological and physical state of the river in this report comments on the impacts of the dams. Ironically, as Hugh MacLennan (1974: 94) points out for many rivers in Canada, “...dam-building became so fashionable [in the 1950-60s] that politicians were afraid of being forgotten unless they got into the act.” The Mactaquac Dam was approved by government despite knowledge that it would have a tremendous negative impact on the state of the river. “Upon receiving the report [about the impacts of the dam] in 1960, both the federal and provincial governments decided “that the time was not propitious for the release of the report to sources outside of the government”” (Kenny and Secord 2011: 13). Mactaquac and the other hydroelectric dams on the Saint John River further compound their impacts by flow management regimes that are dictated by energy demands.

Table 3.1 Details of hydroelectric dams in the Saint John River Basin (data from Ruggles and Watt 1975; Carr 2001).

Dam	Location	Reach	Head (m)	Built ¹
Edmundston	Madawaska River	1B	6.1	1918
Grand Falls	Saint John River	1C	39.9	1928
Beechwood	Saint John River	2D	16.7	1957
Mactaquac	Saint John River	2E/3A	36.6	1968/69
Second Falls	Green River	1C	7.5	1924
Sisson	Tobique River	2C	41.0	1965
Tobique Narrows	Tobique River	2C	21.5	1953
Squapan	Aroostook River	2B	9.1	1941
Caribou	Aroostook River	2B	3.7	1890
Tinker	Aroostook River	2B	25.3	1922 ²
Hargrove	Monquart Stream	2D	21.0	1966

¹ Approximate year of construction. ² First constructed in 1906, reconstructed in 1922.

Wastewater effluents

Studies in the early 1960s (Dept. of National Health and Welfare 1961; Sprague 1964) drew attention to the severely polluted state of some stretches of the Saint John River caused by nutrient enrichment. The need to address this pollution led to the creation of the Saint John River Basin Board in 1970 and the Canada-United States International Saint John River Water Quality Committee (International Committee) in 1972. At the heart of each group's mandate was the goal of providing a management plan for the improvement of the river's water quality.

Poor water quality in the Saint John River Basin was not a new issue. Beginning in the early 1800s, the waste from sawmills was indicted as responsible for the decline of fish populations in many Saint John River tributaries. As Wynn (1981: 93) noted, "Early nineteenth century sawmilling was a wasteful process, and each spring and summer as the industry expanded, sawdust, slabs, bark, and edging were dumped into the rivers of the province to the detriment of their ecology and their appearance. ...Sawdust dumped into the rivers soon became sodden, sank to the bottom of the stream, disturbed the river ecology, and obstructed navigation. In suspension it floated downstream, was deposited on banks and intervals, and drastically reduced fish populations" (see also Perley 1852; Allardyce 1972; Thomas 2001).

The work of the SJRBB, the International Committee, and early studies revealed that the biochemical oxygen demand (BOD) of poorly or untreated wastewater being

discharged into the river from several point sources, which are single, localized sources of pollution, was severely depleting the river's oxygen. (This matter and its history are more fully discussed in Chapter 6 Water Quality and Chapter 7 Primary Production). The International Committee noted that at that time (1984: 2), "pulp and paper mills and the potato processing industries cause most of the pollution in the Basin" (see also SJRBB 1975). All of this attention on the water quality of the river resulted in many industries and municipalities installing wastewater treatment systems. As a result, the International Committee (1984) estimated that BOD from these sources was reduced by 88% between 1972 and 1984.

Despite this improvement, these same point sources are today still discharging large amounts of nutrients into the Saint John River, under permits issued by government regulators (**Table 3.2**). Additional pollutants such as nutrients and chemicals in sediment are also entering the river from non-point sources, mostly as runoff from agricultural and urban areas. These are not always easy to measure, but no less important: "Sediment is the number one pollutant in streams in North America, and can impact fish populations through turbidity, suspended sediments, and deposition of sediments" (Brasfield 2007: 75, citing Waters 1995). Finally, there is the issue of chemical contaminants, such as mercury, pesticides, and hydrocarbons that are found throughout the Saint John River. While this matter is not covered in this report, it is clear these contaminants are in the Saint John River because it is identified as the greatest source of contaminants to the Bay of Fundy (Pierce et al. 1998).

Table 3.2 Nitrogen (N) and total phosphorus (TP) discharges (in tonnes) into the Saint John River from selected facilities, 2004-2009. Nitrogen sources are ammonia (total; unshaded) and nitrate ions in solution at pH \geq 6.0 (shaded). (Data from NPRI 2011).

Facility	Reach	2004		2005		2006		2007		2008		2009	
		N	TP	N	TP	N	TP	N	TP	N	TP	N	TP
Fraser Papers ¹ - Edmundston	1B/1C	161	59	127	24	63	11	53	38	79	50	35	43
McCains Foods - Grand Falls	1C/2A	100		92	15	70	13	94	16	109	14	35	16
McCains Foods - Florenceville	2D	81	40	65	30	70	35	68	30	47	17	36	21
AV Nackawic ² - Nackawic	2E	-	-	-	-	72	15	85	24	99	28	106	10
Wastewater facilities - Fredericton	3A	96	15	131	27	97	14	137	9	157	6	182	8

¹ Now Two Rivers Paper Company. ² Pulp and paper mill.

3.5 Fishing

The present state of the river is not simply a dam and wastewater issue. As is discussed in Chapter 8, historic over-fishing of Atlantic salmon in the river and its tributaries helped precipitate the dramatic decline in their numbers (Bailey 1894; Thomas 2001). Parenteau (2001) wrote that in the late 1860s, the average official commercial catch of salmon in the Saint John River was 550,000 pounds per year (250,000 kg). By 1890, the average was down to no more than 200,000 pounds per year (90,000 kg). He also notes these figures do not include salmon taken for local residents or by illegal fishing. In 1966, the total salmon landings in the basin and Saint John County (which includes lands and waters in and outside the basin) was 275,000 pounds (125,000 kg; SJRBB 1975). Our treatment of this once seemingly inexhaustible resource is

summed up by Bailey (1894: 157), “In former years the salmon frequented all the principal southern tributaries of the [Saint] John, more especially the Nashwaak, Oromocto, Canaan, and Kennebecasis, with the two Salmon Rivers, where now they are virtually extinct. On the Nashwaak their disappearance is chiefly due to the construction of dams and mills, -- for what fish will venture up a stream paved several feet deep with decomposing sawdust? -- while on the Kennebecasis and Canaan it has resulted from insufficient protection [from over-fishing] ... with regard to the Kennebecasis [a government official said], “The inhabitants seem to be actuated by an insane desire to destroy every salmon that appears in its waters” .”

3.6 Conclusion

As the remainder of this report will show, human activities and developments over the past 200 years have increasingly altered the ecological state of the Saint John River. Much of this change is associated with dams, pollution, and over-fishing. Other changes to the region such as that caused by climate change and increasing population and urbanization, will place further pressure on the ecological resilience of the river and its basin. However, timely and concentrated actions, like those of the 1970s required to address the then grossly polluted state of the river, can lessen or reverse our degradation of this ecologically and socially vital ecosystem, should we have the will to undertake them.

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Data Sources – Figures 3.2, 3.3

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www.datagateway.nrcs.usda.gov/

4. Socioeconomic Conditions in the Saint John River Basin

Shawn Dalton
Reid McLean



4.1 Introduction

Why socioeconomic conditions are assessed

The Saint John River basin is a human-dominated ecosystem. Land use and land cover are largely the results of people's decisions, and are not only a function of today's activities, but also of the historical legacy we have inherited from the daily rounds of our predecessors. Our land tenure system and the patterns of individual parcels bear the mark of decisions that were made almost 300 years ago. In this chapter, we present socioeconomic conditions in the Saint John River Basin. Based on information about where we are, and where we're headed, we can decide how we want to move forward both locally and regionally.

Assessing socioeconomic conditions in the Saint John River Basin

Socioeconomic data are, in many cases, much more readily available than biophysical data: Statistics Canada collects and releases data about a variety of conditions in our households and communities. This is done regularly over time, with rigorous data collection, documentation, storage, and dissemination

protocols. Thus, it is often more challenging to decide how to limit our data presentation of socioeconomic conditions, than to figure out what kinds of information to gather. It is important to assess the status of human communities in the Saint John River Basin not only because human activities are the key drivers of ecosystem change in this system, but also because an absence of information about human communities diminishes our overall understanding of the basin. Understanding current socioeconomic conditions exposes opportunities and constraints to integrated watershed management.

Indicators for assessing socioeconomic conditions

The Human Ecosystem Model (**Figure 4.1**) was developed in the 1980s and 1990s and has been a powerful theoretical framework for studying energy policy (Burch 1984), threats to national parks (Machlis and Tichnell 1985), anthropogenic impacts upon biodiversity (Machlis 1992), watershed dynamics (Dalton and Bornemann 2005; Dalton and McLean 2005), and understanding mechanisms determining the allocation and distribution of critical

Chapter 4: Socioeconomic Conditions

resources at various scales (Machlis et al. 1994; Machlis et al. 1997). This model is composed of a set of Critical Resources (*natural, social, and cultural*) and a Human Social System (including *social institutions, cycles, and order*). The model can be used as a tool to improve our understanding of the reciprocal relationships between natural and social systems. Here, we have selected a subset of variables from the Human Ecosystem Model, and developed indicators for each, to assess and report on socioeconomic conditions in the Saint John

River Basin. These are the following seven indicators:

- Total population
- Population density
- Percent population under 20 years of age
- Percent population over 64 years of age
- Percent single parent households
- Median household income
- Unemployment rate

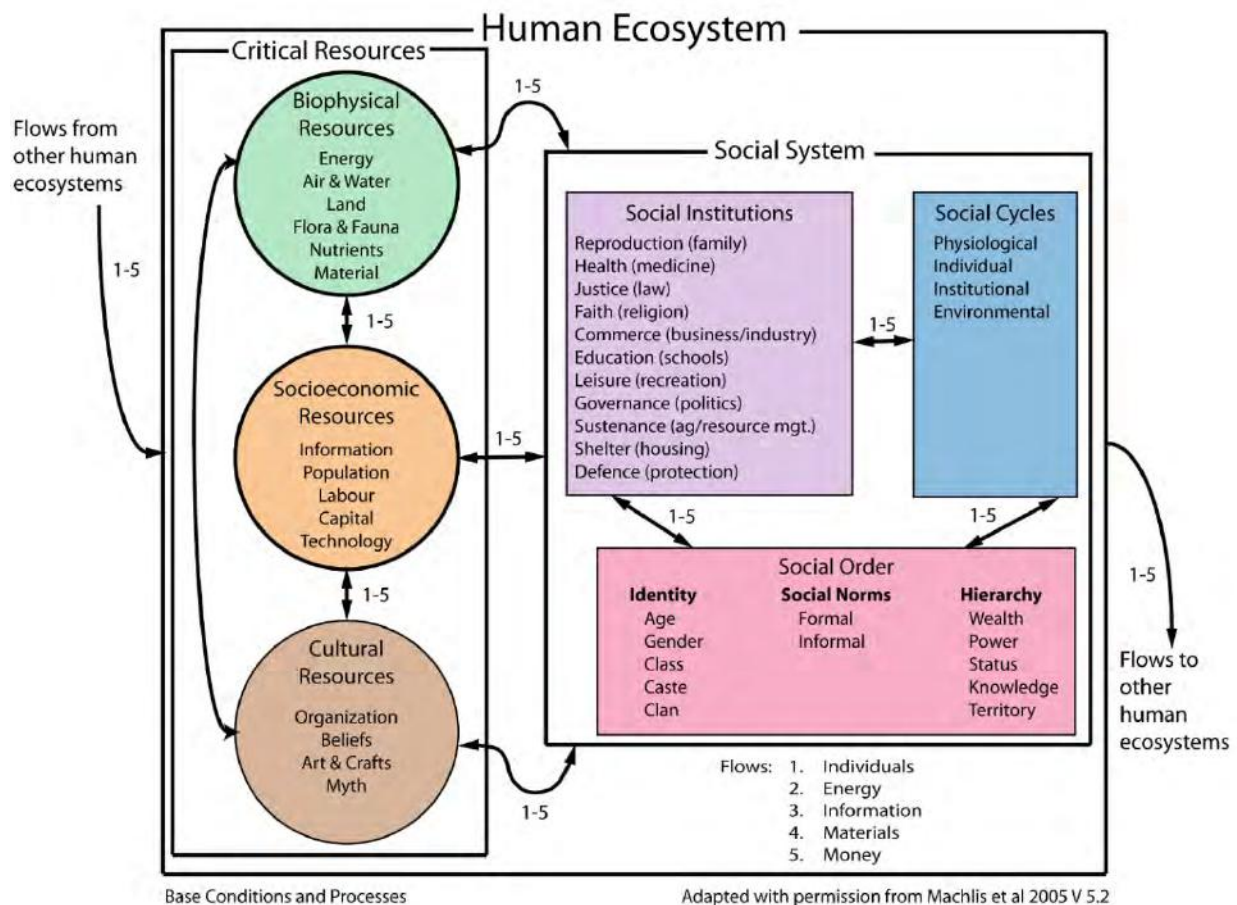


Figure 4.1 Human Ecosystem Framework.

Population

Population includes both the number of individuals and the number of social groups and cohorts within a social system.

Population as a socioeconomic resource includes the consumption impacts of people, as well as their creative actions (accreting knowledge, engaging in sexual behaviour, providing labour, and so forth). Human population growth is a dominant factor influencing much of human ecology (Hawley 1986) and social systems (Durkheim 1938), both historically (Turner et al. 1990), and within contemporary nation-states, regions, and cities.

Growth can be measured by natural increases (births over deaths/year) as well as migration flows. While population can act as an ecosystem stressor, it also is a supply source for many critical components within human ecosystems such as labour, information (including genetic code), and social institutions (Geertz 1963).

We have selected two indicators of population for this report: total absolute population, and population density. Total population is important as an indicator of the human capital available in a system, and population density is one indicator of the potential stresses placed on ecosystem structure and function by human activity.

Percent population under 20 years of age and over 65 years of age

Age is important, for much of human activity is age-dependent (Eisenstadt 1956): Certain occupations (such as mining) are mainly for the young; certain recreational activities (such as white-water sports) likewise are often specialized by age. In

addition, age distribution within a population determines requirements for social institutions such as education and health services.

The two indicators of age in this report are percent population under 20 years of age; and percent population over 65 years of age. Combined, this gives us an indication of both the structure and function of the human population in a region. Places with high concentrations of youth are often considered to be growing, and require services such as educational and recreational facilities. Communities with a high concentration of people over 65 years of age, especially combined with a low concentration of young people, are ripe for change. In addition, elderly communities require special consideration in terms of health care, transportation, and other services. A high dependency ratio, that is a high concentration of both young and elderly relative to the working population, indicates potential strain on the cohort of persons aged 20-65, both economically and socially.

Percent single parent households

Informal norms are the unwritten, and sometimes unspoken, rules that govern human behaviour. Informal norms are delivered to children as they are socialized; as we age, we continue to acquire expertise regarding structure and function of our social interactions. We are often unaware of informal norms until they have been violated.

Informal norms are administered through community or social group disapproval: deviating from the norm is noticed by sanctions that are slight. Speaking too loud

in a museum or too soft at a football game are examples, as are norms for behaviour in campgrounds, along trails, or on fishing boats. The full range of etiquettes for eating, socializing, courtship, and so forth are also informal norms.

Sometimes, a community's informal norms may conflict with its formal (legal) norms. The results are "folk crimes" i.e. activities that are against the law but not considered harmful by the population. Some kinds of wildlife poaching or illegal wood cutting are folk crimes (Scialfa 1992).

The indicator of informal norms in this report is percent single-parent households. While this includes both genders, in fact women represent some 76% of single-parent households. This is important in terms of community structure and function, both because single-parent households are more likely to also be low-income households in need of more active social support (whether formal institutional, or informal familial) than two-parent households, and also because the fact of single-parenthood may minimize adults' ability to participate in civil society.

Median household income

Capital can have a range of meanings. A narrow definition treats capital as the "durable physical goods produced in the economic system to be used for the production of other goods and services" (Eckaus 1972).

In the human ecosystem framework, capital is defined as the economic instruments of production; that is, financial resources (money or credit supply), resource values (such as underground oil), and the human

ability to manipulate these (human capital).

These instruments of production provide the basic materials for producing (with labour inputs) commodities. Capital is a critical socioeconomic resource; its influence over production, consumption, transformation of natural resources, and creation of by-products (such as pollution) is significant.

Capital often is measured in dollar values, either for commodities produced or the stock of capital on hand. Changes in capital, either in its mix of sources (a new processing plant or mill) or output (a reduction in profits earned by the plant or mill), can alter social institutions as well as hierarchies of wealth, class identities, and other features of the human social system.

Here, we measure capital in terms of median household income. This indicator was selected as both a potential measure of power (i.e. those with a higher income have more of it than those with a lower income); and because it also gives us a proxy indicator of consumption patterns and mobility.

Unemployment rate

Labour has many definitions; in the human ecosystem framework, it is defined as the individual's capacity for work (economists sometimes label this as labour power; Thompson 1983). Applied to raw materials and machinery, labour can create commodities and is a critical socioeconomic resource. There are many measures: labour time needed to create a unit of economic value (hrs/\$100 value), labour value (measured in real wages), labour output (units of production per worker or hour

labour), or surplus labour capacity (unemployment rates) are examples.

Labour is critical to human ecosystems in terms of both of its energy and information content. That is, both relatively unskilled yet physically demanding labour (such as harvesting crops) and specialized, sedentary skills (such as resource planning or stockbroking) have economic and sociocultural importance. Changes in labour, such as increased unemployment, can impact a variety of social institutions and hierarchies from health care to income distribution.

Here, labour is measured in terms of people's access to work and income. Those areas that experience high unemployment rates may be less stable than others; in addition, unemployment rates can inform us about the social cycles of a community.

4.2 Methods of Data Collection and Analysis

Census data were obtained from two sources. For Canadian Census Subdivision data, a computer program called Beyond 2020 was obtained from Statistics Canada through the University of New Brunswick's Harriet Irving Library and census information for geographies (census areas) within the watershed were extracted. For United States census tract information, the census geographies were downloaded from NOAA's STICS (Spatial Trends in Coastal Socioeconomics) website, and additional census information was downloaded from the American Fact Finder website. Once the census data were obtained, they were entered into ESRI ArcView 9.1 software and

the U.S. and Canadian Census information was compared to find common variables that could be measured across the national boundary.

Calculations for each indicator were performed as follows:

Total Population: Both U.S. Census and Statistics Canada had tallied the total population per geography. No additional calculations were needed.

Canada Beyond 2020

- Population, 2001-100%

U.S. American Fact Finder 2000 Census

- Table P1. On population – Total Population

Population Density: Census geography area was also present in both the U.S. and Canadian data. The U.S. area was converted from square mile to square kilometre and then divided into the total population to get population density: population per square kilometre.

Percent Population under Age 20: Age data for the U.S. census data were based on the gender and number of people per year of age from 0-85+. Statistics Canada tallied the number of people by gender as well and had several age groups such as 0-4, 5-9 etc. To calculate the population under the age of 20, the age groups from 20 – 0 were summed for both male and female, added, and then divided by total population, * 100.

Canada Beyond 2020: 100%

- Male 0-4,5-9,10-14,15-19
- Female 0-4,5-9,10-14,15-19
- Sum of above values/ Total population *100

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U.S. American Fact Finder 2000 Census

- Table P8. Sex By Age
- Male 0-19
- Female 0-19
- Sum above Values/Total * 100

Percent Population over Age 65: For percent population over age 65, the same procedure described for percent population under 20 was used but the ages were summed based on groups 65 years old and over.

Canada Beyond 2020: 100%

- Male 65-69,70-74,75-79,80-84,85+
- Female 65-69,70-74,75-79,80-84,85+
- Sum of above values/ Total population *100

U.S. American Fact Finder 2000 Census

- Table P8. Sex By Age
- Male 65-85+
- Female 65-85+
- Sum above Values/Total * 100

Percent Single Parent Household: Both U.S. and Canadian census data had number of male and female lone parent households with children. Number of male and female households were summed and then divided by the total number of private households, times 100 to come up with the percentage.

Canada Beyond 2020: 20%

- Total lone-parent families by sex of parent and number of children - 20% Sample Data
- Male Parent + Female Parent / Total # of census Families in private household * 100

U.S. American Fact Finder 2000 Census

- Table P10.
- Male Household, no wife w/ children under 18 + Female Household, no wife w/ children under 18 / Total Family Households * 100

Median House Hold Income: No calculations were necessary; data were downloaded and used as provided.

Canada Beyond 2020

- Household income for all private households:
- Median Household income

U.S. American Fact Finder 2000 Census

- Table P53.
- Median Household income (1999)

Unemployment Rate:

Canada Beyond 2020

- Total male and female in labour force, unemployed/Total male and female in labour force * 100

U.S. American Fact Finder 2000 Census

- Table P43.
- Total male and female in labour force, unemployed/Total male and female in labour force * 100

4.3 Findings

4.3.1 Total population

Total year-round residential population in the basin ranges from less than 1000 to over 72,000 per census geography. By census geography, these are fairly evenly distributed, along the main stem of the river, from upstream to downstream. The total resident population in the watershed is 513,544, distributed among New Brunswick, Quebec, and Maine. The greatest proportion of these people lives in New Brunswick, the least in Maine.

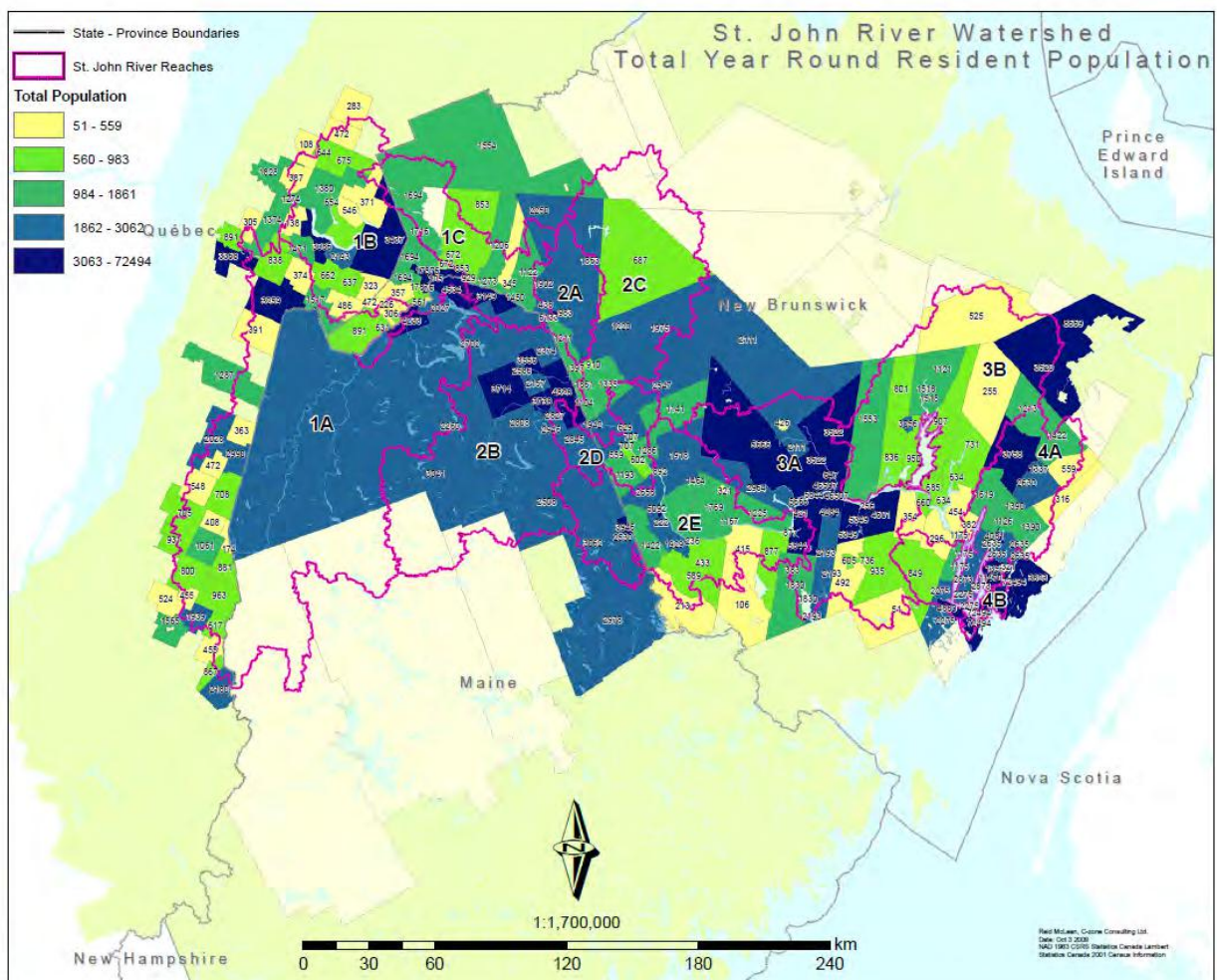


Figure 4.2 Total population of census areas in the Saint John River Basin.

4.3.2 Population density

Population density ranges from as low as 0.1 persons per km² to as high as 914.3 persons per km². Population density is greatest nearest to the river itself, and shows increased concentration in the lower reaches of the system.

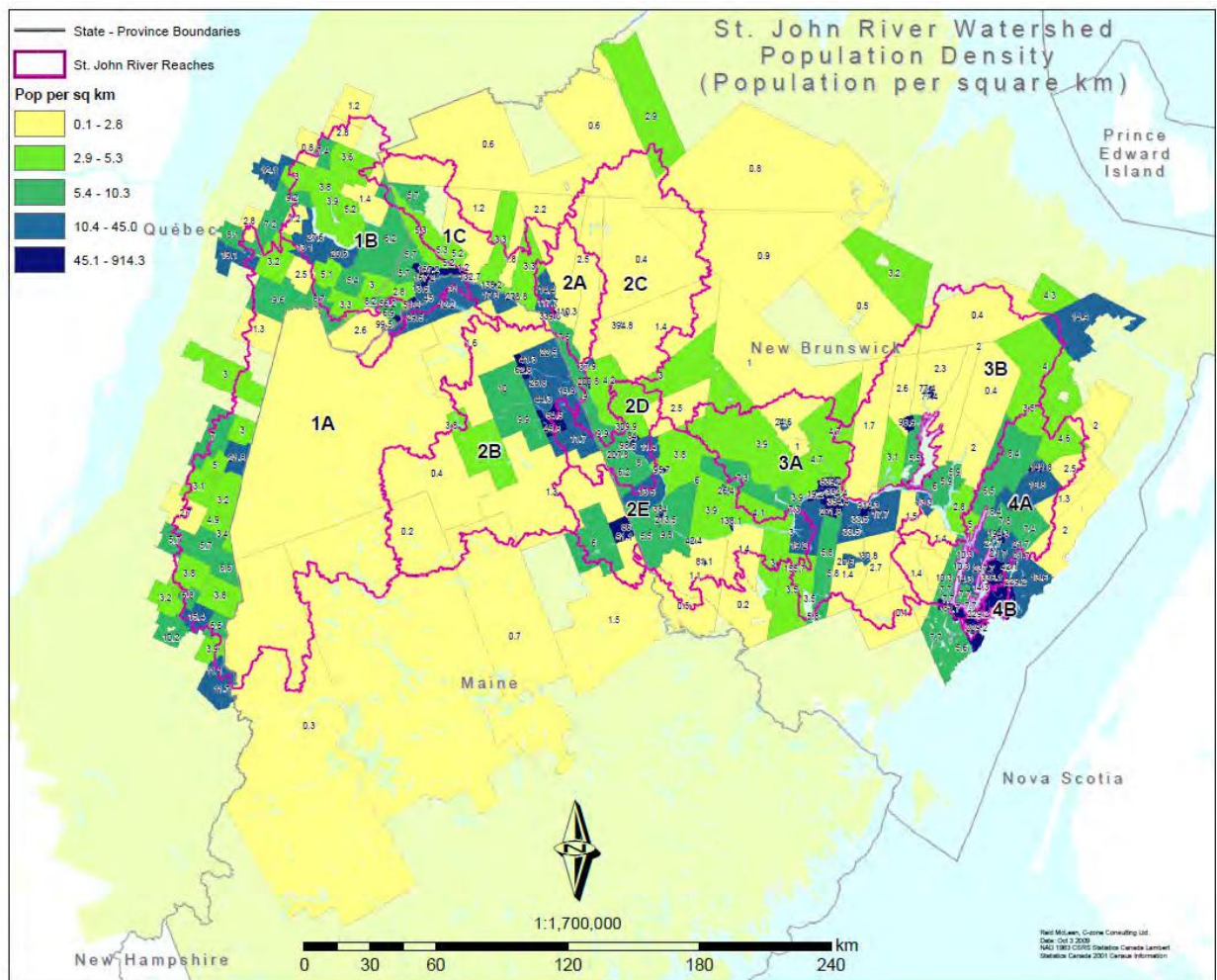


Figure 4.3 Population densities of census areas in the Saint John River Basin.

4.3.3 Percent population under 20 years of age

There are high concentrations of young people along the main stem of the river, with a marked increase in concentration from upstream to downstream.

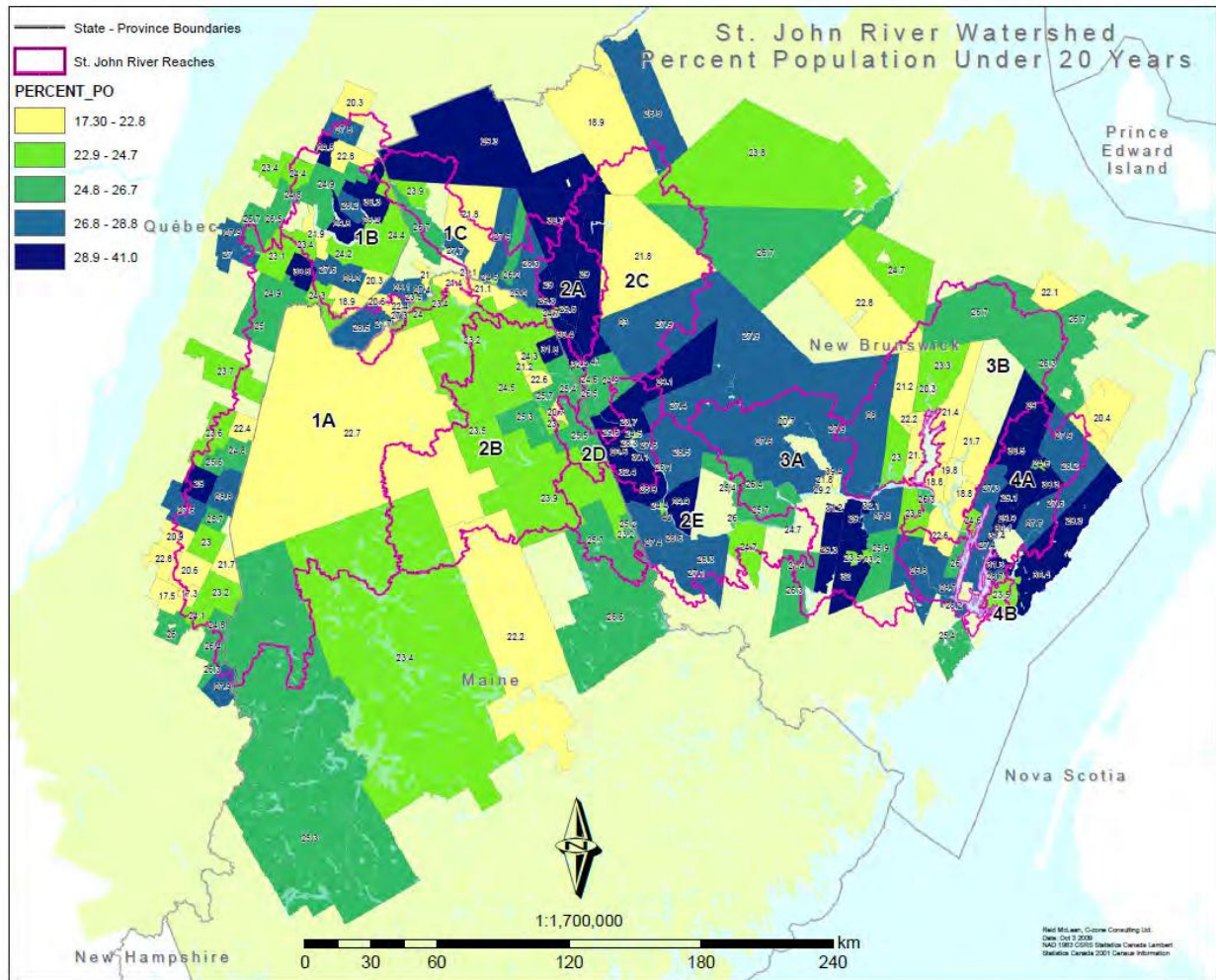


Figure 4.4 Percentage of the population under the age of 20 in census areas in the Saint John River Basin.

4.3.4 Percent population over 64 years of age

The percent population over 64 in the basin is the inverse of the percent population under 20 years of age: that is, there are increasing concentrations of elderly people in the upper reaches of the watershed, with the exception of the areas around Grand Lake and Washademoak Lake in the lower reaches of system.

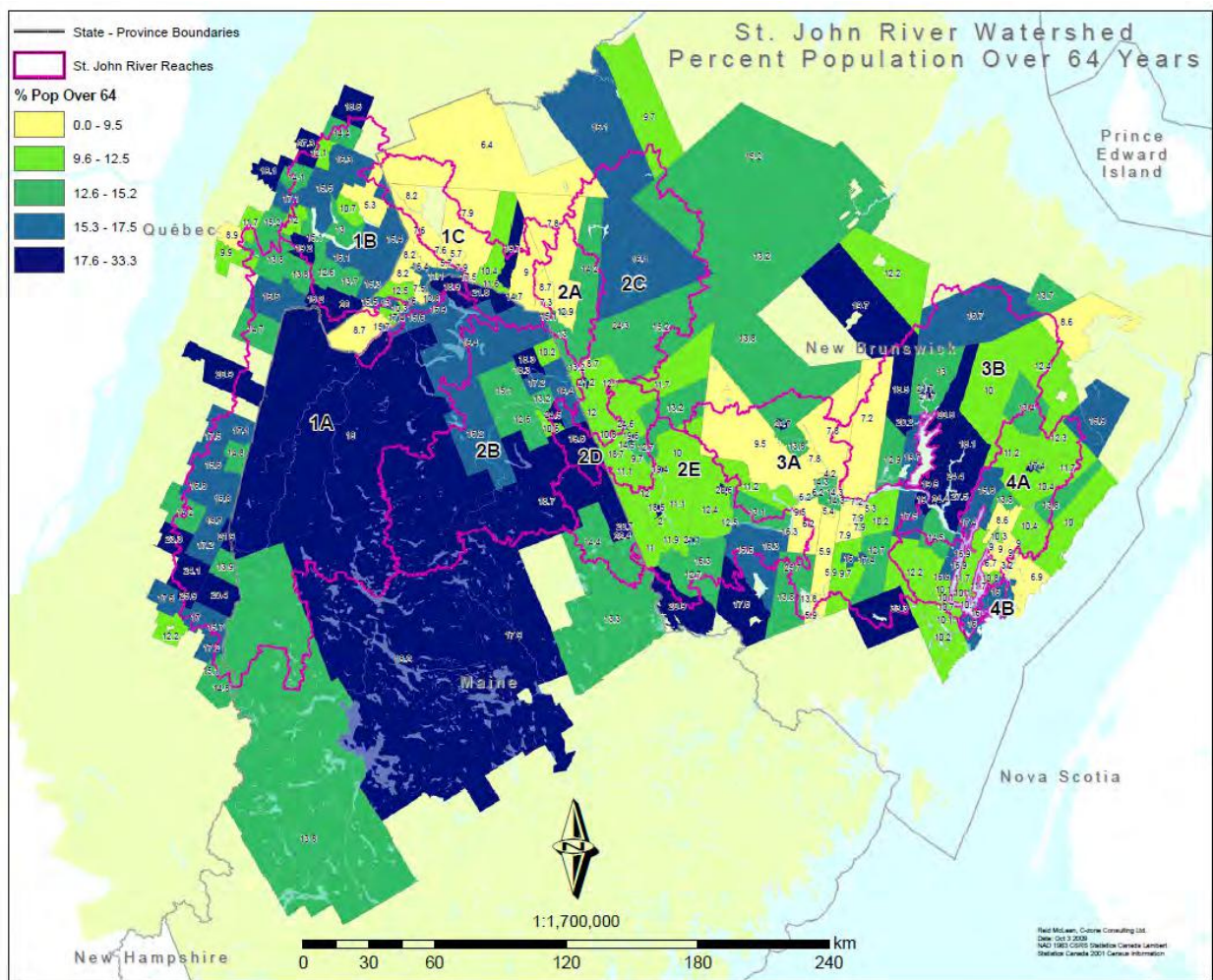


Figure 4.5 Percentage of the population over the age of 65 in census areas in the Saint John River Basin.

4.3.5 Percent single-parent households

The incidence of single-parent households in the basin is varied, exhibiting no particular trends or patterns. Percentages of incidence range from zero to 50% and are distributed fairly evenly throughout the basin.

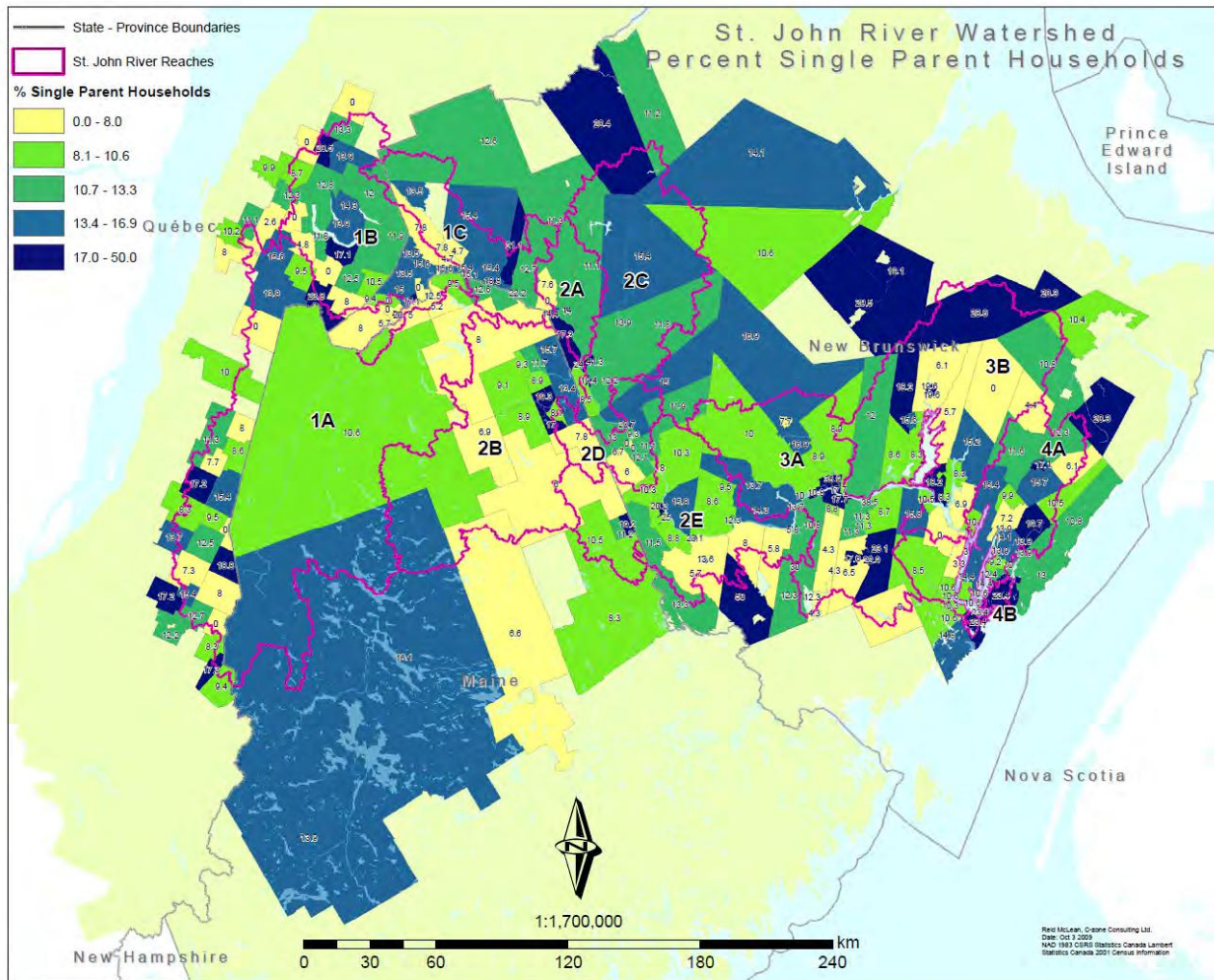


Figure 4.6 Percentage of single parent households in census areas in the Saint John River Basin.

4.3.6 Median household income

Median household income is far lower upstream than downstream, with lower rates present in Maine than in New Brunswick or Quebec. The rates range from 0% (in essentially unoccupied census geographies) to over \$75,000/year. The census geographies in and near urban areas, in particular Fredericton and Saint John, are those with the highest median household income.

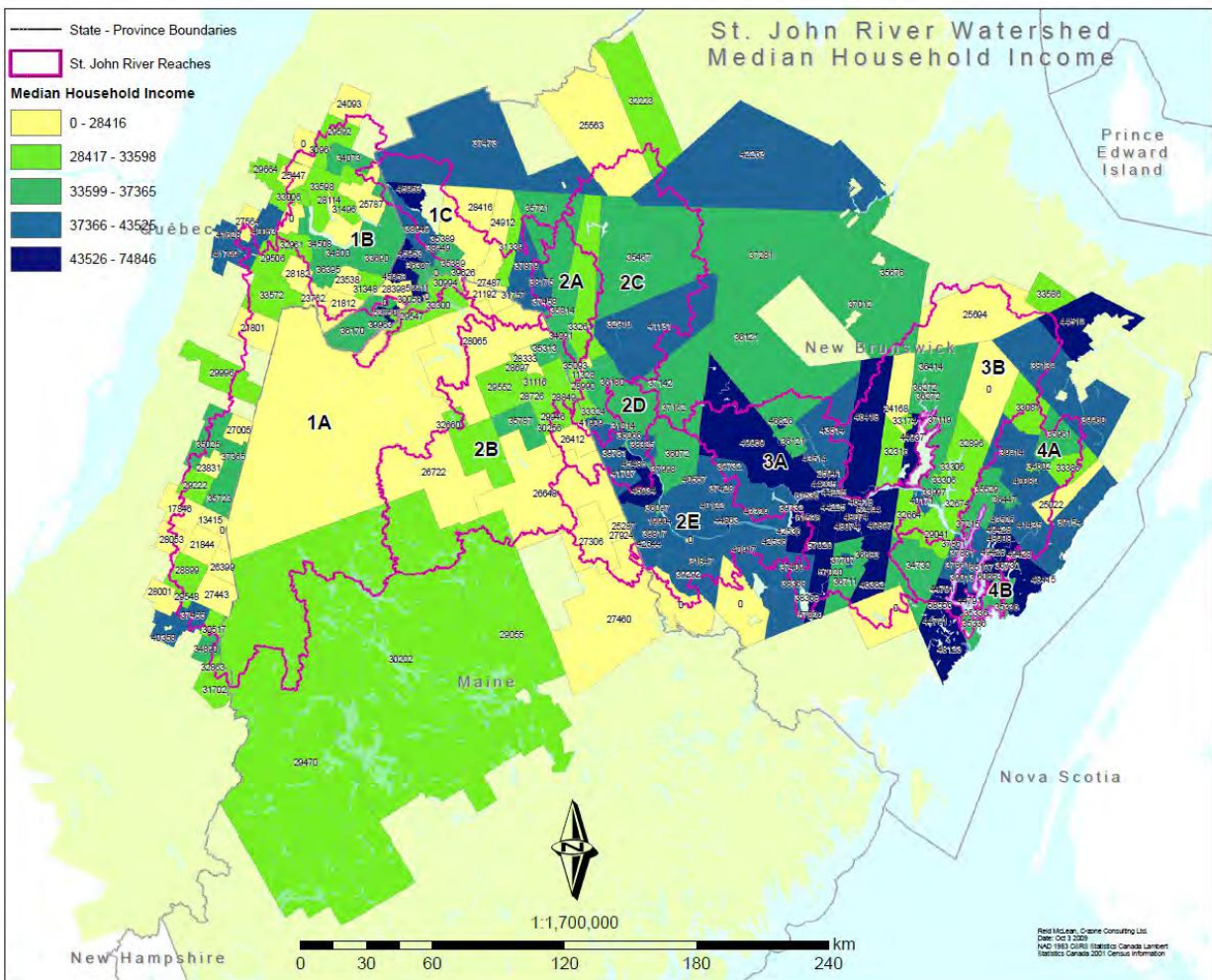


Figure 4.7 Median household income of census areas in the Saint John River Basin.

4.3.7 Unemployment rate

Unemployment rates are often a strong indicator of community stability and cohesion. However, this is not always the case in resource-dependent communities where work may be seasonal and people are partially employed for some of the year. Thus, this indicator may be less robust than

others in this dataset. Overall, there are high unemployment rates in the Saint John River Basin. These range from zero to 46.5%, with high concentrations being in the upland geographies. However, even along the main stem of the river, most geographies are in the 7-18% ranges.

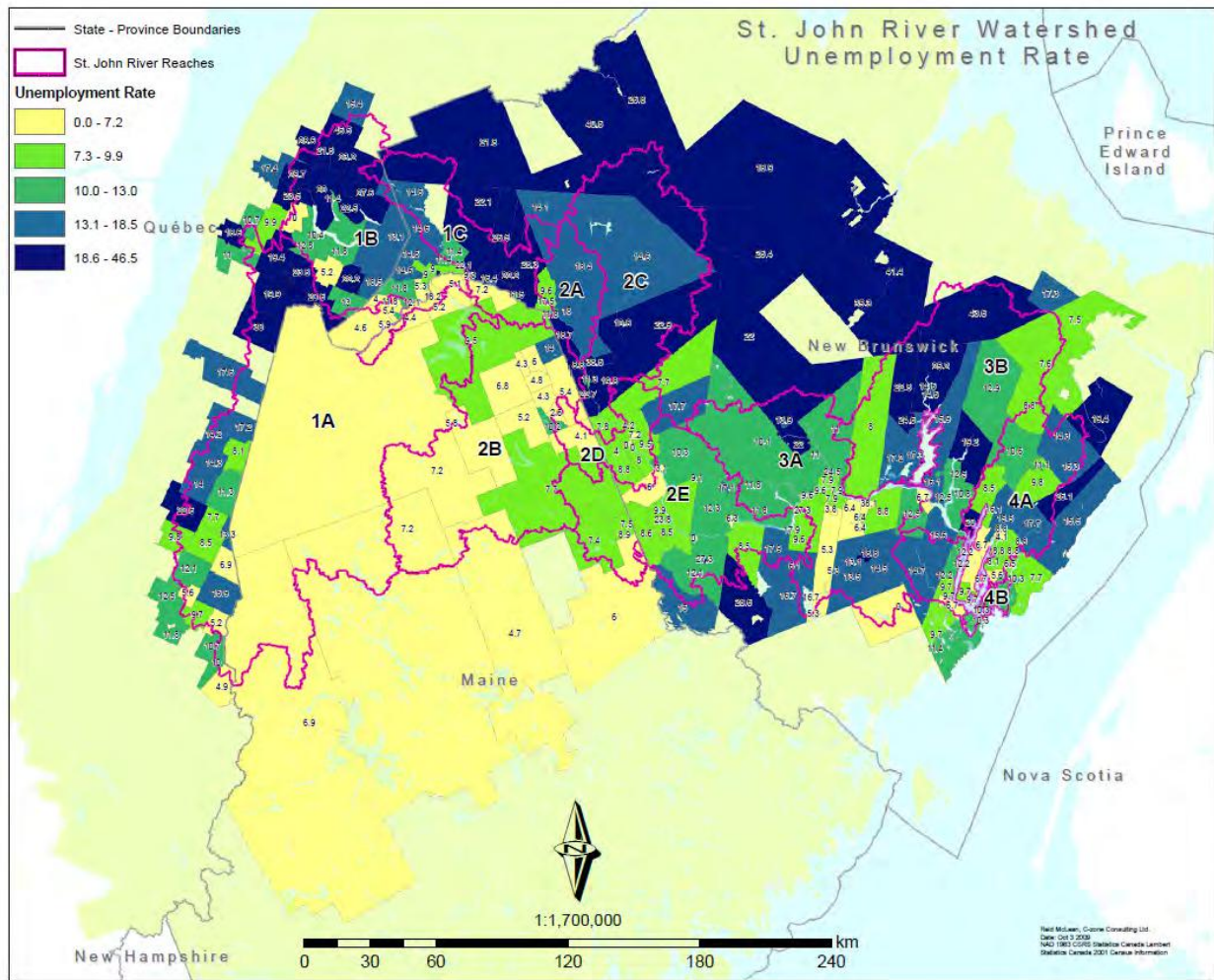


Figure 4.8 Unemployment rate in census areas in the Saint John River Basin.

4.4 Conclusion

In total, some 514,148 people reside in the Saint John River Basin. The lowest population count is 2,306 and the highest is 72,494 (that is, 14% of the total resident population lives in one census geography). The population density ranges from 47 to 914 people per square km. A minimum of 14% and a maximum of 46% of the population are over 64, while a minimum of 25% and a maximum of 48% are under 20 years of age. This is somewhat surprising, given the statistics we read about the aging population throughout North America in general, and New Brunswick in particular.

Median household income ranges from \$11,328/year to \$74,856, with the average of these being at \$33,193; unemployment rates range from 13% to 46%, and the percentage of single-parent households ranges from 12 to 50. We cannot determine from the data, as presented, whether destabilizing factors such as lower income and high percentage of single-family households co-occur or the factors that lend themselves to community cohesion and well-being such as higher income and lower unemployment rates co-occur. Future analyses of this nature should include both means by which to measure co-occurrence of both stabilizing and destabilizing factors, and comparative analyses of the same indicators in each subwatershed, to determine trends in the system over time.

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5. River Habitats

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Donald J. Baird

5.1 Introduction

Why river habitats are assessed

Aquatic habitats provide important features (physical, chemical and biological) to which organisms respond and adapt, at various stages throughout their lives. Consequently, habitats are frequently surveyed and form the basis of models used by biologists and resource managers for explaining the distribution of fishes, other animals, and plants (Fausch et al. 1988; Rice et al. 2001). River systems, in particular, are characterized by having a high degree of habitat variability spatially (headwaters to estuary) and over time (e.g., seasons; see for example Hynes 1970). Consequently, river habitats control the biodiversity and biological functions that act to maintain the ecological stability of a river system (Vannote et al. 1980).

The identification of aquatic habitat is also important as a basis for assessing environmental impacts and is often used as a management tool for regulating activities within catchments. For example, Fisheries and Oceans Canada (DFO) established its Policy for the Management of Fish Habitat in 1986 as the principal framework to guide its regulatory responsibilities for protecting Canadian aquatic resources (Goodchild 2004). That policy focuses on habitat-based



Figure 5.1 The Saint John River at Hartland, NB with covered bridge in background. The mouth of the Becaguimec River is shown in the left foreground where it joins the main river, and a mid-channel island is seen to the upper right.

initiatives such as protecting “productive capacity”, the “no net loss” principle, and avoiding activities that might result in the harmful alteration, disruption or destruction of fish habitat (also known as HADD).

Typically, habitat represents common physical structures or features that we can easily recognize, such as rapids, riffles, pools, backwaters, etc. The classification of habitat is scale dependent or in other words, defining habitats depends on the question you ask about the space along the river, e.g., habitat for an individual fish versus a community of fishes (Frissell et al. 1986; Hawkins et al. 1993). Mitchell (2005) reviewed the various ways that “habitat” is defined and interpreted and noted that habitat should be described in relation to physical attributes and include the biological components as well. ‘Habitat’ as used in this report is described by identifiable physical, abiotic attributes (e.g.,

islands, slope) and the relevance to riverine biota (animals and plants).

Habitat and the Saint John River ecosystem

Quantification of aquatic habitat in the Saint John River is sorely lacking. The only previous research was reported by the Saint John River Basin Board (SJRBB) in the 1970's, but it focused on water quality issues, primarily in the headpond reservoirs created behind hydroelectric dams (SJRBB 1974; Watt 1973).

Cunjak and Newbury (2005) reviewed the issue of habitat fragmentation and poor survival of diadromous species such as the Atlantic salmon (*Salmo salar*) and concluded the Saint John River probably represents the worst case in eastern Canada. The combination of hydroelectric dams on the main channel, together with industrial pollution, were discussed as the most significant reasons for the problem.

Indicators used to assess river habitats

Riverine habitat, as defined in this chapter, is restricted to the main stem of the Saint John River from the headwaters in northern Maine to the river mouth at the City of Saint John. Tributary sub-basins are not considered herein, except for their lowermost reach and junction with the main stem of the river (there is simply not enough data to assess the tributaries at this time). We have chosen to concentrate on the following four indicators of river habitats:

- Hydrologic regime
- River gradient (slope)
- Biophysical discontinuities
- Benthic macroinvertebrates

Hydrologic regime

The quantity of water flowing in the Saint John River has been measured historically at various locations along the river by the Water Survey of Canada and the United States Geological Survey. It is measured either as a volume of flow (or discharge, m^3/s) or as water level (m).

The hydrologic regime is one factor that determines the physical habitat quality for aquatic species. A river's flow affects its speed, depth, river width, temperature, oxygen levels, channel shape, and sediment movement. Hence, this is an important indicator of habitat suitability for fishes and invertebrates.

River gradient (slope)

A river's slope dictates the speed (velocity) of the moving waters of a river because water has a mass and gravity that draws it to sea level. Riverine biota have evolved traits to adapt to the variable flow habitats available in river ecosystems (Huet 1959; Pont et al. 2005). Amiro (1993) found a strong correlation between river gradient and the density of juvenile Atlantic salmon across the Maritime provinces. Although we recognize that gradient alone cannot fully explain how fishes and other aquatic biota use habitat, it provides one measure of the major flow patterns in a river which will in turn dictate the distribution of biota.

Biophysical discontinuities

"Edge" habitats or the discontinuity of habitats along the river have long been recognized for their ecological value. The discontinuities are associated with changes in physical attributes, e.g., islands, or any

alteration of flow patterns and water velocity that provide critical energetic benefits for biota (Thorp 1992; Newbury and Bates 2006). Vannote et al. (1980), in describing the structure and function of communities along a river continuum, clearly note the importance of tributary junctions for having major “bioenergetic influences” in terms of localized changes in energy processing and species composition.

Benthic macroinvertebrates

Benthic macroinvertebrates are a group of organisms - mostly insect larvae such as blackflies and midges - which live on and in the river bed. This group of organisms is diverse and abundant and thus often used to assess the state of river ecosystems (e.g., Monk and Curry 2008). Amongst the diverse number of species in rivers, there is variable sensitivity to stressors such as changes in water quality. One commonly employed measure is the Hilsenhoff Index that is based on the presence or absence of benthic macroinvertebrates sensitive to organic pollution (Hilsenhoff 1987). Ideally, for the most accurate river assessment based on benthic macroinvertebrates, we need many samples along a river taken over several years. There are no historic records of benthic invertebrate communities along the river. Our best existing data sets are the onetime survey of Heard and Curry (2003) and Maine’s water classification programme (see reference Maine BLWQ undated).

Past assessments of habitat

The only previous, comprehensive study of habitat in the river was the estimate of the loss of juvenile Atlantic salmon habitat as a result of the construction of the major

hydroelectric dams (Washburn & Gillis Associates Limited 1996). Those estimates were based on estimates of production derived from measure of gradient for the main stem and major tributaries (Amiro 1993; Marshall et al. 1998).

5.2 Hydrologic Regime

5.2.1 Present status

Historically, we can detect multiple, distinct hydrologic regime periods caused by development of the various dams over time along the main stem of the Saint John River and its tributaries. The present hydrologic regime period is considered to have started in 1968 following the construction of the Mactaquac Dam.

Methods of data analyses

Water flow and level have been recorded for many years at various points along the Saint John River. Some data sets date back to the 1920s.

For the purpose of understanding past and current hydrologic regimes, complete data sets that extended back in time prior to building any dams was required. Three data sets comprised of flow and/or water level measurements collected at hydrometric gauge stations at Fort Kent (Maine), and Grand Falls and Fredericton (NB) best met these criteria to assess the spatial and temporal changes of the hydrologic regime of the river (**Figure 5.2**). There were no flow data recorded along the main stem of the Saint John River prior to the construction of the Tinker Dam on the Aroostook River in 1922, and similarly, the data collection

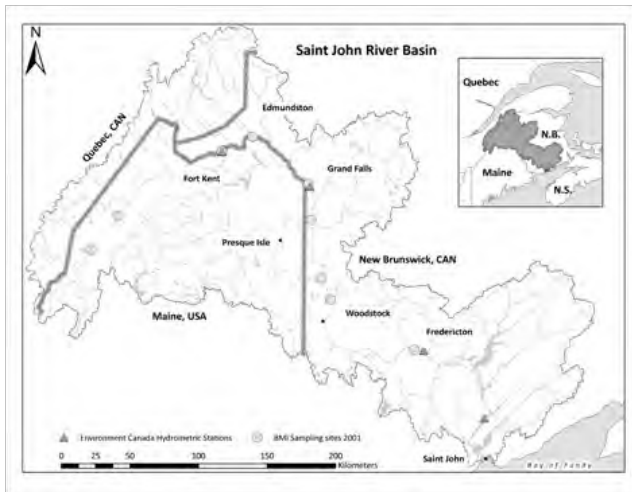


Figure 5.2 Hydrometric stations (▲) discussed and used in the analysis of hydrologic regimes in the main stem of the Saint John River.

initiated in 1929 lacked sufficient time series prior to the construction of the Grand Falls Dam in 1931. Our study focuses on the effects of the construction of the Tobique (1955) and Beechwood (1957) Dams (which are close enough temporally to be considered as a single event in 1957) and the Mactaquac Dam (1968) on the hydrologic regime of the main stem of the Saint John River. We have adopted three distinct hydrologic periods for temporal comparative analyses: pre-Tobique/Beechwood; pre-Mactaquac; and post-Mactaquac (i.e., our present conditions). For spatial comparison, we focused on the following two river reaches: Fort Kent to Grand Falls (the “Upper Reach”); and Grand Falls to Fredericton (the “Lower Reach”). It was not possible to establish a middle reach, as there was no gauging station between Grand Falls and Fredericton that met the study criteria.

The data are compared between the Upper and Lower reaches and across the three distinct hydrologic regimes (pre-

Beechwood/Tobique Dams to post-Mactaquac Dam). Although there is a lack of historic data available prior to the Grand Falls Dam being constructed, it was assumed that the structure did not have a great influence on the hydrologic regime because of the relatively small size of the dam and created headpond. The pre-Tobique/Beechwood time period is therefore considered to be a reasonable representation of the natural, unregulated system prior to construction of the dams.

The water levels were analysed for all years available using the Indicators of Hydrologic Alteration (IHA) software developed by the Nature Conservancy (Nature Conservancy 2009). There was a longterm record for Oak Point, NB, but we couldn’t accurately adjust the data after the change in its base datum in the 1960s.

The results from the analysis of the long-term flow and water level records are included for each reach as **Figures 5.3 – 5.5**. The default values for the settings within the software were used for analysis. These defaults define an ‘extreme low flow’ event as a flow value less than the 10th percentile of the daily low flows, a ‘low flow’ event as a flow less than the 50th percentile of daily flows, and a ‘high flow’ as a flow greater than the 75th percentile of daily flows. A ‘small flood’ is defined as a high flow event that has a peak flow greater than a storm flow that statistically has a 50% chance of occurring that year, and a ‘large flood’ as an event where the peak flow is greater than a storm flow that has a 10% chance of occurring that year. As water levels are collected in the future, they can be added to the record, and the analysis can be re-run to track trends into the future.

5.2.2 Comparison to historical regimes and among reaches

The frequency and magnitude of large floods in the Upper Reach of the Saint John River (as represented by the Fort Kent gauging station data) have increased in the post-Mactaquac Dam period (**Figure 5.3**).

Similarly, an increase in the frequency and magnitude of large floods post-Mactaquac Dam was evident at the Grand Falls gauging station (**Figure 5.4**).

Figure 5.5 shows an increase in the frequency and magnitude of large floods in the Lower Reach of the Saint John River post-Mactaquac Dam (measured at the Fredericton gauging station). An attenuation (reduced) number of low flow events occurred following the construction of the Tobique/Beechwood Dams (1955-

1957), but this is not apparent following construction of the Mactaquac Dam.

As shown in **Figure 5.5** (Fredericton), the construction of the Tobique/Beechwood Dams had a more substantial effect on the flow regime than did the construction of the Mactaquac Dam. Specifically, the extreme low flows were attenuated by the construction of the Tobique/Beechwood Dams and presumably, regulated minimum flows in operating permits.

River discharge is a primary factor influencing the structure and function of river ecosystems (Uehlinger et al. 2003) and the natural pulse of flows in a river are necessary to sustain the productive capacity of its habitats and biodiversity (Junk et al. 1989; Poff et al. 1997). The implications for the Saint John River are discussed in Chapters 6, 7, and 8.

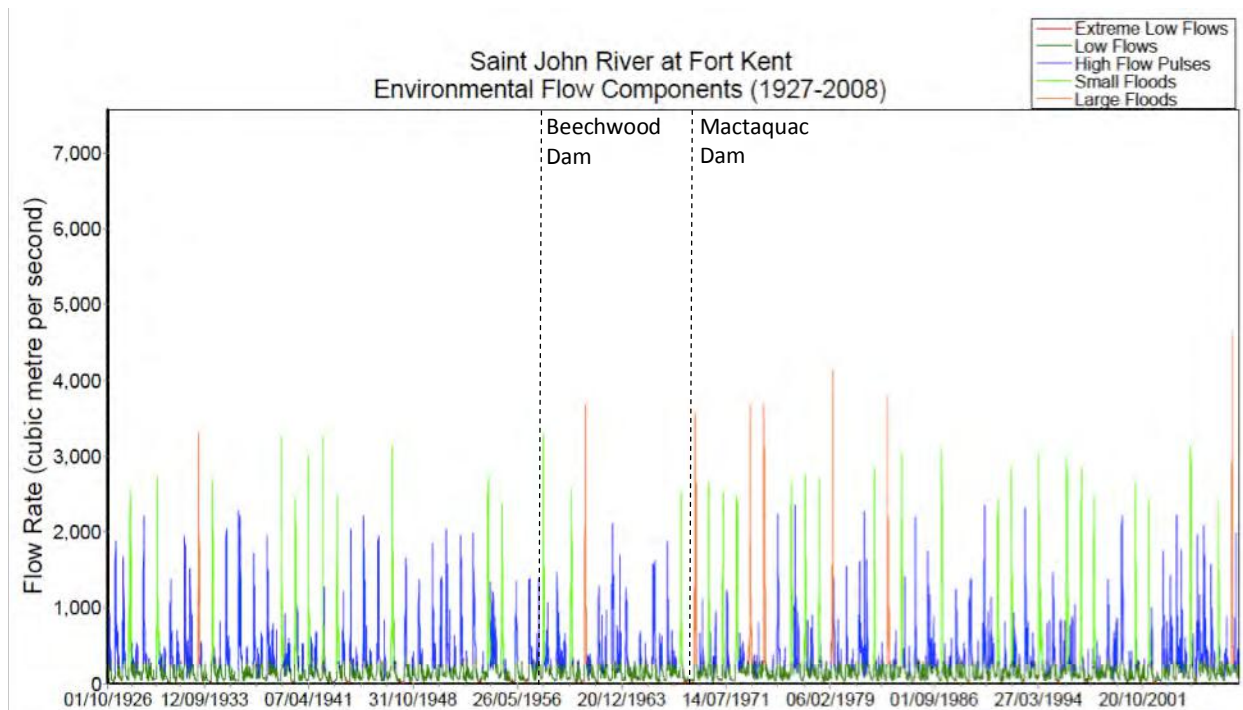


Figure 5.3 IHA Software output of time series showing flow changes over time period from 1927 to 2008 in the Saint John River at Fort Kent.

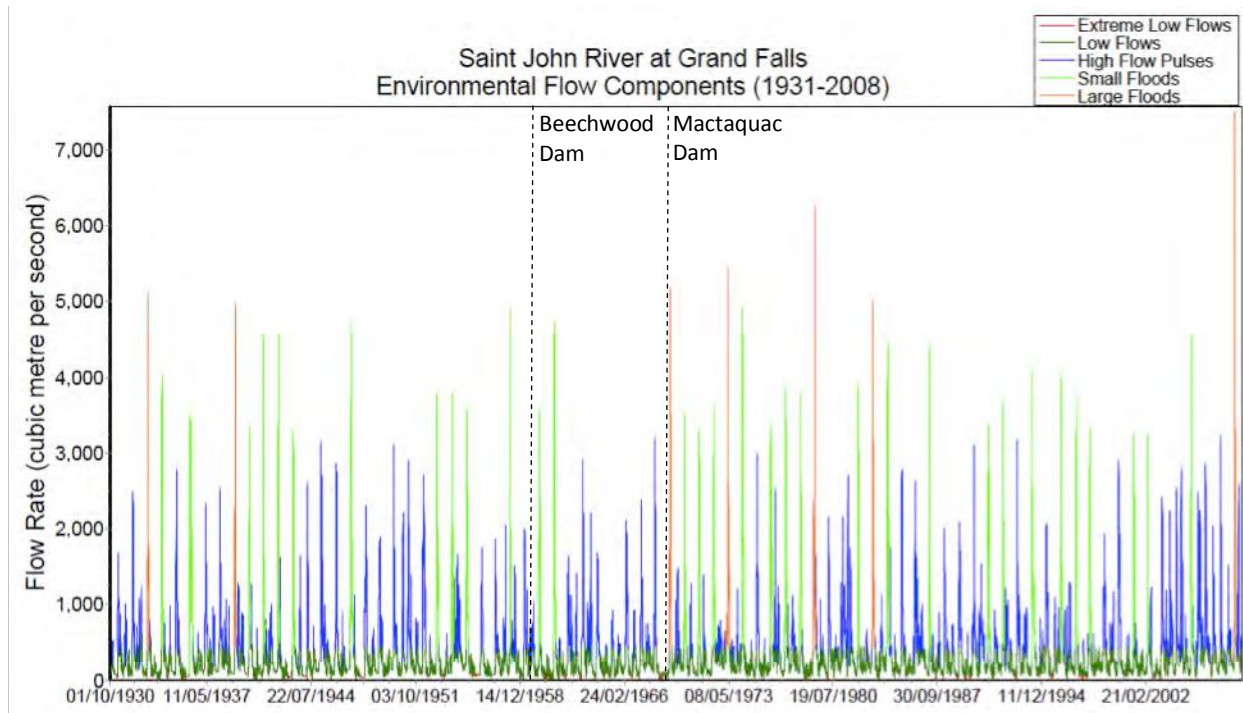


Figure 5.4 IHA Software output of time series showing flow changes over time period from 1931 to 2008 in the Saint John River at Grand Falls.

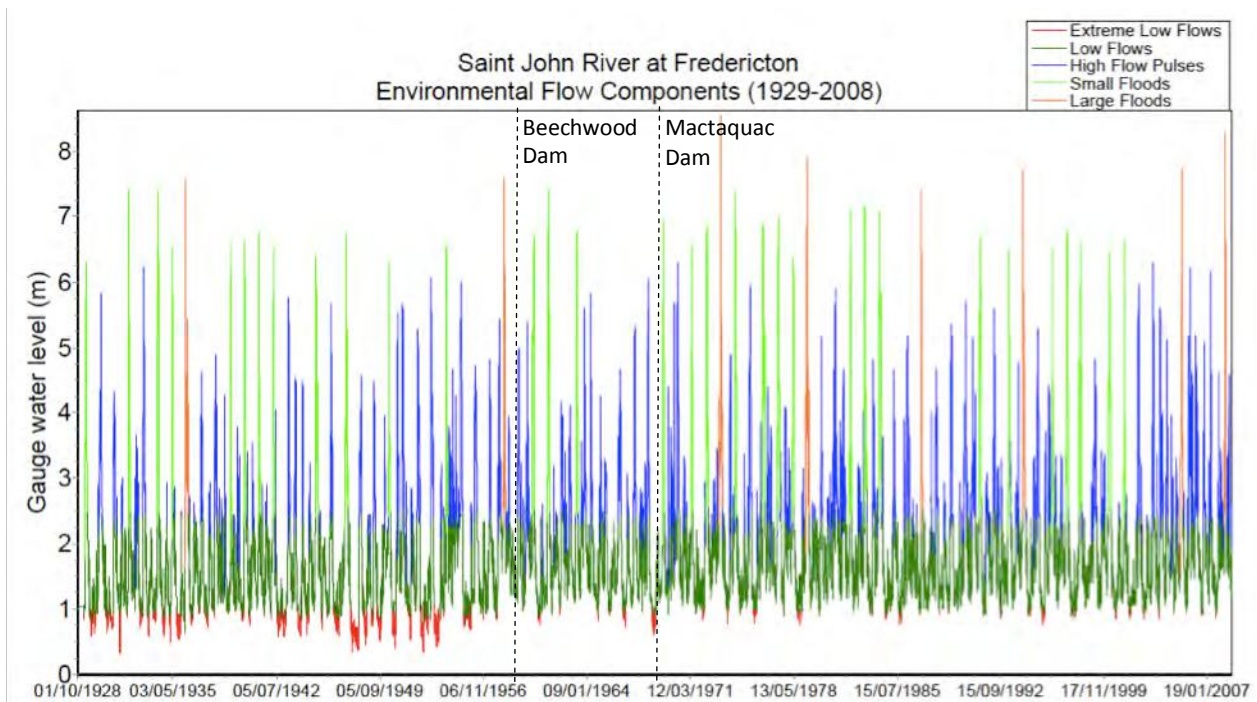


Figure 5.5 IHA Software output of time series showing water level changes over time for the period from 1929 to 2008 in the Saint John River at Fredericton.

Interestingly, the construction of the Mactaquac Dam did not substantively change the long-term water levels in the Lower Reach, although the water levels fluctuate on a daily basis because the Mactaquac Generating Station is managed to meet fluctuating regional energy requirements. There are periods within a day and within a season when flow-through substantively alters low and high flows downstream. This rate of change (highs to lows within a short time period) is stressful for aquatic biota if it deviates from the normal hydrologic cycle (Poff 1997). Downstream of Beechwood Dam, Culp et al. (2007) noted that water level "...was found to fluctuate by ~1.5m daily and large portions (sometimes greater than 50%) of the river bottom and the benthic community was exposed daily." Such a flow regime also alters water temperature and oxygen levels. For example, there could be daily temperature fluctuations of 7°C in the regulated reach compared to only a 1°C fluctuation in the unregulated reach (Culp et al. 2007). These changes can alter the biodiversity and biological functions of the river (see Chapters 7 and 8).

The frequency and magnitude of large floods (larger than a 1/10 year event) have increased in the post-Mactaquac Dam period in all reaches of the river, and therefore there is no correlation between these increases and the construction of the dams.

Other changes to the hydrologic regime may have occurred as a result of the construction of the dams that are not detected through the IHA analysis. For example, ice jams are known to change the hydrologic regime and alter fish habitat (Beltaos and Burrell 2002). The construction

of the dams is likely to have altered the probability and location of ice jam formation and thus the timing of ice dynamics (Jasek and Bernard 2009; Prowse and Conly 1998). The influences of climate change could also not be discerned from our analyses. The more frequent and larger floods may be indicative of our changing climate, but more analyses are required to address the issue of climate change and the flow regime of the Saint John River (see for example Monk and Curry 2009).

5.3 River Gradient (slope)

5.3.1 Present status

Methods of data analyses

We measured river gradient using a geographical information system, ArcMap 9.2. A 3 arc-second (approximately 90m) continuous Shuttle Radar Topography Mission digital terrain model (DTM) was extracted (Jarvis et al. 2006; and see <http://srtm.csi.cgiar.org>). The DTM was processed at 30m resolution to remove all depressions through a combination of filling and breaching. The centre-line for the river was provided by the NB Aquatic Data Warehouse.¹ Using the Convert Paths to Points function in Hawth's tools (Beyer 2004), points were created every 100m along the centre-line. Elevation values (m) were estimated from the DTM using the Extract Values to Points tool in ArcMap. Gradient was calculated by dividing the elevation gain between two points with the distance travelled (i.e., rise over run).

¹<http://www.unb.ca/research/institutes/cri/nb/aquatic/>

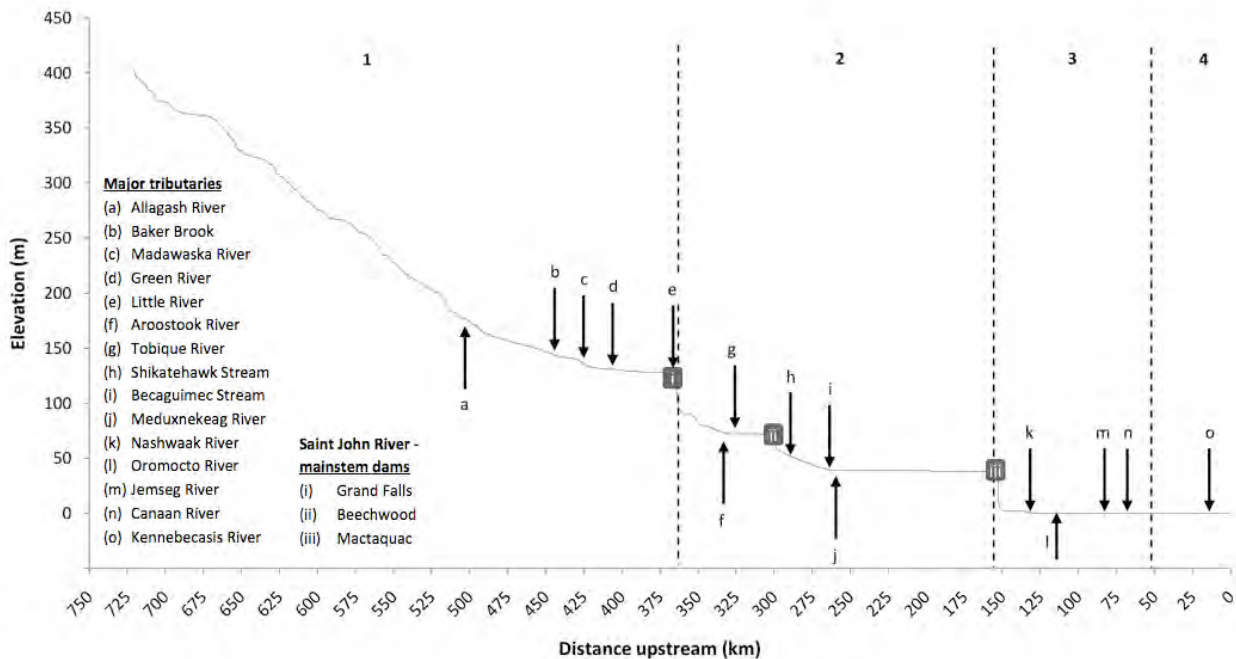


Figure 5.6 Elevational profile of the Saint John River from the headwaters to the river mouth. Arrows indicate location of major tributaries; squares represent location of main stem hydroelectric dams. Vertical dashed lines show divisions between the four study reaches.

5.3.2 Comparison to historical data: pre-dams

Marshall et al. (1998) noted that juvenile Atlantic salmon habitat upstream from the Mactaquac Dam was restricted to those river reaches with a gradient between 0.1% and <15.0% based on previous work by Amiro (1993). Before the construction of hydroelectric dams on the Aroostook River (1922) and Tobique River (1955), and at Beechwood (1957) and Mactaquac (1968), 2,379 ha of such habitat was available for salmon production upstream of Mactaquac Dam (Washburn & Gillis Associates Limited 1996). After the dams there was 1,347 ha of habitat, of which 58% was located in the Tobique River basin. This represents an overall loss of 44% of juvenile salmon rearing habitat in the Saint John River in Reaches 1 and 2 (upstream of Mactaquac

Dam) as a consequence of the dams and associated habitat changes (from river to headpond reservoir).

Another major problem after converting the river to reservoirs is created for migrating Atlantic salmon smolts. As flow is reduced and disappears in the reservoirs, salmon smolts appear to lose their orientation and downstream movements stop. In the Mactaquac Dam's reservoir, up to 100% of tagged migrating smolts that entered the reservoir failed to find the downstream exit (Carr 2001). Delays of lesser magnitude were also detected in the other reservoirs upriver.

5.3.4 Comparison between reaches

The dams and their reservoirs have

converted habitats from riverine to lacustrine (lake-like) and broken connections for migrating fishes. The inundation of riffles and rapids behind hydroelectric dams has resulted in reservoir gradients that are an order of magnitude less than the adjacent free-flowing river sections (**Table 5.1**). Such changes in habitat favours warmwater fishes that prefer lacustrine environments such as yellow perch (*Perca flavescens*) and smallmouth bass (*Micropterus dolomieu*), and also promotes the continuing invasion of introduced species (see Chapter 8). Many fishes in the Saint John River typically move long distances along rivers, e.g., Atlantic salmon, brook trout (*Salvelinus fontinalis*), and American eels (*Anguilla rostrata*). Such movement is severely compromised by the inefficient or absence of fish passage at the dams along the Saint John River (see Chapter 8).

Table 5.1 Slope and length measurements in the free-flowing and inundated reservoirs of the main stem of the Saint John River (**Figure 5.6**). Reservoir lengths are taken from Carr (2001).

Reach	Sub-reach and descriptor	Linear length (km)	Slope (%)
1	1B (free-flowing)	36	0.042
	1C (reservoir)	41	0.007
2	2A & 2B (free-flowing)	23	0.069
	2C (reservoir)	35	0.006
	2D (free-flowing)	29	0.042
	2E (reservoir)	100	0.001

5.4 Structural Discontinuities

Methods of data analyses

For this report, we examined two measures of structural discontinuities:

- Tributaries
- Islands

Tributaries

The junction where a tributary joins the main stem of a river provides spatial and temporal habitats for river biota (Rice et al. 2001). Such junctions can alter flows, temperatures, and primary production. For fish, junctions can provide thermal refugia, staging points during migratory phases, and access to important life-stage habitats (Cunjak 1996). Herein, we compare and contrast the number and location of several tributaries where they join the main stem of the Saint John River in terms of fish habitat.

Islands

Islands in the main channel of large rivers are distributed in relation to the landscape and geology that control flow and sediment in the river. Islands are common in the river. They provide unique and significant habitat complexity in terms of flow refuge zones, increased littoral (shoreline) habitats, and ultimately, increase the habitat complexity along the river (Thorp 1992). River islands are also important as stepping-stone habitats for the movement and colonization of river corridors (Sommerwerk et al. 2010). Thus, any alteration or reduction of these riverscape features may affect their contribution as habitat. We again focused on habitat for fish.

5.4.1 Tributaries

5.4.1.1 Present status of tributaries

Methods of data analyses

Only tributaries \geq order 3 were included for analysis (order 3 streams are created by two order 2 streams which are each created by two first order streams). Tributaries were further distinguished as to which side of the Saint John River they entered the main stem, river-right or river-left, determined by facing downstream (mostly south/west and north/east orientations, respectively). These data were obtained from the GIS analyses as already described. Identification of summer plumes of cold water at the mouths of tributaries was based on personal communications with biologists from the CRI, DFO and NB Department of Natural Resources.

5.4.1.2 Comparison to historical data for tributaries

Hydroelectric dams are located in the lower reaches of four tributaries, in reaches 1 and 2 (**Table 5.2**). These are the Tobique River (km 1, 1953), Monquart Stream (km 0.5, 1966), Aroostook River (km 4.5, 1906), Green River (km 19, 1924) and Madawaska River (km 0.5, 1918). Prior to these dates, there were no barriers to upstream fish passage and there was no regulation of flow characteristics where tributaries joined the main stem of the Saint John River.

There are no long-term historical temperature data to establish the occurrence, and importance, of thermal plumes at the confluence of tributaries.

Table 5.2 Tributaries \geq order 3 located in the four reaches of the Saint John River. Bracketed letters refer to the river-side of entry of the tributary. Asterisks refer to tributaries with man-made barriers in their lower reaches. Shading indicates coolwater sources.

Reach	Tributaries
1	Big Black (L), Little Black (L), Allagash (R), Francis (L), Fish (R), Madawaska*(L), Baker (L), Green*(L), Quisbis (L), Grande (L)
2	Little (L), Salmon (L), Aroostook*(R), Tobique*(L), Monquart*(L), Shikatehawk (L), Big Presquile (R), Little Presquile (R), Eel (R), Meduxnekeag (R), Becaquimec (L)
3	Keswick (L), Nashwaak (L), Oromocto (R), Jemseg (L), Canaan (L)
4	Nerepis (R), Kennebecasis (L)

5.4.1.3 Comparison between and within reaches

Summer cool water plumes are known to occur at the mouths of four major tributaries (**Table 5.2**). All these tributaries enter the Saint John River from river-left. In Reach 1, no tributaries \geq order 3 provide significant coolwater habitat in summer. However, main channel groundwater discharge zones are known in some sub-reaches such as amongst islands near the mouth of Baker Brook. In Reach 2, the three coolwater tributaries drain the central New Brunswick highlands. The Shikatehawk River is well-known to have a significantly cooler plume of water at its mouth, probably reflecting the influence of the Coldstream sub-tributary. This coolwater habitat in the

main river likely explains the occurrence of salmonids like Atlantic salmon, brook trout and rainbow trout captured at the nearby “Florenceville” site sampled by Curry and Munkittrick (2005). By contrast, tributaries entering from river-right in Reach 2 drain lands of comparatively low relief. The suitability of the mouth of the Tobique River as a thermal refuge habitat was likely compromised by the creation of the headpond behind the Tobique Narrows Dam in 1953. Consequently, there is no accessible thermal refuge provided by a tributary in sub-reaches 2B and 2C. This may be especially problematic for fishes in sub-reach 2C which is largely impounded behind the Beechwood Dam and which may experience warmer summer temperatures. In the lower reaches of the Saint John River, the Kennebecasis River provides potential thermal refuge for coolwater fishes.

5.4.1.4 Comparison between and within reaches

Summer cool water plumes are known to occur at the mouths of three tributaries (**Table 5.2**). All these tributaries enter the Saint John River from river-left (east/north). They all drain highland areas (see **Figure 1.1** for elevations) and are without major dams. Both the Green and Tobique rivers historically created summer, coldwater plumes in the main stem of the Saint John River, but now both have flows that are highly regulated.

5.4.2 Islands

5.4.2.1 Present status of islands

Methods and data analyses

Using data from the New Brunswick Aquatic

Data Warehouse and the National Hydrological Network, river islands were identified along the New Brunswick portion of the Saint John River. The perimeter or island shoreline (km) and area (km²) for each island was calculated using the Calculate Geometry function in ArcMap 9.2.

5.4.2.2 Comparison to historical data for islands

There are no historical data available for the Saint John River relating to island-associated habitat. It is well established that many islands were flooded (lost) when the Mactaquac Dam’s reservoir was created.

5.4.2.3 Comparison between and within reaches

Main stem islands are most common in Reach 2 although the average size of islands is significantly higher in the lower river reaches (**Table 5.3**). In Reach 3, island perimeters contribute 186 km of additional shoreline habitat, which is more shoreline habitat than occurs among the other three reaches combined. The impounded reaches (1C, 2C, 2E) provide some of the lowest estimates of island-associated habitat, especially in comparison with adjacent sub-reaches. The drowned islands in dam reservoirs may still provide habitat, but the value as habitat if any, of these submerged features structure is unknown.

Table 5.3 Characteristics of potential aquatic habitat around main stem islands in different reaches of the Saint John River. Grey shading represents those reaches affected by impoundment behind hydroelectric dams.

Reach	Perimeter (km)	# Islands	Avg Island Area (km ²)	habitat (km) / linear river km
1A*	17.285	21	0.054	0.432
1B	14.908	22	0.055	0.521
1C	3.220	3	0.080	0.057
2A	1.368	6	0.002	0.046
2B	0.000	0	0.000	0.000
2C	2.627	7	0.007	0.074
2D	23.811	30	0.038	0.781
2E	23.745	34	0.019	0.217
3A	121.755	47	0.433	1.729
3B	64.192	7	1.561	1.987
4A	16.112	12	0.113	0.422
4B	6.788	4	0.341	0.561
1*	35.413	46	0.056	0.099
2	51.551	77	0.024	0.244
3	185.947	54	0.579	1.811
4	22.900	16	0.170	0.455
* GIS data only available for that part of reach in Canada.				

5.5 Benthic Macroinvertebrates

5.5.1 Present status

Methods of data analyses

The benthic macroinvertebrate (BMI) community of the Saint John River main stem was sampled at nine locations from Priestly Bridge in Maine to Fredericton, New Brunswick in September 2001 (Heard and Curry 2003; **Figure 5.7**).

Samples were collected using a U-net sampler along the wadable shoreline areas. Organisms were identified to lowest taxonomic level (normally genus or species, but in some cases, only to taxonomic family). Rare species were eliminated from the statistical analysis because these have been shown to introduce variability which can obscure true differences among samples. Site differences were expressed in terms of their dissimilarity, employing the Bray-Curtis statistic (Clarke and Gorley 2006). Sites were clustered using multivariate analysis (non-metric multidimensional scaling method) using the Primer statistical package. To assess organic pollution, the Hilsenhoff Family Biotic Index was calculated for each site based on taxonomic family-level tolerances. Hilsenhoff Index tolerance values were obtained from the Canadian Aquatic Biomonitoring Network (CABIN, <http://cabin.cciw.ca>).

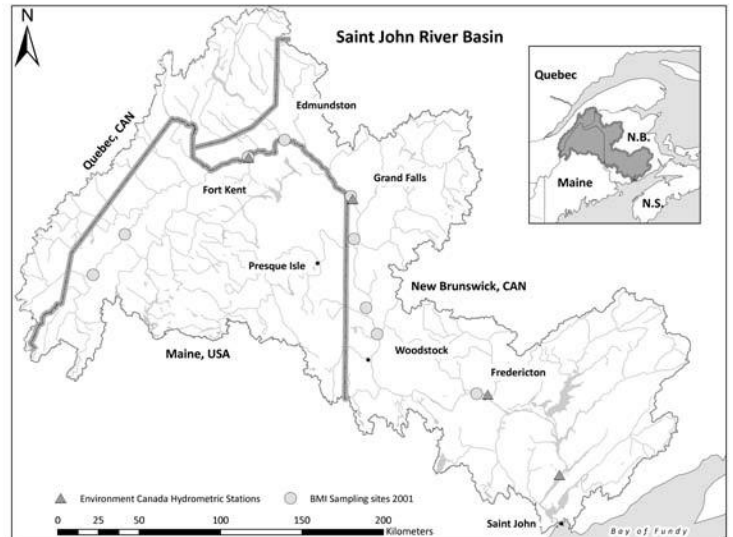


Figure 5.7 Location of benthic invertebrates sampling sites (O) along the Saint John River, 2001 (Heard and Curry 2003).

5.5.2 Comparison within and among reaches

Figure 5.8 represents the grouping of benthic community samples in multidimensional space following multivariate analysis. The relatively even spatial distribution of the samples indicates that the BMI communities were more than 65% similar among sites along the river. The global R value obtained (0.391) indicated that differences among the structure of benthic communities were minimal. Generally, the upper reach sites in Maine (Moody Bridge and Priestly Bridge) were highly similar in composition (>80%) and consistent with Maine samples for the headwaters of the Saint John River. Baker Brook and Edmundston were separating from the upstream sites and both were in sub-reaches with various inputs of wastewaters. Grand Falls at the

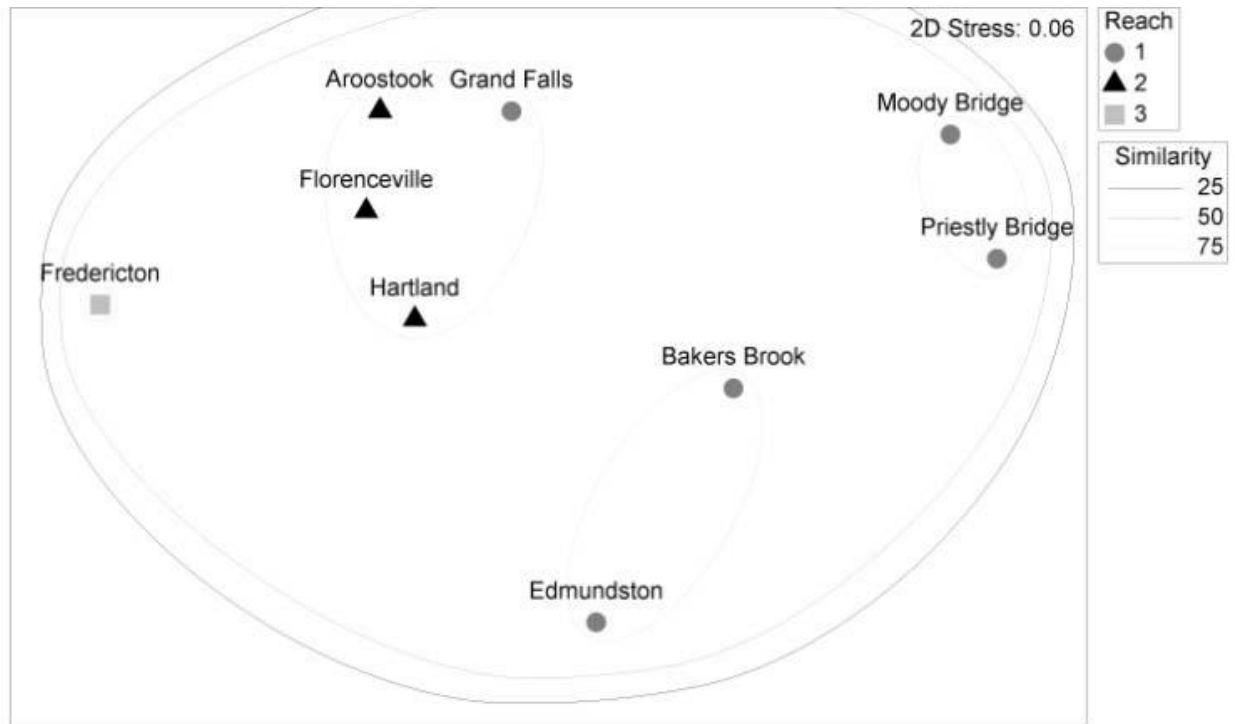


Figure 5.8 Grouping of benthic invertebrate communities among sites along the Saint John River in multidimensional space.

downstream area of Reach 1 and at a reservoir was more similar to Reach 2 sites. Fredericton, the only reach 3 site, did not plot close to other sites which may reflect its downstream location and thus the multiple and cumulative potential influences on the benthic community here.

The calculated Hilsenhoff Index values indicated good-excellent status regarding organic pollution among all the river sites (**Figure 5.9**). The most organic pollution according to this index would be located at Edmundston and Hartland. These findings are consistent with the water quality at these sites as discussed in Chapter 6, but again the benthic invertebrate data is sparse and further sampling among sites and over time is warranted.

5.6 Conclusion

Summary of findings

We cannot go back in time to assess the potential changes in the physical habitat that began at the turn of the last century with the construction of the many dams along the Saint John River. We are forced to speculate based on our knowledge from other rivers about the habitat changes and their associated alteration of the ecosystem when dams are built and rivers become reservoirs. Based on this understanding of change and the biological data we have in hand (see also Chapters 6, 7, and 8), there is evidence that our altering of the habitat has changed the ecosystem along the middle reaches of the main stem of the Saint John River.

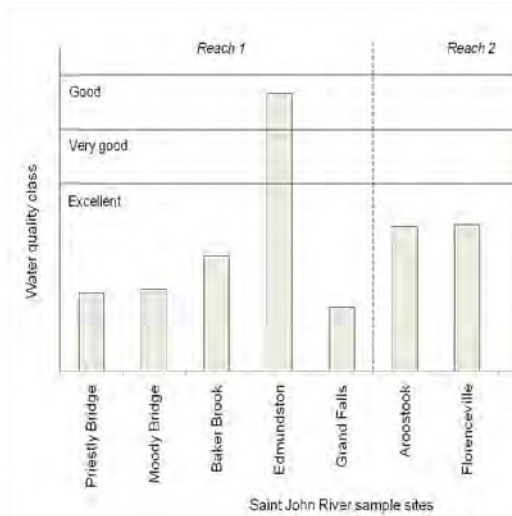


Figure 5.9 Hilsenhoff Index results for sites along the Saint John River. The results are expressed in terms of the water quality class thresholds as they are defined by Hilsenhoff (1987).

- The frequency and magnitude of large floods in the Upper and Lower Reaches of the Saint John River increased in the post-Mactaquac Dam period. This most probably reflects changes in the basin’s climate (see Chapter 10).
- In the Lower Reach, there was an attenuation of low flow events following construction of the Tobique/Beechwood Dams (1955-1957). No similar attenuation was observed following construction of the Mactaquac Dam.
- Construction of the Mactaquac Dam did not substantively change water levels in the Lower Reach; however, both Beechwood and Mactaquac Dams have highly regulated daily fluctuations that are not discernible in the analysis used herein.
- Creation of reservoirs behind hydroelectric dams has resulted in river level gradients that are an order of

magnitude less than the adjacent, free-flowing river sections (most pronounced in the Mactaquac headpond which extends 100km upriver). This change favours warmwater species adapted to lake-environments as well as promoting the range extension of invasive, non-native species.

- Summer, cool water plumes were identified at the mouths of three tributaries entering the main stem in Reach 2. Historic, coldwater refugia afforded by the Green and Tobique rivers are no longer apparent in these rivers where flows are highly regulated.
- There are >200 dams located in the tributaries of the Saint John River. Each represents a barrier to upstream fish passage and a change in the river environment (river to reservoir, temperatures, etc.).
- Main channel islands are most common in Reach 2. Average size of islands is highest in the lower river reaches where they contribute 186 km of additional shoreline habitat.
- Impounded reaches have few islands. Submerged islands may still provide some structure representing habitat.
- The discrimination among river reaches based on the benthic macroinvertebrate community structure was consistent with the known state of habitats and water quality along the river.

Data gaps, quality concerns, and future considerations

The best habitat data, i.e., spatial and temporal coverage, is the federal hydrologic records of flow (discharge) and water depth at several locations along the river. The

record is long in a few places and such data will continue to be useful. The more recent sites that have been added will be useful if they are each sustained for more than 10 years.

Continuous water temperature data are sorely lacking for the watershed. These data combined with the hydrometric station data will be invaluable in the future for assessing possible changes in the river ecosystem, especially in light of predicted water temperature increases related to global warming trends.

Water level results from the most downstream site, Oak Point, were discarded because of a changed datum in the mid 1960s. It is important for future analyses of hydrologic regimes that the historic data for Oak Point be verified so that comparisons can be made with the Lower reaches of the Saint John River (downstream of Fredericton).

Benthic macroinvertebrate community data samples are the most commonly used tool in biomonitoring to assess river health. Canada lags behind other countries in the application of this approach, and clearly this is reflected here. Future monitoring should be linked to the hydrometric and temperature data, including long term monitoring of these sites for benthos. Similarly, the benthos monitoring should include some of the key tributaries, e.g., some at or near pristine conditions and some with known human impacts.

Conclusion

The habitat analyses highlight the poorer state of the Saint John River ecosystem in its middle reaches, from the Edmundston

area to Fredericton. From a habitat perspective the problem is the dams, reservoirs, and flow management

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6. Water Quality

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6.1 Introduction

Why is water quality assessed?

The quality of water in a river is affected by natural processes and human activities. Many different physical, chemical, and biological measurements can be used to determine the river's status and whether it is getting worse or better over time. We can assess water quality against a set of criteria that were developed for the many uses of water. The water quality standards are different if the water is used for drinking, recreation, watering livestock, or supporting the life within the river. These standards are set by governments and are defined by science (our existing knowledge) to be protective of the people or wildlife using the water.

Water quality and the Saint John River Basin

Water quality can change from one location to another in the Saint John River (SJR) because of the varied geology and climate across the basin (Cunjak and Newbury 2005) and the many human activities at different sites in the watershed (e.g., Curry and Munkittrick 2005). These activities include forestry operations and agriculture (Gray et al. 2005), dams and their reservoirs (Culp et al. 2008), and the discharge of



municipal sewage and industrial effluents (e.g., Galloway et al. 2003; Luiker et al. 2009). There are close to 200 municipal and non-municipal wastewater discharges, 19 aquaculture/fish hatcheries, 21 food processing plants, and 15 pulp and paper or sawmills in the Saint John River Basin (see **Figure 3.2**). These activities input sediment, nutrients, metals, chemicals, bacteria, and oxygen-consuming wastes into the river. The result can be a reduction in the river's ability to support fish and other aquatic life or to be used for drinking water or recreation.

Indicators used to assess water quality

The river's water quality is best assessed against a set of standards or benchmarks. The Canadian Council of Ministers of the Environment (CCME) has developed a set of guidelines to protect human health (drinking water or recreational use) and aquatic life (**Table 6.1**). We compared water quality measurements from the river to the CCME guidelines to examine the historical and current status of the river. Our intent was to understand if the quality of the water in the Saint John River has improved

over time and where problems may currently exist. Using recent and historic records, we examined trends in water quality indicators regularly measured over the past five decades, those being:

- pH
- dissolved oxygen
- metals - aluminum, iron, manganese, copper, zinc
- bacteria

Many more parameters have been measured in the river over time. Phosphorus and nitrogen are reported in Chapter 7 Primary Production. Other parameters were either similar to those we are reporting (e.g., calcium) or too infrequently sampled to use for any analyses (e.g., selenium).

Table 6.1 Water quality guidelines for various uses (Health Canada 2010; CCME 1998, 2007).

Use	Variable	Guideline
Drinking Water Source*	pH	6.5 – 8.5
	Dissolved oxygen	Not applicable
	Aluminum	0.1 mg/L
	Iron	0.3 mg/L
	<i>Escherichia coli</i> (bacteria)	0 per 100 mL
Recreation	pH	5.0 to 9.0
	<i>Escherichia coli</i>	200 per 100 mL
Protection of Aquatic Life	pH	> 6.5 and < 9.0
	Dissolved oxygen	6.5 to 9.5 mg/L
	Aluminum	0.005 mg/L at pH < 6.5 0.1 mg/L at pH ≥ 6.5
	Iron	0.3 mg/L

*These values are from the *Guidelines for Canadian Drinking Water Quality* and apply to finished (treated) drinking water and not to the original source of the drinking water (i.e., surface waters). Values for pH, aluminum, iron and manganese are targets to meet good aesthetic quality (taste, odour, colour) or for operational considerations during drinking water treatment.

pH (acidity)

The acidity of water is reported as pH. This indicates the concentration of hydrogen ions on a logarithmic scale (i.e., a change of one pH unit = a ten-fold change in the concentration). The pH scale ranges from 0 (very acidic) to 14 (very alkaline). Natural

rain and snow have a pH 5.7 and most unpolluted rivers have a pH that ranges from pH 6 to 9, depending on the pH of the precipitation and the local geology. When pH goes below 6.5 or above 9.0, many types of fish and other aquatic organisms cannot survive. The pH also changes the toxicity of some metals in water. For example,

aluminum becomes more toxic to aquatic life at a lower pH (**Table 6.1**).

A river's pH at one location is generally similar over time. If it changes, this typically means that some major geological event occurred or that human activities have altered water quality. For example, acid precipitation (either as rain or snow) caused by metal smelting, coal burning, and vehicle emissions can lower the pH of river waters. Runoff from metal mining sites and urban areas as well as industrial wastes can also increase or decrease a river's pH.

Dissolved oxygen

Animals need oxygen to survive. Oxygen is dissolved in water but is less abundant and available than in the atmosphere. The level of dissolved oxygen (DO) is affected by the temperature, depth, and flow of the water, as well as the number of creatures consuming the oxygen. DO in surface waters can range from 0 to 18 mg/L. To survive and grow, most water breathing organisms living in the Saint John River need DO levels above 5.5 mg/L for warm water species (e.g., yellow perch) and above 6.5 mg/L for cold water species (e.g., brook trout). Early life stages of some organisms require DO levels above 9.5 mg/L to survive.

Oxygen levels vary naturally along a river as it is captured from the atmosphere by rapids or riffles, produced by aquatic plants, and used by all aquatic life. Humans alter DO when they change natural flow regimes, e.g., building dams and reservoirs, and introduce wastes, particularly organic matter that consumes oxygen during decomposition (e.g., sewage).

Metals

Metals occur naturally in water from the weathering of rocks and soils. Some metals such as iron, copper, and zinc are needed in small amounts by living organisms, but too much can be toxic to them. Metal levels in water depend on local geology, however human activities can dramatically alter both the type and concentration of metals in rivers. Humans increase metal concentrations in water through runoff or discharges from rock processing (e.g., metal mining), industries, and municipalities.

In this report we examined metals with the most complete records for the Saint John River. These and other metals occur naturally in the bedrock in the Saint John River basin (NB Department of the Environment 2008). Data exist for other metals that are of concern for human and wildlife health, e.g. mercury and selenium, but the information is very limited or not available for recent years. For more information on mercury in NB surface waters and wildlife, reports are available from NB Environment, Environment Canada, and the Canadian Rivers Institute (e.g., Dennis et al. 2005; Barry and Curry 1999). Other metals of concern for aquatic life such as cadmium and arsenic are not discussed because levels in the Saint John River are almost always below the NB Environment's laboratory's ability to measure them.

Coliform bacteria

Coliform bacteria are a group of very common bacteria found in soil, water, and the digestive tracts of animals. Fecal coliforms are a specific group of bacteria found only in the digestive system of warm-blooded animals, i.e., humans, farm animals, deer, other mammals, and birds.

The presence of fecal coliforms in water indicates that it has been contaminated by human and/or animal waste. *Escherichia coli* or *E. coli* is the major type of fecal coliform bacteria. The common forms of these bacteria are not harmful, but they co-exist with other disease-causing bacteria or viruses that are dangerous to human health.

The Water Quality Index of the SJR

The Water Quality Index (WQI) was developed by the CCME to provide a broad overview of the environmental performance of surface waters (www.ccme.ca/ourwork/water.html). The index takes information on how often and by how much the CCME guidelines for each measurement is exceeded (“failed tests”) and combines it into a single value. The WQI is an attempt to simplify large amounts of data into something more meaningful for the public. However, it cannot replace detailed analyses of water chemistry and biological measures of performance, e.g., biodiversity. The WQI always ranges from 0 to 100 with four rankings: excellent (95-100; waters very close to natural quality); good (80-94); fair (65-79); marginal (45-64); and poor (0-44; waters almost always threatened or impaired).

The WQI has been used in water quality reporting by NB Department of Environment (www.gnb.ca/0009/0371/0013/index-e.asp). We calculated WQIs for each decade using the available data for aluminum, copper, iron, lead, manganese, zinc, dissolved oxygen, and pH. For a few sites and decades only dissolved oxygen could be included in the calculations and, in a few cases, no useable data existed. The WQI values we report are the averages

among sites within each decade.

Sources of data

There are many individual sites across the basin in NB and Maine for which water quality data exist. The most consistent data are for 15 sites on the main stem of the river and, thus, these were used in our analyses (**Figure 6.1**). The farthest upstream site we used was Clair, NB. Upstream of Clair into and across northern Maine there are very few people, no industries, and no evidence of major water quality issues or changes over time.

The first extensive water quality survey was conducted by the Department of National Health and Welfare Canada in 1959-60 associated with the construction of the dam at Beechwood, NB (1957). The second period of intensive monitoring began with the formation of the Saint John River Basin Board when the Mactaquac Dam and hydroelectric facility opened (1968). A water quality monitoring program was established under the United States-Canada Committee on Water Quality in the Saint John River and there was a special sampling program of 23 stations in the main stem and tributaries from 1970-79. All of this pre-1980 sampling was irregular across the basin and over time. Data since 1980 were collected by the NB Department of the Environment (NBENV) as part of their regular water quality monitoring programmes.

In recent years, they typically sampled sites 1 to 4 times per year, but not every site was visited each year. The historic and current data can be accessed from NBENV databases, Envirodat (Environment Canada), and various CRI reports (cited herein). We

assumed that all data in the government records had been checked for quality. In total, 9204 water quality records were used in this report.

Sample collection and processing

It is not known how the Saint John River was sampled before 1980 but we assumed that the methods met national standards because samples were collected by or for the federal government. Since 1980, water samples were collected by NBENV trained

staff mainly at moving water sites reachable from the shoreline or from bridges. Subsurface (~30 cm deep) grab samples were collected and put on ice until delivered to the provincial laboratory (Marysville, NB). The laboratory follows well-established protocols and is certified by the Canadian Association for Laboratory Accreditation, Inc. Dissolved oxygen is measured on site at the same time using a routinely calibrated YSI 55A with the probe ~30 cm below the surface in moving water. Bacteria samples were measured as total

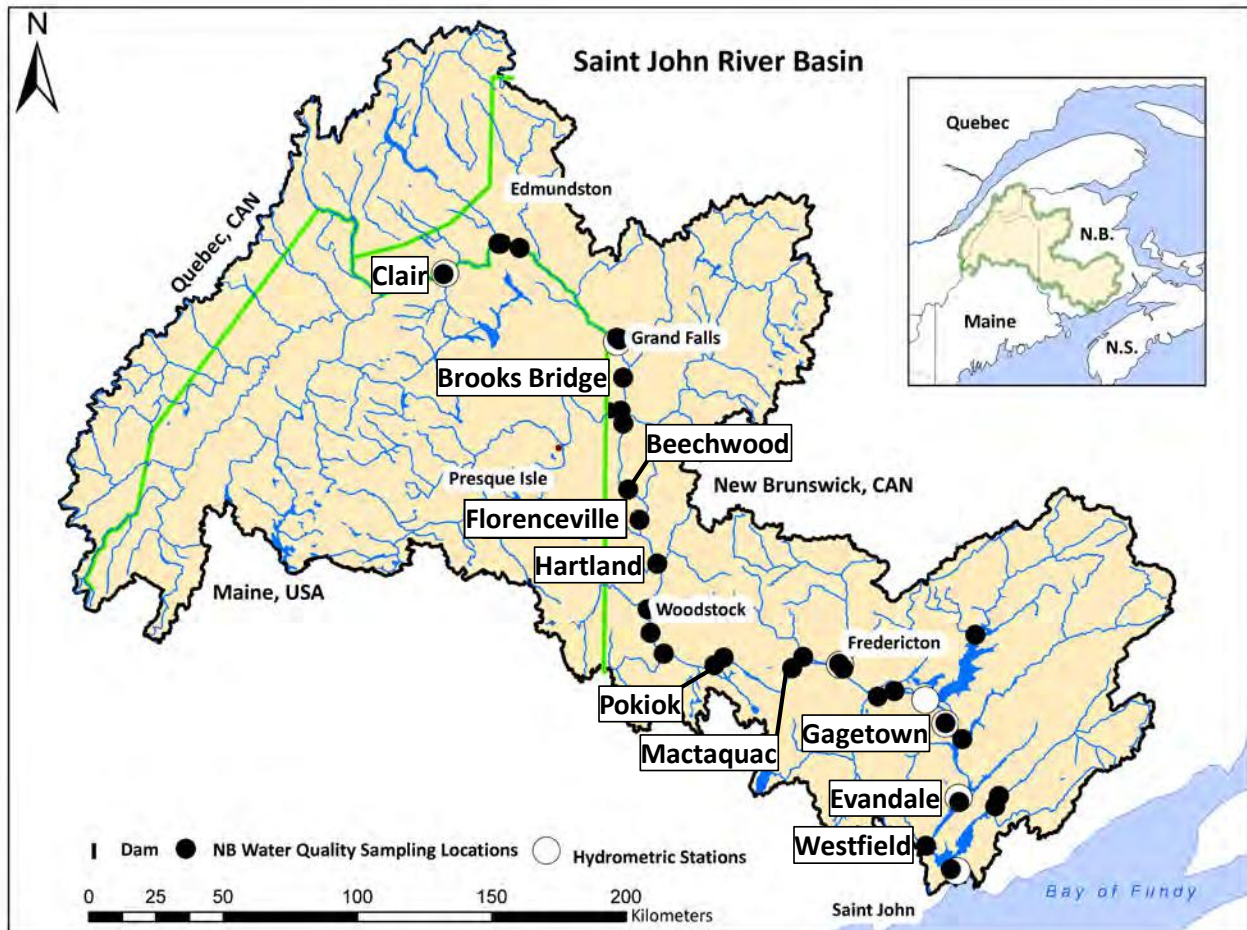


Figure 6.1 Location of the sites where water quality was measured along the main stem of the Saint John River from 1959 to 2008. The sampling stations are identified as the associated towns and cities, and by sample site names as discussed in the text.

coliforms in the 1960s (the source of data and laboratory are uncertain). In the 1970s and 1980s, fecal coliforms were analyzed by the New Brunswick Department of Health (Dr. Everett Chalmers Hospital; C. Dilworth, pers. comm.). By the 1990s, the NBENV was analysing bacteria in its laboratory as *E. coli* using Defined Substrate Technology (Idexx) which assesses the enzyme activity of the bacteria. The bacteria data are the most difficult to interpret because the methods have changed over time and measurements of bacteria are not as reliable or precise as, for example, analyses of water for major ions.

6.2 pH

The pH of the main stem of the Saint John River is slightly alkaline, averaging 7.2 to 8.1 (**Figure 6.2**). There are few differences in pH along the river or over time, but it is generally lowest upstream in Reach 1 and before the 1980s when precipitation in our region was more acidic (Evers et al. 2007). In general, pH levels will increase as water moves downstream in a river. Over time and sites, pH in the Saint John River was mainly above the minimum CCME guidelines. However, 168 of 2266 samples were below the guidelines and the average of these values was 6.2. At this time there are generally no concerns related to pH levels in the main stem of the Saint John River.

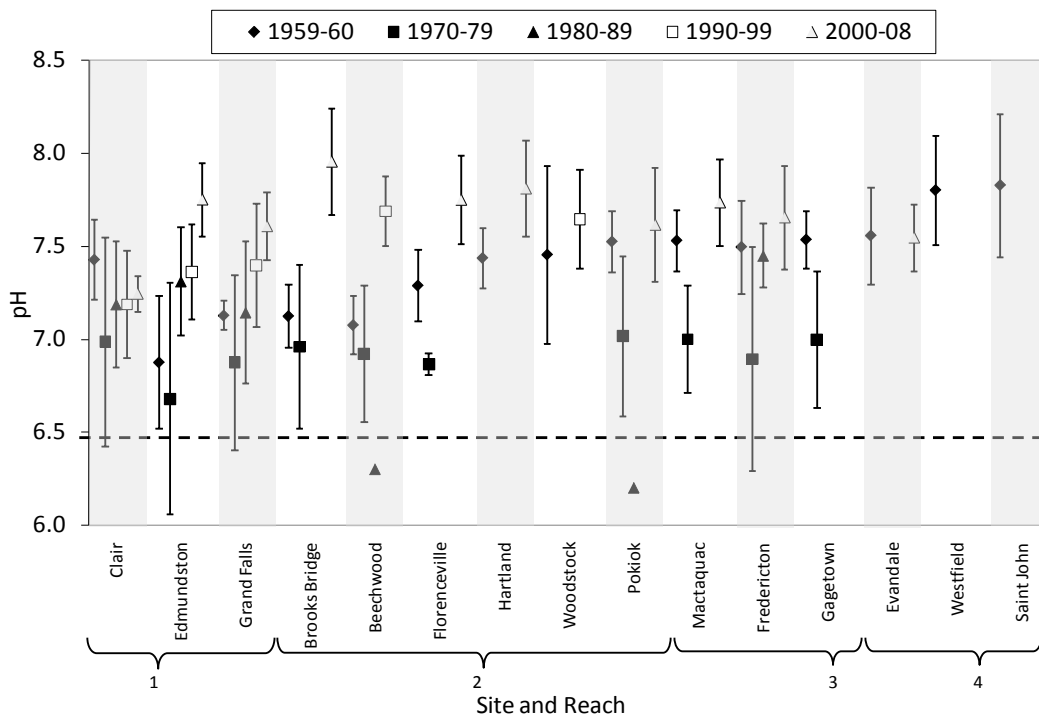


Figure 6.2 The pH along the main stem of the Saint John River from 1959 to 2008. Values are the average \pm 1 standard deviation. The dashed line is the minimum levels for the protection of aquatic life based on CCME guidelines (2007).

6.3 Dissolved Oxygen

It was the low DO concentrations reported from Edmundston to Fredericton in the 1950s that sparked the first public concerns about poor water quality in the Saint John River. The problems existed because untreated industrial and municipal wastewaters were being discharged into the river (Sprague 1964). The Department of National Health and Welfare Canada reported in 1961, “that conditions, resulting from pollution in the international reach of the river between Edmundston and Grand Falls, represent gross pollution. The effects of chemical pollution in this section produced average values of dissolved oxygen below the objective of 5 ppm [Ed. note: equivalent to mg/L] and minimums of 0.0 ppm which resulted in fish kills which were observed and recorded. Sewage contributed to the river, creates grossly polluted conditions below each major centre of population. A physical and chemical pollution problem existed on the east side of the river at Florenceville due to waste discharges from a food-processing plant” (Dept. of National Health 1961: 3).

The low DO levels are apparent in the earlier data from the 1950s and 1970s (**Figure 6.4**). Improvements in waste management at industrial facilities and municipal wastewater treatment have led to the marked improvement in DO concentrations along the river, particularly from Edmundston to Woodstock. Only once since 1980 was DO below 6.5 mg/L (5.1 mg/L, Grand Falls, 1990). Since 2000, concentrations along the river have averaged 8.5 to 11 mg/L, well above the CCME guidelines for aquatic life.



Figure 6.3 Low river flow exposing the riverbed downstream of Florenceville. River levels varied 1-2 m during a 24 hr period (Culp et al. 2007).

Although this trend is positive, there are low oxygen issues along the river today and these are mostly related to point sources of wastewater discharged into the river. For example, oxygen levels are regularly lowered because of oxygen-consuming wastes discharged at Edmundston, where pulp mill effluents and sewage are released, and at Florenceville, where wastewaters are concentrated by flow reductions from hydroelectric operations (Culp et al. 2008; Luiker et al. 2009). There are additional anecdotal reports of low dissolved oxygen events along the river, e.g., during shutdowns of municipal sewage treatment plants in Woodstock and Edmundston. Doherty et al. (2011) suggested that the fish kill reported downstream of Hartland in spring 2003 was from low oxygen caused by the biological oxygen demand from sewage and food processing wastes and compounded by low water levels in the river under ice. The DO guidelines for young fish and other animals is 9.5 mg/L and the

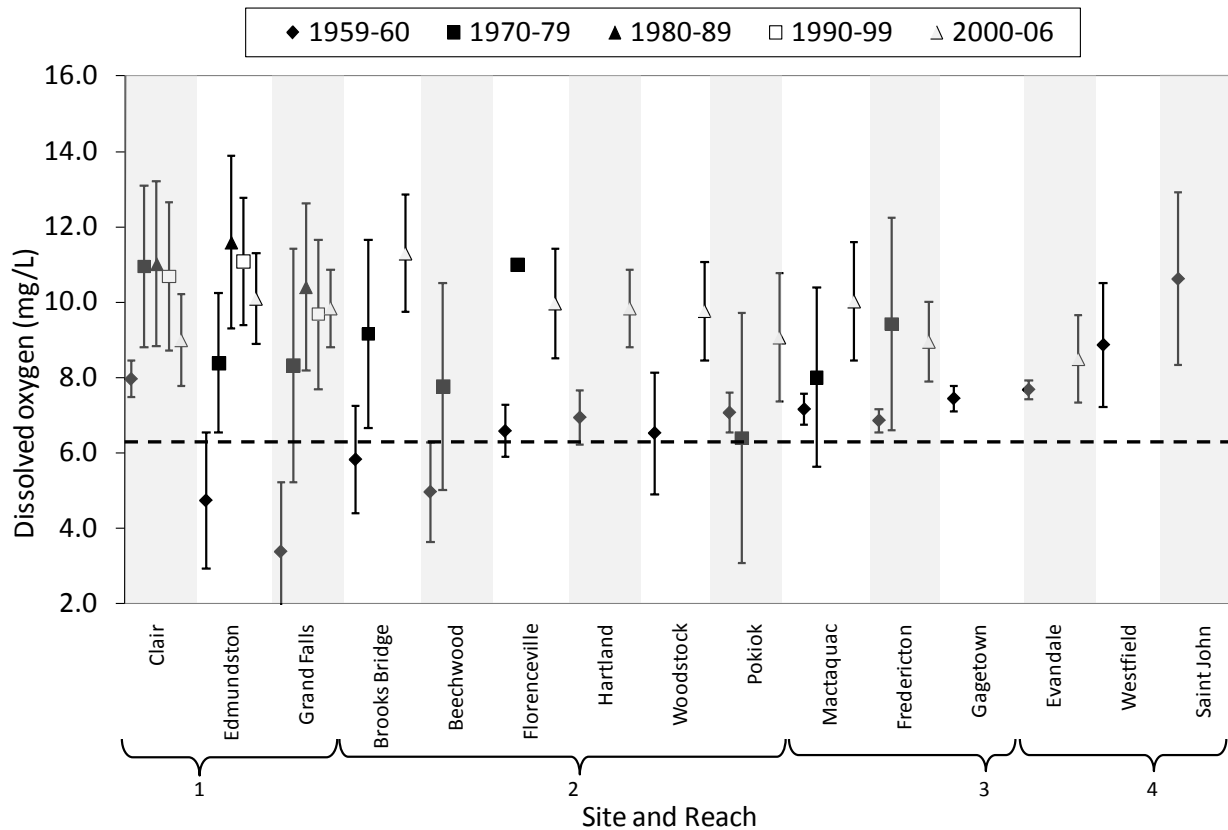


Figure 6.4 Dissolved oxygen levels along the main stem of the Saint John River from 1959 to 2008. Values are average \pm 1 standard deviation. The dashed line is the minimum level for the protection of coldwater animals based on CCME guidelines (2007).

Saint John River is often below this level (47% for all sites since 2000, but note that only 87 DO measures exist for the entire river since 2000).

Another oxygen issue in the Saint John River is related to water temperature. When river temperatures rise, oxygen levels drop. River water becomes warmer when reservoirs are created by dams. In the Saint John River downstream of the Beechwood Dam, river levels in summer can vary by 1-2 m and water temperatures can vary as much as 7°C in a day compared to 1°C upstream of all the main stem dams (Culp et al. 2008; see **Figure 6.3**). Cold- and cool-water fish in the river are most likely stressed by the

warmer, low oxygen waters, conditions which also promote survival and expansion of non-native fish (see Chapter 8 Fishes), and this temperature-oxygen problem will increase as our climate continues to warm (e.g., Monk and Curry 2009).

6.4 Metals

6.4.1 Aluminum

Aluminum concentrations were not measured in the river until the 1980s. The average levels were consistent along the river over time and from upstream to downstream sites (**Figure 6.5**). The highest level of aluminum was 0.714 mg/L at Beechwood in the spring of 1993. The guideline’s maximum level for treated drinking water (0.1 mg/L) was exceeded in 194 of 1155 samples (17% of all samples in all years), most often at Beechwood,

Woodstock, Pokiok, and Fredericton (32 to 38% of samples). Aluminum levels in recent years (2000-2008) sometimes exceeded the CCME guideline (0.1 mg/L for pH > 6.5) to protect aquatic life. This occurred in all seasons (18-19% of samples at each site), which suggests that recent levels of aluminum are due to the geology of the Saint John River (NBENV 2008) rather than to human activities. The high levels at some locations and times may be due to the timing of sampling because sediments washed into the river during heavy rains can increase aluminum concentrations.

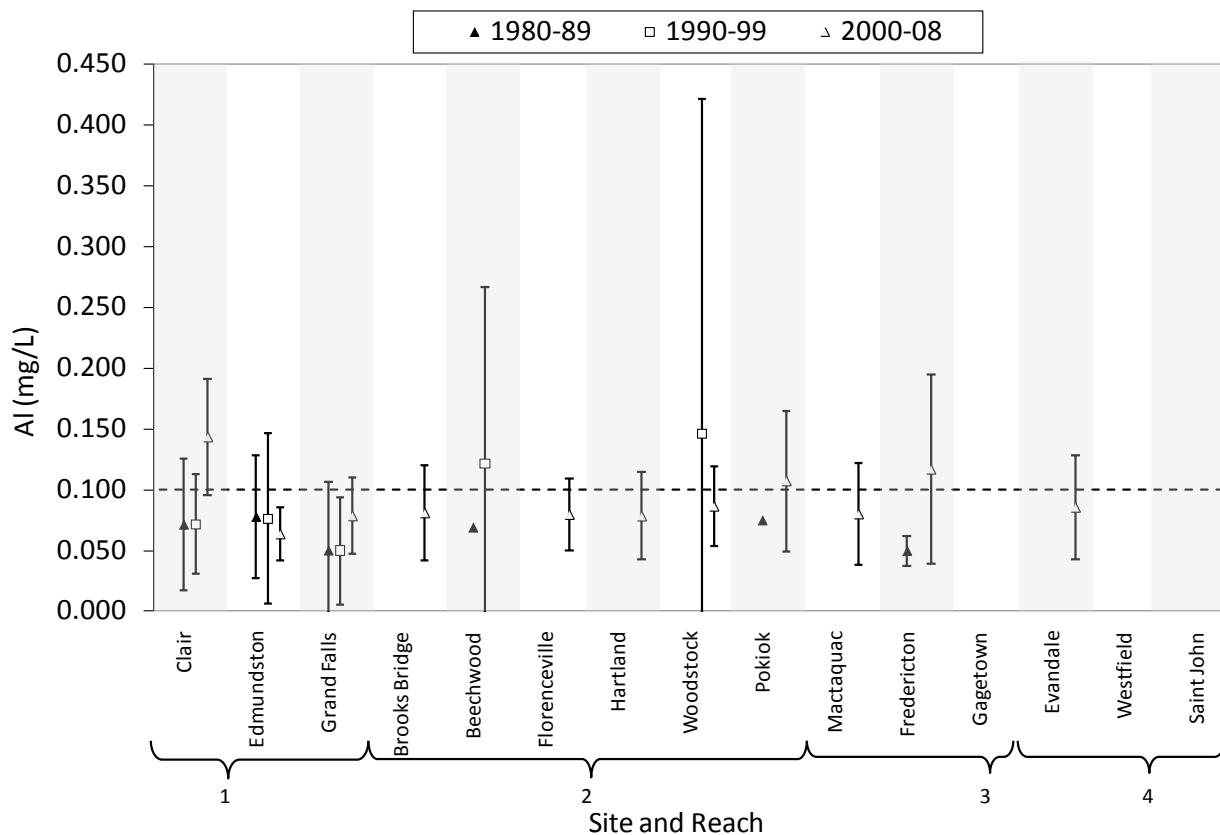


Figure 6.5 Total aluminum levels along the main stem of the Saint John River from 1980 to 2008. Values are the average \pm 1 standard deviation. The dashed line represents both the aesthetics objective for treated drinking water (Health Canada 2010) and the guideline for the protection of aquatic life at pH > 6.5 (CCME 2007).

6.4.2 Iron

Iron levels were generally consistent and below CCME guidelines for finished drinking water and for protecting aquatic life (**Figure 6.6**). The levels measured are normal for the geology of the region (NBENV 2008).

Most sites had occasional levels higher than the guideline, but recently <5% have exceeded this value.

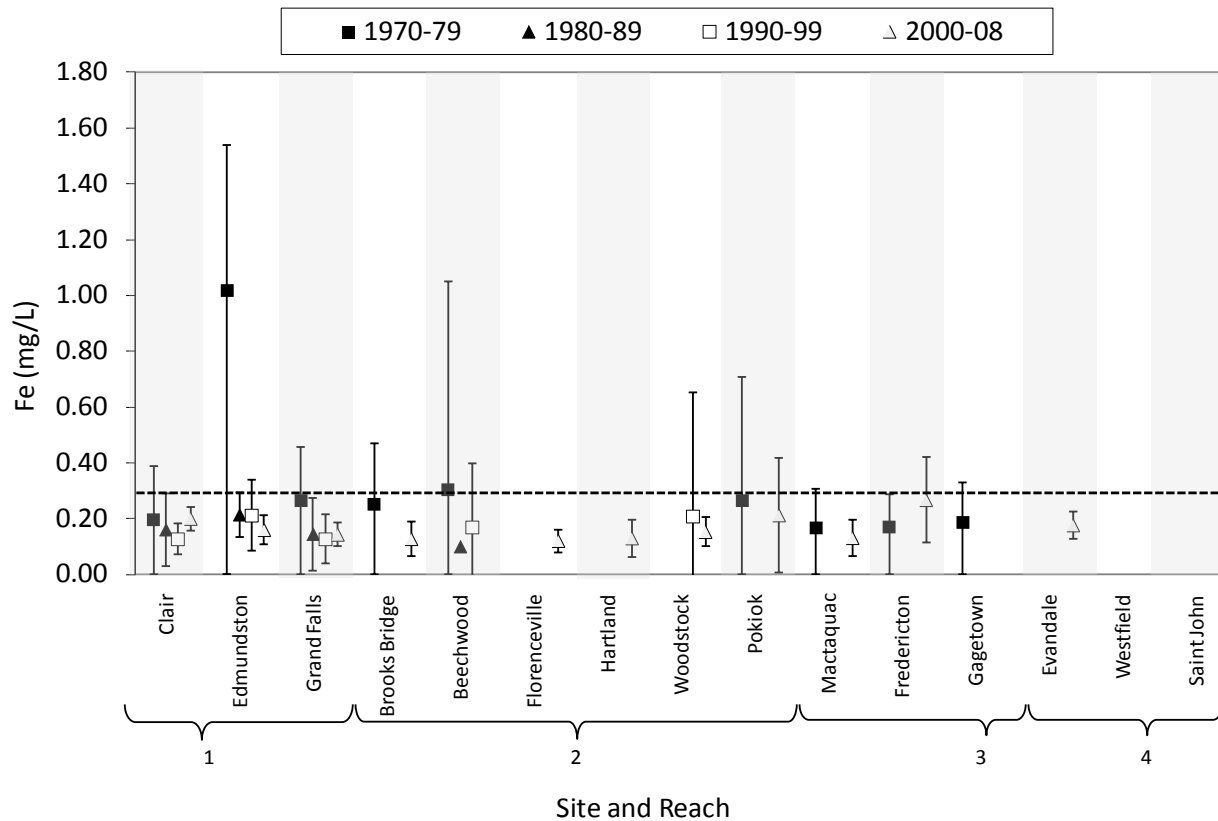


Figure 6.6 Iron levels along the main stem of the Saint John River from 1970 to 2008. Values are the average \pm 1 standard deviation. The dashed line represents both the aesthetics objective for finished drinking water (Health Canada 2010), and the guideline for the protection of aquatic life (CCME 2007).

6.4.3 Other metals

Current manganese levels in the river are normal for the geology of the region (NBENV 2008) and lower than what was measured in previous decades. Some high levels occurred in the 1970s at most of the sites, especially at Edmundston,

Beechwood, and Pokiok; 76, 29, and 21% of samples at these sites exceeded the guidelines for treated drinking water, respectively. It is unknown why some sites in the Saint John River had high manganese levels in the 1970s. In the recent samples, all sites but Edmundston had values well below the guideline for treated drinking

water. No manganese guideline exists for the protection of aquatic life.

Copper levels were measured in the river in the 1970s through 2000s but the best longer term information is available for Reaches 1 and 2. Most of the recent measurements of copper are lower than the historic data, especially at Clair, Grand Falls, and Brooks Bridge where levels were much higher in the 1970s through 1990s. Most of the samples since 2000 are below the CCME guideline for the protection of aquatic life (2 µg/L). Exceedences occurred in just 1 or 2 samples from each site (<9%).

As reported for copper, most of the historical data for zinc is from the upper sites of the Saint John River. In the 1970s, zinc concentrations were higher in Reach 1 and at Grand Falls and Brooks Bridge than at all the other sites. Since 2000, zinc levels were similar throughout the basin and well below Health Canada's guideline for treated drinking water (5.0 mg/L). The CCME guideline for the protection of aquatic life is lower at 0.03 mg/L and was exceeded between 3 to 12% of the time at most sites since 2000. Occasionally, zinc levels were up to 4 times higher than the 0.03 mg/L guideline in spring and fall samples, but this may be the result of more sediments in the river during those seasons.

Recent data for other metals in the Saint John River indicate that levels of nickel, arsenic, and lead were typically below the CCME guidelines for the protection of aquatic life. Lead concentrations exceeded the guidelines (derived using site-specific CaCO₃ data) in 2 of 25 samples at Queensbury and in 2 of 7 samples at Clair since 2000. The levels of these metals appear to be normal for the river.

6.5 Coliform Bacteria

Very high levels of bacteria were found in the late 1950s and 1960s, likely because of the discharge of untreated wastewaters into the river from Edmundston to Fredericton (e.g., Sprague 1964; **Figure 6.7**). More recent measurements have been lower, but bacteria counts are typically highest in Reach 1 and decline downstream. The higher counts in Reach 1 are due to the high concentration of waste inputs from Clair to the Edmundston area. Bacteria counts are presumed to be close to zero upstream of Fort Kent, ME, because there is not much human activity there. In Reach 2, the highest levels were typically recorded at Florenceville and Hartland. In Reach 3, Oromocto and Fredericton recorded the highest bacteria counts. These four locations are the major urban and food processing areas along the river. The lower levels in Reach 4 most likely reflect a dilution phenomenon because of the larger volumes of water downstream.

Of the 1846 samples along the Saint John River from 1960 to 2010, only four samples had a zero bacteria count. For the most recent and accurate data since 2000, bacteria counts in samples were <10 MPN/100mL in 27% of Reach 1, 48% of Reach 2, 50% of Reach 3, and 60% of Reach 4 samples. Measures >200 MPN/100mL occurred 48% of the time in Reach 1 and <20% of the time in the other reaches.

The ongoing detection of *E. coli* bacteria along the entire main stem is a concern. There is a zero tolerance for bacteria in all drinking water in Canada and water for recreational use should be below 200 MPN/100mL. There are a variety of natural

sources of bacteria, e.g., wildlife such as beavers, but the high bacteria counts reported along the Saint John River are located close to populated areas where wastewaters are discharged to the river. We suspect that there are many areas of the river where bacteria counts are insignificant, i.e., upstream of towns or animal concentrations (e.g., livestock farming). Regardless, the presence of bacteria in surface water is a human health risk. Bacteria counts in the Saint John River could be reduced by improving how we

manage and treat the waste we discharge to the river. Before swimming in the river, it is highly recommended to contact the NB Department of Health for information on local water quality.

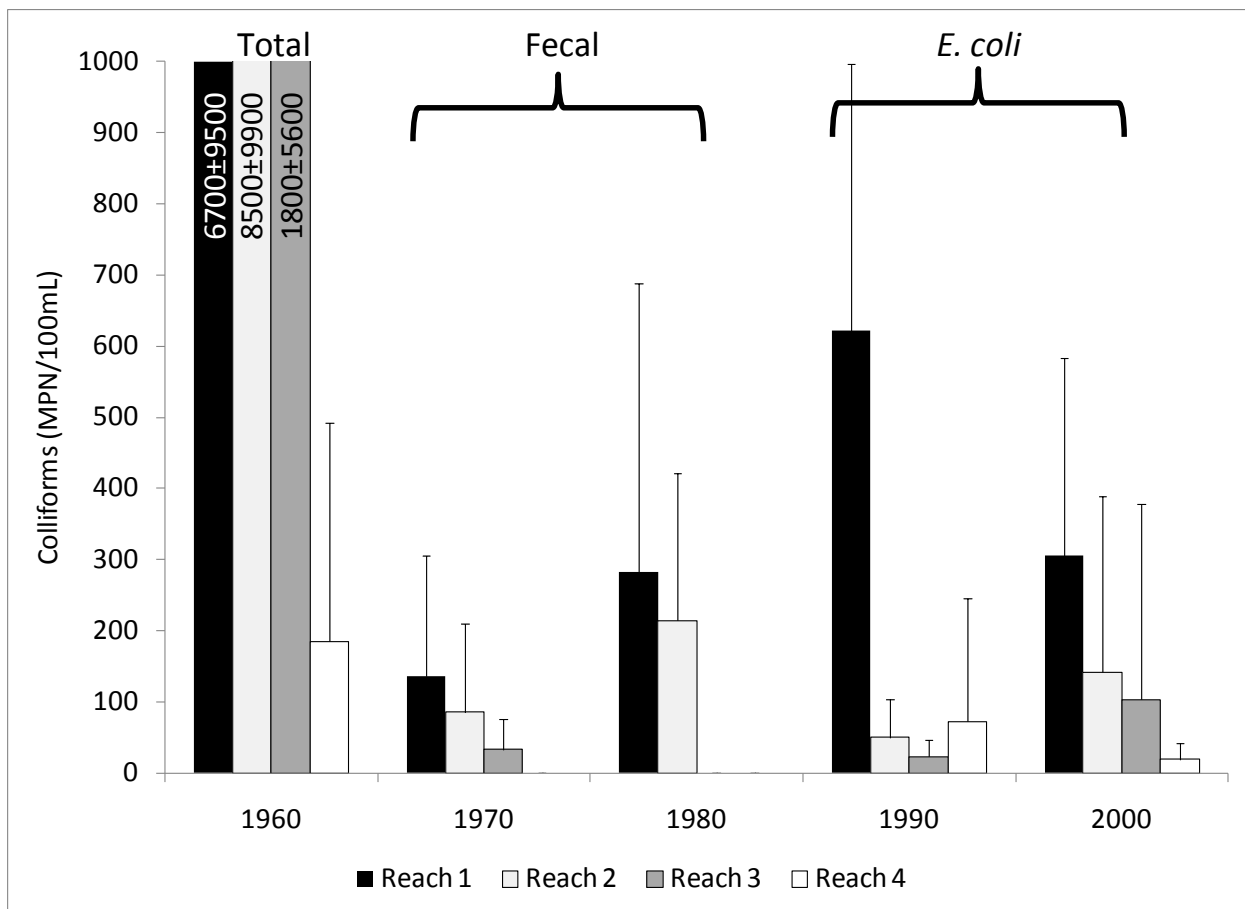


Figure 6.7 Measures of total coliform, fecal coliform, or *Escherichia coli* (*E. coli*) bacteria along the main stem of the Saint John River from 1959 to 2008. Values are the average \pm 1 standard deviation. The CCME guidelines (2007) are zero for drinking water and 200 MPN/100mL for recreational use (CCME 1998).

6.6 The Water Quality Index

Based on the parameters we could use to calculate WQIs (aluminum, copper, iron, lead, manganese, zinc, dissolved oxygen, and pH; **Figure 6.8**), the drinking water quality in the Saint John River would be generally classified as fair, which the CCME WQI describes as “usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.” Reach 1 (upstream of Grand Falls) had consistently lower WQIs than the other reaches. WQIs were higher and more stable for all four reaches since 2000. Similar patterns were observed for the WQIs for aquatic life, although the WQIs were lower than for drinking water. This occurs because the aquatic life standards for metals and dissolved oxygen, two parameters used in our WQI, are lower than those for drinking water.

When considering WQIs, it is important to remember that they are based on the limited measurements and sites of our data set. It would be difficult to make firm conclusions based on the WQIs only.

6.7 Conclusion

Summary of water quality along the river and over time

Water quality along the Saint John River varies among the reaches and has changed over time. Generally, water was of poorer quality in the 1960s but it has improved in recent years, especially since 2000. The improvement since the 1960s is most likely the result of more and better treatment of

municipal and industrial wastewaters (see also Chapter 7 Primary Production). The poorest water quality typically occurs from Edmundston to Pokiok and probably reflects the high level of human activity and multiple, point sources of wastewater discharged along this stretch of the river. The first direct discharges of wastewater to the river occur upstream of Edmundston along the south shore at Fort Kent, ME (municipal wastewater, upgraded in 1997), and along the north shore at Saint-Francois-De-Madawaska, NB (municipal wastewater, upgraded in 2004). From here to Pokiok, NB, the river receives effluent from pulp and paper processing (3 facilities), food processing (5 major facilities: 4 potato, 1 poultry), and municipal waste (at least 20 facilities; see **Figure 3.2**) discharges. There are also inputs from agriculture (sediments, agro-chemicals, animal wastes) in this portion of the river basin, mainly from potato farming (New Brunswick is Canada’s third largest producer). In addition, water quality is impacted by the major dams and reservoirs (their headponds) on the main stem (Grand Falls, Beechwood, and Mactaquac) and on the two principle tributaries in this reach (Aroostook and Tobique). The reservoirs have changed the natural flow regime and dams are operated to generate hydro-electricity with minimal environmental flows management or regulations. Water quality is in a better state downstream of Fredericton because there is less industry and agriculture, no major dams, and more water flowing into the river (from upstream, Grand Lake, Washademoak Lake, Belleisle Bay, and the Kennebecasis Bay) to lower (dilute) chemical and bacterial levels.

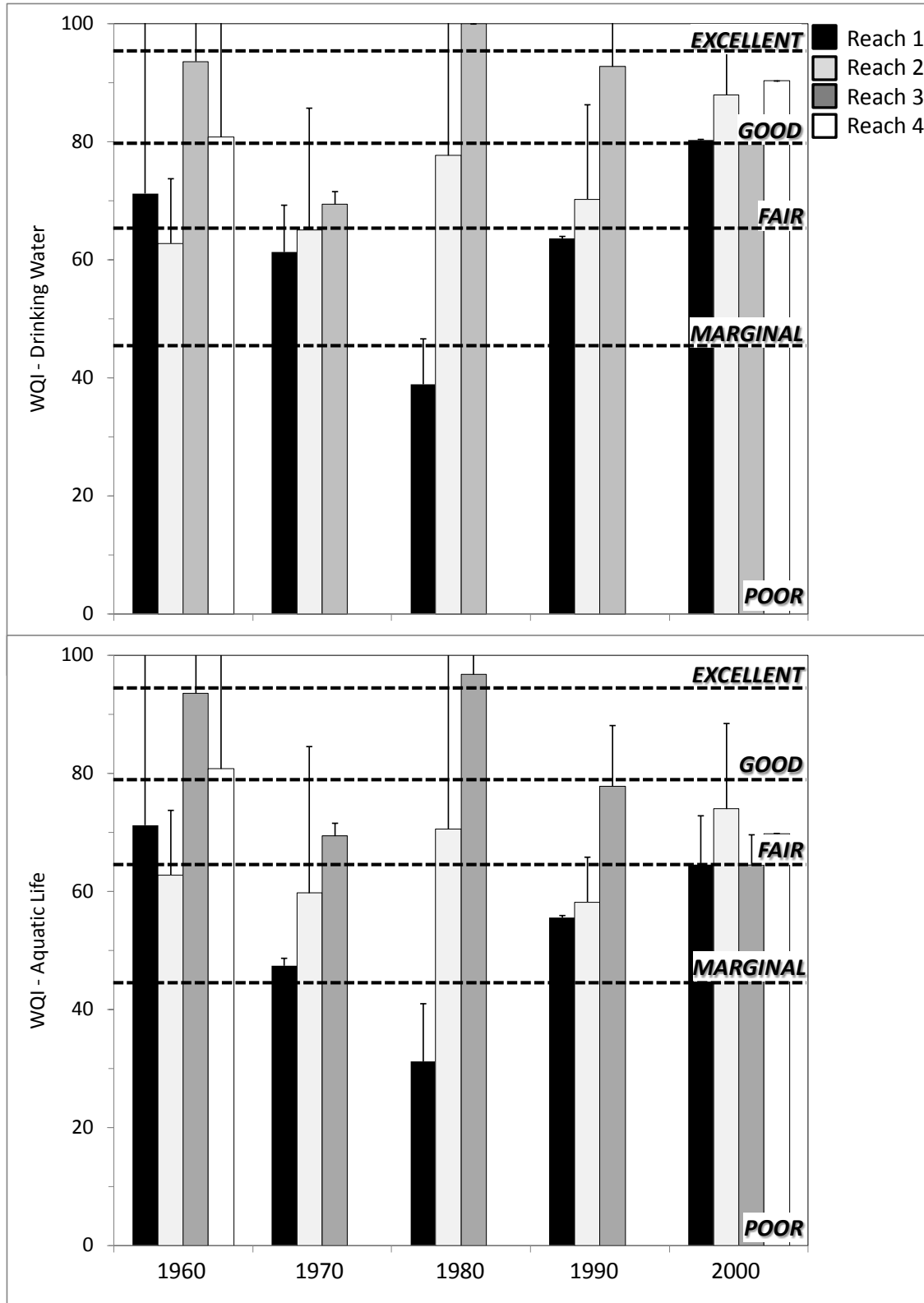


Figure 6.8 Water Quality Index (WQI) for drinking water and aquatic life for the Saint John River from 1960 to 2008. Values are averages \pm 1 standard deviation. See the Methods section for a description of the calculations.

Areas of concern

There has been an improvement in the water quality of the Saint John River since the first serious concerns were raised in the 1950s and 1960s. This is the result of improved enforcement of pollution regulations by government and better wastewater treatment by municipalities and industries along the river. However, a number of areas of concern for humans and wildlife remain.

The locations that are still a concern are areas receiving discharges of minimally-treated wastewaters to the river, areas with many different discharges because of their cumulative impacts, and areas where river flows are managed. Edmundston and downstream into the Grand Falls reservoir have poorer water quality because of the intensity of industrial, municipal, and animal waste (farming and food processing) entering the river in addition to the reservoir effect. The Florenceville to Woodstock reach has poorer water quality because of the organic waste discharged from three food processors and numerous municipal sewage treatment facilities. These impacts on water quality are compounded by the Beechwood Dam which can significantly lower water levels downstream and thus concentrate pollutants, warm the river in summer, and reduce the oxygen available for aquatic life.

The next critical next steps are to: 1) better understand how all of the human activities are impacting water quality along the river, i.e., the cumulative effects; 2) link and make the connection between water chemistry and biota, i.e., what is the health of whole ecosystem; 3) reassess our collective values and align them with current and future uses

of the river, i.e., how important are sustaining ecological integrity, and the needs for drinking water supplies, recreational uses, and hydro-electricity generation; 4) implement and enforce all regulations, operating orders, and policies; and 4) develop and maintain an appropriate monitoring programme that will allow us to achieve our collective goals for the river's water quality and overall ecosystem health.

Data gaps and future needs

The New Brunswick Government collects and maintains records of water quality for the Canadian portion of the river. The State of Maine has selected sites in the northern portion of the watershed and more in the Aroostook and Meduxnekeag river watersheds (<http://www.maine.gov/dep/blwq/>). The CRI has many question-specific studies along the river that produce information about the health of the river. All this information is invaluable for understanding how our activities are affecting the water quality in the river and determining if it is becoming more or less healthy over time. These data are similarly critical for understanding current threats to the health of humans or aquatic life.

Unfortunately, while we can use the available information to assess the river's current state and some changes over time, our understanding is limited. Much of the river has not been sampled and sites with more than a few years of records are rare. There are areas of concern in the river, but our understanding of how often water quality is poor and how far downstream impacts extend is limited. We also do not know whether the elevated levels of some metals or lower levels of oxygen are affecting aquatic life and thus it is critical to

link water chemistry measurements with assessments of the organisms that live in the same location. Chemical monitoring of more sites over longer periods of time paired with biological assessments will provide a much better picture of the river's health and will be critical for the long-term, sustainable management of this socioeconomically important international waterway.

Acknowledgments

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7. PRIMARY PRODUCTION

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7.1 Introduction

Primary production in the Saint John River

The Saint John River and its watershed have a long history of natural resource use which has resulted in on-going discharge of wastewater effluent to the river and runoff water from non-point sources connected to human activities such as urban development, agriculture and forestry. These varied effluent sources can modify the nutrient status of the river and play a critical role in increasing the primary productivity of its ecosystem. Primary production is the conversion of sunlight to the energy that drives an ecosystem, e.g., the work of algae and plants. The rate of total production is controlled by nutrients and in particular, nitrogen and phosphorous.

Excessive nutrient additions can lead to changes in water quality that can affect both ecosystem and human health. In addition, the Saint John River has been fragmented by dams and their associated reservoirs. These reservoirs change the flow regime of the river and have a wide range of effects on primary productivity, including slowing nutrient transport downstream, increasing water temperature, creating



nutrient sinks (held in storage), and changing habitats and production of algae.

Nutrients as an indicator of primary productivity and river health

The indicators of primary production that are assessed in this chapter are:

- Total nitrogen (TN)
- Total phosphorus (TP)
(N and P are measures of limits to primary production)
- Chlorophyll a (chl *a*)
(a pigment found in plants and algae and used to indirectly measure primary production)

Primary production is the production of organic matter from inorganic carbon,

principally through the process of photosynthesis. Photosynthesizing organisms (primarily algae in aquatic ecosystems) are responsible for primary production and form the base of the food chain.

The primary producers are living organisms that grow, multiply, and photosynthesize so they require sunlight, water, carbon dioxide and some key nutrients (Dodds 2002). When nutrients are added to a river ecosystem, e.g., disposal of organic waste into a river, primary production increases and when there is excessive nutrient additions, algae flourish or “bloom”. This is the process of “eutrophication”. Eutrophic conditions producing algal blooms can also lead to algal dieoffs creating large amounts of decaying material which then generate anoxic conditions affecting the biotic community, e.g., changing species diversity and abundance. Wastewater from human activities is often rich in nutrients, e.g., industrial and municipal sewage effluents, as well as runoff from agriculture, forestry, mining, and urban areas.

Two of the limiting and therefore key nutrients in river ecosystems are nitrogen and phosphorus. Nitrogen is an essential element for amino acids, proteins, and chlorophyll. Phosphorus is an element of the ATP molecule that is the key energy molecule in photosynthesis.

Nitrogen and phosphorus were chosen as our indicators of primary production because they are well studied in rivers, and are correlated with chlorophyll measures, e.g., nitrogen and phosphorus can best explain abundance of algal biomass in rivers and streams (Dodds et al. 1997).

To assess nutrient status within the Saint John River we:

1. *Developed and evaluated nutrient criteria for the Saint John River (normal levels for TN, TP, and chl a).*
2. *Assessed the current and historical nutrient status of the river using our proposed criteria.*
3. *Based on our assessment, identified areas of concern on the Saint John River.*

7.2 Methods

Determination of historical Saint John River nutrient status (< 1960)

Prior to 1960, there was no information on Saint John River water chemistry, effluent characterization, or amount of wastewater being discharged to the river. Therefore, the nutrient condition of the river was assessed by a literature review of historical descriptions of activities and events that occurred in the watershed coupled with our contemporary environmental effects knowledge. We used four periods for our assessment, <1650 (dominated by Maliseet habitation, before major settlement of Acadian or Loyalist peoples), 1650-1783 (colonization by Acadians and Loyalists), 1783-1900 (period of land clearing and extensive forest harvesting), and 1900-1960 (industrial expansion).

Synthesis of historical water quality data (1960-1999)

After 1960, when industrial and municipal wastewater or effluent entering the Saint John River became a major environmental concern, monitoring programs and research

studies were conducted by provincial, state and federal governments. Historical status of the river between 1960 and 1999 was based on review of these reports and analysis of existing water quality databases.

Historical water quality data was obtained from Envirodat (Environment Canada), and from the New Brunswick Department of the Environment (NBDOE) databases, and from provincial and federal monitoring reports. Compilation and analysis of historical phosphorous (measured as the total – TP) and nitrogen (total – TN) data from the Saint John River water samples required consolidating data within and between databases to offset temporal, spatial and analytical variability. Historical sampling sites that were adjacent to current monitoring sites were used wherever possible. In some cases, sampling sites had been changed slightly over the years. To increase the number of water quality data points for our analysis, data from these closely located sites were combined. For the determination of median estimates, reported values less than the detection limit were represented at that limit (i.e., < 0.05 mg/L was represented as 0.05 mg/L). Historical data was grouped into two time periods to represent the period before major advances in effluent treatment 1960-1979 and after (1980-1999).

Current assessment of total nitrogen, total phosphorus (2000-present)

For current assessment of the Saint John River, water samples for chemical analysis were collected by NBDE during their routine provincial monitoring program initiated in 2003 and by NWRI (National Water Research Institute, Canadian Rivers Institute) for focused nutrient impact

studies. Water samples were collected in 1 litre bottles that were rinsed with river water three times prior to filling. Samples were kept on ice and delivered within 48 h to the NBDE laboratory in Fredericton, NB. Samples were analyzed for a variety of parameters including trace metals, nutrients and general water chemistry parameters. Of particular interest for this study were nitrogen and phosphorus analysis including: nitrate/nitrite (Method 4500 – cadmium flow injection method), total ammonia (Method 4500), TN (Method 4500-NB) and TP (UV Irradiation, Ascorbic acid method). Analytical techniques are described in Standard Methods for the Examination of Water and Wastewater, 20th Edition (AWWA 1998).

NWRI/CRI conducted more detailed studies from December 2003 to November 2007 expanding to include reference sites in Maine, USA and additional sites on the main channel within identified areas of concern (Culp et al. 2006, 2007, 2008; Luiker et al. 2009). Water was collected in 125 ml Wheaton bottles, with those samples requiring filtration being passed through 0.45 µm filters. Samples were shipped on ice to Environment Canada's, National Laboratory for Environmental Testing (NLET) in Burlington, Ontario. NLET samples were used to obtain lower detection limits for nutrients (TP NLET method 01-1190; SRP NLET method 01-1200; nitrite/nitrate and ammonia NLET methods 01-1181, 01-1182 and 01-1161; total kjeldahl nitrogen NLET method 01-1170), and dissolved inorganic/organic carbon (NLET method 01-1020). NLET methods are described in detail in Environment Canada (1994).

Chlorophyll (Periphyton)

As reported in Culp et al. (2006), chlorophyll pigment was measured as chl *a* collected from the periphyton – the algal community that lives on the substrate of rivers.

Samples were collected from 5-10 cobbles (4-6 cm diameter) in riffle habitat at selected water sampling sites in ≥ 50 cm of water. A scalpel was used to remove the algal biomass from a 9.6 cm² template placed on the upper surface of a rock. Samples were placed in vials and either immediately frozen or held on ice in the dark until frozen within 8 h. In the laboratory each sample was homogenized, filtered through a GF/C filter, and chl *a* concentration (mg/m²) determined by extracting the filter and retained material in an 80°C bath of 90% ethanol for 5 minutes, then measuring fluorescence with a Turner Designs, model 10 series fluorometer.

Derivation and application of Saint John River nutrient criteria

To develop nutrient criteria for the Saint John River, we used a combination of estimated reference condition, empirical observations, and nutrient thresholds from the literature.

The US EPA (Environmental Protection Agency) has developed a “reference-reach” approach for creating regional or watershed specific water quality criteria, including the nutrient parameters of TN and TP (USEPA 2000). Reference reaches are defined as minimally disturbed by humans, and are assumed to provide examples of natural biological integrity of a river system. By identifying these reference reaches, the remainder of the system can be evaluated in terms of nutrient condition (e.g.,

magnitude of difference from reference conditions). When reference reaches are available, the US EPA approach uses the nutrient concentration at the upper 75th percentile in the distribution of all reference samples within the identified region. This concentration then becomes the “ideal” target value for the watershed. If reference reaches are not available in sufficient number, an alternate approach is to use nutrient data from all sites within the watershed and to determine the lower 25th percentile in the distribution of sampling sites.

For the Saint John River, we applied the US EPA reference condition methods for development of nutrient criteria for TN and TP. These reference condition values were compared with EPA’s nutrient criteria parameters that were developed for Ecoregion VIII (Subcoregion 82), which includes nearby watersheds in Maine, USA (USEPA 2001), existing nutrient criteria levels on the Saint John River developed in 1975 (SJRBB 1975) and criteria based on prevention of excessive chl *a* growth (Dodds et al. 1997; Dodds and Welch 2000). The growth criteria define nuisance levels of benthic chlorophyll *a* as mean values which exceed 100 mg/m² or maximum values greater than 200 mg/m². Values less than these critical amounts are considered acceptable in terms of algal biomass, with a value of 50 mg/m² or less being the target (Dodds and Welch 2000). Based on correlation analysis, TN and TP criteria were developed from this chl *a* target concentration.

We applied the derived nutrient criteria to TN and TP concentrations from Saint John River water samples for each designated river reach and represented time period.

Trophic state thresholds identified by Dodds et al. (1998) were used to indicate the current trophic status of the Saint John River. These trophic categories describe the overall level of primary production in a river ecosystem from low production, “oligotrophy”, to high production, “eutrophy”. Levels are based on cumulative frequency distributions of TN, TP and chl *a* data for a large number of temperate, North American rivers. This assessment framework sets the upper threshold for oligotrophic rivers at 0.7 mg/L for TN, 0.025 mg/L for TP, and 20 mg/m² for chl *a*. The upper boundary of mesotrophic rivers is 1.5 mg/L for TN, 0.075 mg/L for TP and 70 mg/m² for chl *a*.

7.3 Results

Proposed nutrient status categories for TN and TP

Reference criteria for TN and TP concentrations in the Saint John River were 0.31 mg/L for TN and 0.008 mg/L for TP which are similar to those calculated for the nearby US EPA Subcoregion 82 in Maine (Table 7.1).

In general for the river, nitrogen is naturally in sufficient quantity for unlimited production of algal biomass (Culp et. al. 2006). In contrast, reference criteria determined for TP (0.008 mg/L) is very low, which is approximately seven times lower than the critical threshold for excessive algal growth of 0.060 mg/L (Dodds and Welch 2000). Culp et al. (2006) demonstrated that indeed, phosphorus limits primary production in the reference

reach portion of the Saint John River. This difference underscores the observation of naturally low TP concentrations for the Saint John River and, considering that nitrogen seldom limits primary production, management objectives likely need to focus initially on phosphorus control. Interestingly, Culp et al. (2006) also revealed that in the Saint John River excessive algal biomass of more than 100 mg/m² can develop below the 0.060 mg/L threshold for of Dodds and Welch (2000). Thus, to prevent excessive algal growth, a more conservative TP threshold such as the Ontario algal growth criteria of 0.030 mg/L TP was recommended for the Saint John River.

After completing those studies, we proposed a graded set of three nutrient status categories: **ideal**, **moderately impaired**, and **concern** (Table 7.1). We envisioned that reaches classified into the “concern” state may require increased monitoring of ecological condition, e.g., nutrient regime, algal biomass, dissolved oxygen regime, benthic invertebrates, and fish. This classification scheme was applied to both historical and current Saint John River nutrient data.

Nutrient conditions pre 1960

Due to a lack of water quality data or information on industrial and municipal effluent loadings prior to 1960, condition of the Saint John River during this period was assessed based on historical descriptions. The following review summarizes historical activities along the Saint John River, and nutrient status of each reach was assessed based on this review.

Table 7.1 The target concentrations for total nitrogen (TN) and total phosphorous (TP) in the Saint John River.

Approach	Total N (mg/L)	Total P (mg/L)
25 th % all streams ¹	0.31	0.008
75 th % all streams ²	0.43	0.008
EPA subcoregion 82 ³	0.34	0.012
Saint John River Basin Board (SJRBB 1975)		0.2 (drinking water guidelines)
SJRBB International Technical Advisory Committee (1980)		0.015 (safe) and 0.1 (acute)
Water Quality Objectives (provincial guidelines)	1 mg/L (AB, SK)	<0.030 (rivers and streams, ON) 0.02 - 0.03 (QC)
Dodds and Welch (2000)	0.47 ⁴	0.06 ⁴

Proposed TN and TP criteria for the Saint John River

	Total N (mg/L)	Total P (mg/L)
Ideal	≤ 0.31	≤ 0.008
Moderately Impaired	0.31 – 0.5	0.008 – 0.030
Concern	> 0.5	> 0.030

¹ Standard EPA analysis, all streams, median of four seasonal 25th % values; ² Standard EPA analysis if reference streams are present in sufficient number; ³ Corresponding 25% values for USA subcoregion 82. ⁴ Nutrient thresholds that maintain mean benthic chlorophyll <50 mg/m².

< 1650 (Pre –European, Maliseet Occupation)

During this period, there was very little human impact on the nutrient condition of the river. All reaches are estimated to have “ideal” nutrient conditions (**Table 7.2**).

1650-1783 (Period of Colonization)

This is the first period where there appears to be some human impact on the nutrient status of the river, however this impact is considered minimal, and all reaches were estimated to have “ideal” nutrient conditions (**Table 7.2**).

1784 – 1900 (Period of land clearing and wood harvesting)

During this period, erosion from land clearing, wood debris from log cutting/ transportation/ sawmill operations as well as human sewage increased nutrient loading to the Saint John River.

Unfortunately, there is no data available to assess the magnitude of effect of these activities on the nutrient condition of the river. However, from similar contemporary scenarios, we would anticipate that increased soil erosion and the release of large quantities of fine organic matter would have significantly increased nutrient loading to some reaches of the river. Therefore, we suggest that the nutrient

Table 7.2 Total nitrogen (TN) and total phosphorous (TP) assessment for the Saint John River by category: I = ideal; M = moderately impaired; and C = concern.

Historical nutrient rating based on descriptive assessments								
Period	Reach 1		Reach 2		Reach 3		Reach 4	
<1650	I		I		I		I	
1650-1783	I		I		I		I	
1783-1900	I/M		I/M		M		M	
1900-1960	I/C		C		C		C	

Recent Status of Total Nitrogen

Period	Reach 1			Reach 2					Reach 3		Reach 4	
	1A	1B	1C	2A	2B	2C	2D	2E	3A	3B		
1960-1979	I	C	C	C	- ¹	C	C	C	C	-	-	-
1980-1999	M	M	M	M	C	C	-	C	M	-	-	-
1999-2008	M	I	M	M	-	-	C	M	M	-	-	-

Recent Status of Total Phosphorus

Period	Reach 1			Reach 2					Reach 3		Reach 4	
	1A	1B	1C	2A	2B	2C	2D	2E	3A	3B		
1960-1979	M	C	M	C	-	M	C	C	M	-	-	-
1980-1999	I	M	M	M	M	M	-	M	M	-	-	-
2000-2008	M	M	M	M	-	-	M	M	M	-	-	-

¹ insufficient data to assign a classification.

conditions on those inhabited reaches of the river increased to the “moderately impaired” category; however, for some sections of the river immediately adjacent to industrial activities, a rating of “concern” may have been appropriate (Table 7.2).

1900-1960 (industrialization)

The reduction of wood harvesting for the ship industry was offset by continued demand for construction lumber and the expansion of pulp and paper mill operations. The first sulphite pulp mill in New Brunswick was opened by Donald Fraser in Edmundston in 1917. This was the beginning of large volume point source

effluent into the Saint John River.

Along with the increase in large scale agricultural activity resulting primarily in increased vegetable production, there has been an increase in the number of food processing facilities located along the river. The first McCains Plant, located in Florenceville opened in 1957. Prior to the 1950s, none of these communities had effluent treatment and raw sewage entered untreated into the Saint John River.

During this period, the Saint John River had an increase in large scale point source effluent releases, primarily from pulp and paper mill activities in Edmundston, NB and

Madawaska, ME, food processing in the Florenceville area and municipal sewage from communities located adjacent to the river. The first signs of severe pollution were documented by Sprague (1964) in the river between Edmundston and Grand Falls and near Florenceville. Downstream of urban centres, water quality was assessed as poor due to the release of untreated sewage. We assessed the majority of the river reaches were assessed at a “concern” level (**Table 7.2**).

Nutrient conditions post 1960

Assessment of the nutrient status from 1960 to present was done using water chemistry data collected for provincial and federal Government departments.

1960-1979

This period is characterized by high concentrations of TN and TP caused by large scale untreated industrial and municipal effluents entering the river. In addition, the construction of the Mactaquac Dam in 1968/69 created significant changes to the water flow regime (affecting nutrient transportation, settling and uptake) for a large portion of the river. These activities created anoxic conditions on many reaches which frequently resulted in fish kills (Dept. of National Health and Welfare Canada 1961). The public, provincial, federal and state governments began to notice the environmental degradation, and thus initiated several monitoring programs.

TN concentrations on the Saint John River for this period were historically the highest, with all but one of the sampled reaches in “concern” category (**Figure 7.1, Table 7.2**). Highest concentrations were in Reach 1B in

the area of Edmundston with its multiple sources of wastewater entering the river (for a complete description of effluent sources and activities in the basin, see Chapter 3 Development in the Saint John River Basin).

TP was at “concern” concentrations at four reaches, and “moderately impaired” at the remaining four reaches (**Figure 7.1, Table 7.2**). Highest concentrations were found in Reaches 1B (Edmundston area), 2A (Grand Falls area), 2D (Florenceville area), and 2E (upstream of the Mactaquac Dam).

1980 – 1999

This period was characterized by reduction of TN and TP at most reaches of the Saint John River. This corresponded with the ongoing studies and recommendations of the work of the Saint John River Basin Board, the wider spread enforcement of the Fish Habitat Protection and Pollution Prevention sections of the *Fisheries Act* (1976), which prohibit “...the deposit of a deleterious substance of any type in water frequented by fish”, sewage treatment facilities were built for most communities along the Saint John River, and effluent treatment was added to many industries along the river.

1980 – 1999

This period was characterized by reduction of TN and TP at most reaches of the Saint John River. This corresponded with the ongoing studies and recommendations of the work of the Saint John River Basin Board, the wider spread enforcement of the Fish Habitat Protection and Pollution Prevention sections of the *Fisheries Act* (1976), which prohibit “...the deposit of a

deleterious substance of any type in water frequented by fish”, sewage treatment facilities were built for most communities along the Saint John River, and effluent treatment was added to many industries along the river.

For TN, all but two reaches showed a reduction from historical conditions (**Figure 7.1, Table 7.2**). Three reaches (down from 7 previously) were at “concern” levels (2B, 2C and 2E), with an increase in reaches at “moderately impaired” levels from zero previously to five. There were still no reaches in the “ideal” category.

Concentrations of TP were lower at all reaches in comparison with the previous time period. There were no reaches at or above “concern” levels, with seven “moderately impaired” reaches and one “ideal” reach. The highest TP concentrations were in the Edmundston and Grand Falls areas of the river.

2000 – Present

Water quality of the Saint John River in the most recent period was on average, about the same as the 1980-1999 periods with respect to TN and TP.

All communities along the river currently have at least primary sewage treatment, with many acquiring secondary treatment. Pulp and paper facilities have been part of the National Environmental Effects Monitoring Program since the late 1990s (see www.ec.gc.ca/eseee-eesm/), and have made improvements to their effluent processing and thus quality of wastewater discharged to the river. The food processing facility in Florenceville has expanded, including a new effluent treatment plant. Despite these many improvements, there have been no increases in the number of “ideal” reaches.

For TN, during this period there was a further reduction of river reaches at the “concern” level (just one, 2D, Florenceville area), and the remaining reaches were at “moderately impaired” (5 reaches) or “ideal” (1 reach) categories. The lowest concentrations for TN were found in reach 1, highest concentrations were found in reach 2D (**Figure 7.1, Table 7.2**).

For TP, all reaches for this period were in at the “moderately impaired” level. Although still at moderately impaired levels, 1B and 2D had the highest concentrations (**Figure 7.1, Table 7.2**).

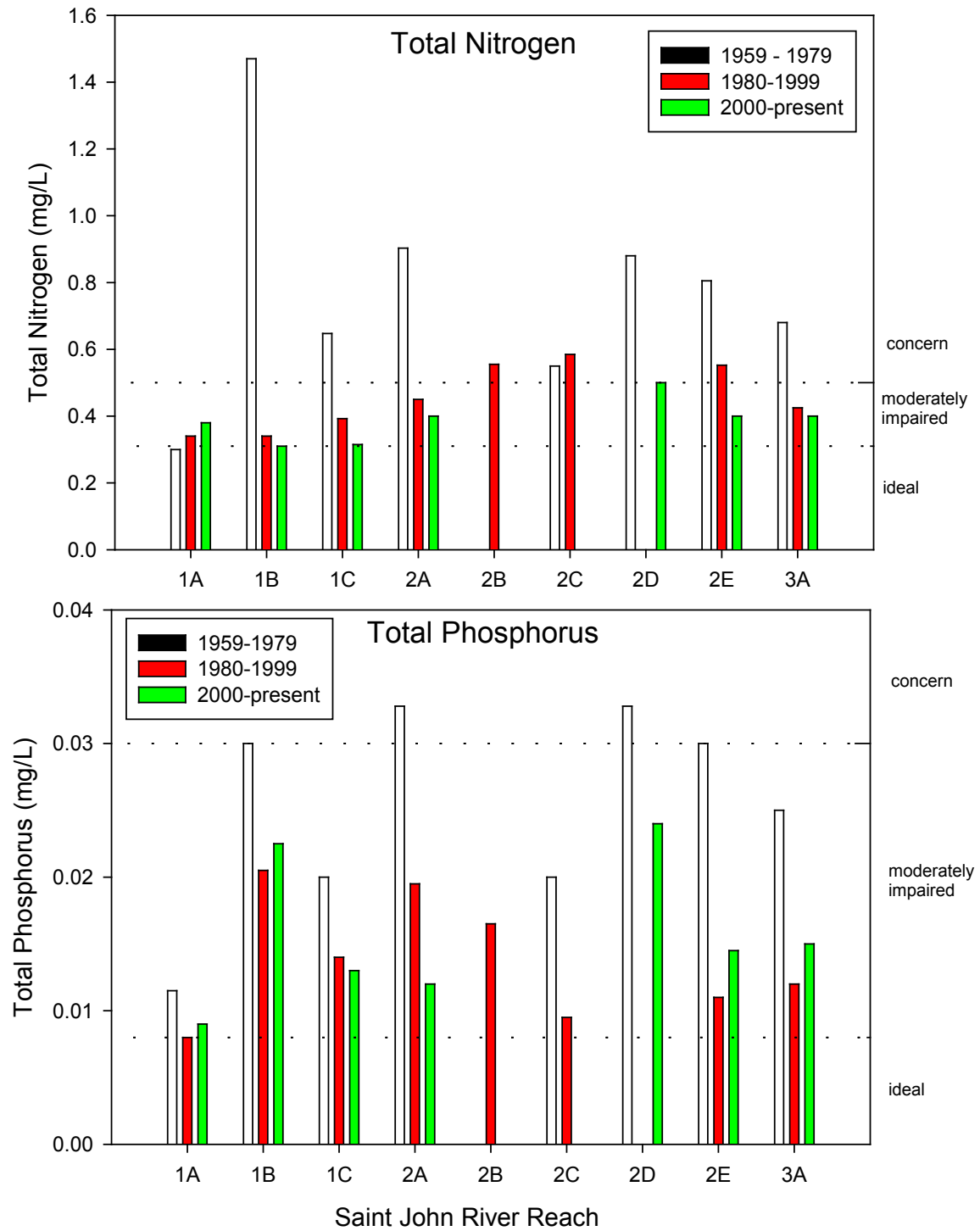


Figure 7.1 Historical and current total nitrogen (TN) and total phosphorous (TP) median concentrations from reaches of the Saint John River compared to proposed nutrient criteria.

Periphyton chlorophyll *a*

The median concentrations of periphyton chl *a* measured from the Saint John River bed were above the accepted target level for algal growth of 50 mg/m² at 15 of 24 sites. (**Figure 7.2**; Culp et al. 2006). Eleven of the 15 sites had median periphyton chl *a* concentrations that indicate nuisance levels of algal growth (nine sites were greater

than 100 mg/m², two sites were greater than 200 mg/m²). Since most of these sites had TP concentrations below the Dodds and Welch (2000) TP criteria, we concluded their TP criteria of 0.060 mg/L is too high to prevent excessive algal growth in the Saint John River. Although there is considerable variability within our data, overall, it reflects the trend in TN and TP concentrations throughout the river.

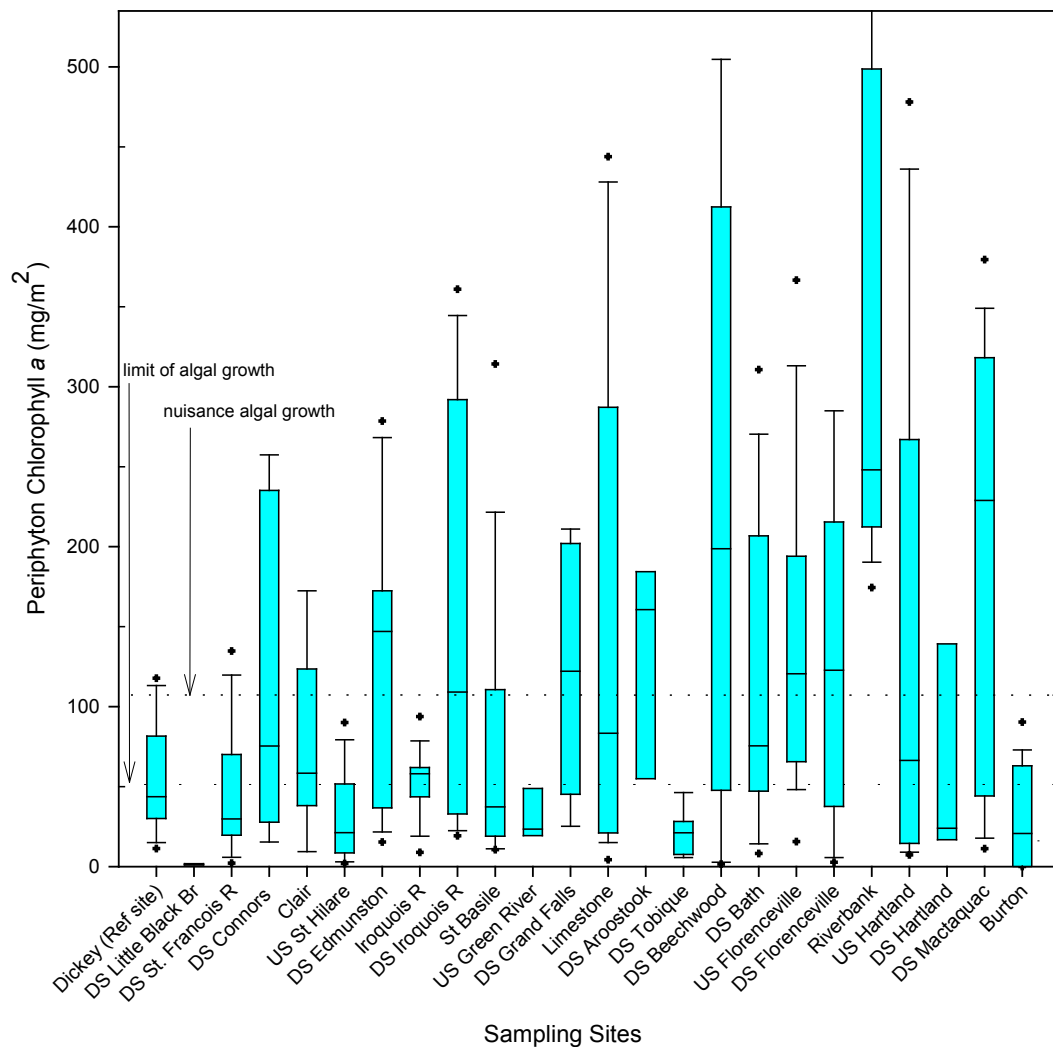


Figure 7.2 Median periphyton chl *a* concentrations Saint John River main channel sites (2003-2005). Box represents middle 50% of data, line through box represents median. Whisker from box represent 25% (lower), and 75% of data, 5th and 95th percentile of data represented by +.

Current status of primary production

Reach 1

The headwaters of the Saint John (upstream of Edmundston, NB) exhibit relatively low concentrations of TN, TP and benthic chl *a*, and are considered to be in an oligotrophic state (**Figure 7.3**). There are very few direct sources of wastewater making this portion of the river a good reference reach to which nutrient conditions in the remainder of the river can be compared. In contrast, downstream of the major effluent sources that begin at Clair, NB and Fort Kent, ME, TN, TP and chl *a* status were at “concern” levels and the trophic state shifted to mesotrophic/eutrophic.

Reach 2

In the reach downstream of Grand Falls, nutrient conditions and trophic state remained mesotrophic/eutrophic (**Figure 7.3**). TN and TP concentrations in the Florenceville area were consistently the highest on the Saint John River. Levels generally exceeded the target values of Dodds and Welch (2000) pushing the river to a eutrophic state on some occasions, i.e., beyond limits that would result in significant biological impairment.

Reach 3

The river section below Mactaquac Dam was classified as mesotrophic largely based on consistently high levels of algal biomass (**Figure 7.3**). No distinct peaks in TP or TN were noted in this stretch of river, but nutrient and algal biomass levels were higher than reservoir values or reference condition criteria for TN and TP.

Reach 4

There was insufficient data to establish a trophic state for the most downstream reach of the river.

7.4 Conclusion

Nutrient (TP, TN) conditions in the Saint John River have improved since the period 1960-1979, with an overall reduction in the number of reaches with concentrations at concern levels: 7 sub-reaches for TN and 4 for TP during 1960-1979 compared to only 1 sub-reach having a TP concern level during 2000-2008.

Currently, the Saint John River is classified in the “moderately impaired” category for TN and TP values along most of its main stem. It changes from an oligotrophic trophic status upstream of the Edmundston area to mesotrophic status along its main stem. Nutrient enrichment historically has been, and currently is greatest in the Edmundston and Florenceville sections of the river.

Areas of concern

Even though water quality based on nutrient levels for much of the river is considered “moderately impaired”, there are two specific areas that were at the “concern” level: Edmundston to St. Basille and Florenceville to Hartland.

Edmundston Reach

The Edmundston reach of the Saint John River is not dammed and receives municipal sewage from eight wastewater treatment

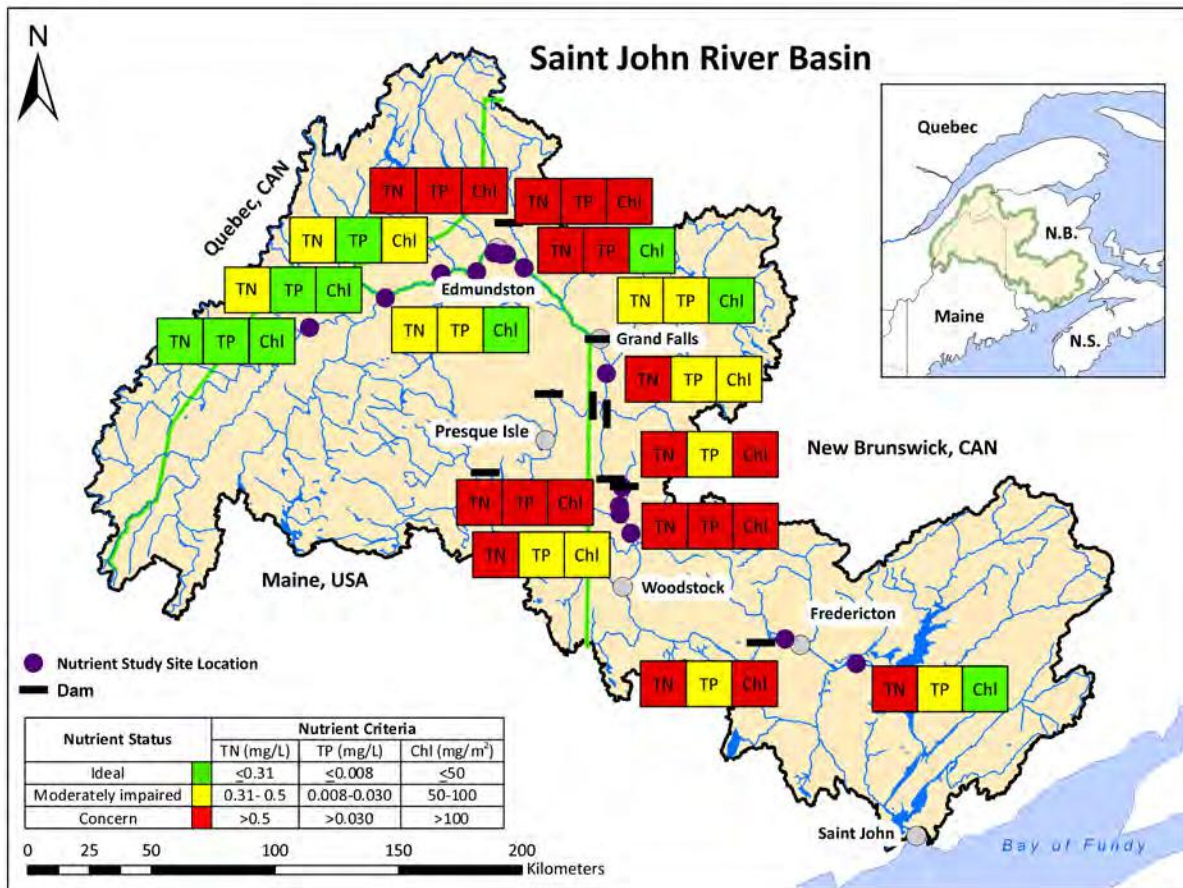


Figure 7.3 Nutrient status of the Saint John River Basin.

plants (maximum discharge ~15,000 m³/day) and two pulp and paper mills (maximum discharge 74,000 m³/day). Upstream at St. Hilaire, nutrient (TN, TP) and algal biomass (chl *a*) levels were low; this section of the river was oligotrophic and algal biomass was limited by phosphorus (Culp et al. 2006). In contrast, downstream of the major effluent sources at St. Basille, the trophic state shifted to mesotrophic/eutrophic, with algal growth most probably unlimited by nutrients during late-summer at least.

Florenceville Reach

The section of the river at Florenceville receives effluent from a food processing plant and municipal sewage with maximum discharges of 12,000 m³/day, and 450 m³/day respectively. In addition, this portion of the river is vigorously regulated by the Beechwood hydroelectric dam which produces most of its electricity during periods of highest demand (i.e., it is a peaking facility). TN and TP concentrations in this reach were consistently the highest on the Saint John River and generally exceeded the target values of Dodds and Welch (2000). Culp et al. (2006) reported

the monthly mean, 24-hour water flow changes at the Beechwood Dam ranged between 32-64% during July-August (2003-2004), with maximum 24-hour water flow changes ranging from 76-91% (NB Power, unpublished data). The recorded large diurnal changes in dissolved oxygen in this section of the river are likely related to the combination of low flow (water in the river) and thus a reduced dilution of effluent entering the river. During periods of reduced flow, large sections of river bottom were dewatered, and chemical conductivity increased by >2.5 times which is consistent with an increase in effluent concentrations as river levels declined.

Challenges and next steps

With respect to nutrient data, the greatest data gaps relate to the lack of a comprehensive monitoring programme for the Saint John River. The historic and current records are intermittent and directed to sample known point-sources (as per regulatory requirements). So, while there has been an improvement in monitoring (more sites and better analytical procedures), the current monitoring lacks broad consideration of issues such as the cumulative effects of multiple inputs (e.g., wastewater) and activities (e.g., dams) along the river and therefore doesn't allow for a complete assessment of the state of the river's environment.

Based on our current incomplete understanding of the nutrient status in the Saint John River, it is recommended that a comprehensive monitoring programme be designed and implemented, one that considers the spatial and temporal characteristics of the river's ecosystem including all human activities and inputs.

Such a programme would require all stakeholders to agree to targets for nutrient levels in the river, the design of an appropriate monitoring programme which may require additional research (e.g., what is the appropriate minimum flow in each season required to protect the river's ecosystem), and regulatory agencies committed to the implementation and sustained long-term monitoring, including reporting, programme.

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8. Fishes of the Saint John River

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8.1 Introduction

Why fishes are assessed

There are 53 species of fish currently found in the Saint John River Basin, ranging in size from the tiny threespine stickleback (<5 cm) to the impressive Atlantic sturgeon which may grow to 3 m over its 50+ years of life (**Table 8.1**; Curry and Gautreau 2010). Other fish like the Atlantic silverside live only a single year. Some are freshwater residents, (e.g., slimy sculpin), and some are diadromous travelling between the river and sea, using the river to reproduce (e.g., Atlantic salmon), or to grow and mature (e.g., American eel). There are an additional 17 species found in the marine waters near the mouth of the river.

Most of the public consider fish to be good indicators of a river's state. Indeed, fish in freshwater ecosystems represent an integration of the system's environmental condition and thus can be sentinels of change in the system. The diversity, distributions, and abundances of species represent key features that reflect the current state of a river's environment. For example, the dramatic decline of Atlantic

salmon in the Saint John River since the 1960s has led people to question the health of this river ecosystem.

We have relatively extensive historical information about fishes in the Saint John River ecosystem because of the federal *Fisheries Act* (1868), written to protect commercial fisheries. This Act commits the federal government (now Fisheries and Oceans Canada - DFO) to undertake examinations of the fish populations when potential impacts are identified, such as the construction of the last major dam at Mactaquac in the late 1960s. The first extensive study was shepherded by the Saint John River Basin Board (SJRBB) (Meth 1973). Surveys of the entire main stem of the river conducted by the Canadian Rivers Institute (CRI) since 2000 provide information on changes over time.

Fishes and the Saint John River ecosystem

The greatest natural diversity of freshwater fish in Maine and Atlantic Canada is found in the Saint John River, downstream of the Mactaquac Dam (Curry 2007; Curry and Gautreau 2010). Fish have always been socially and economically important

components of the culture of the basin (Thomas 2001). Historically, the important species were the diadromous fish (Cunjak and Newbury 2005) which, before any dams were constructed, could ascend the river to Grand Falls. Atlantic salmon (*Salmo salar*) were the core of subsistence, recreational, and commercial fisheries of the Saint John River for Europeans after their arrival, but Aboriginal peoples also harvested the gaspereau, which is both alewife and blueback herring (*Alosa pseudoharengus* and *A. aestivalis*), American shad (*A. sapidissima*), American eel (*Anguilla rostrata*), rainbow smelt (*Osmerus mordax*) and the two sturgeons (*Acipenser oxyrinchus* and *A. brevirostrum*).

Europeans also developed commercial fisheries for most of these species. Fisheries for gaspereau, eel, and sturgeon persist today, but these are now restricted to downstream of the Mactaquac Dam. Recreational fisheries originally focused on Atlantic salmon and to a lesser degree brook trout (*Salvelinus fontinalis*). DFO has invested heavily in management of the Saint John River Atlantic salmon since 1967 at its hatchery located just downriver of the Mactaquac Dam. Built to mitigate the effects of the dam, it was the largest salmon hatchery in the world at the time. Now rebranded as the Mactaquac Biodiversity Centre, it produces ~350,000 salmon for stocking annually (R. Jones, unpublished data), annually captures and transports adult salmon to tributaries upstream, conducts annual juvenile assessments in the salmon-bearing tributaries, and conducts various additional assessment and research projects. Despite this investment, very little information has been collected on the other species in the river or at locations where salmon don't occur. Today, the recreational

fishery for Atlantic salmon is closed and the most sought after species are brook trout (principally fished in the tributaries) and smallmouth bass (*Micropterus dolomieu*; C. Doherty, NB Dept. of Natural Resources, unpublished data). The smallmouth bass is an introduced species, but can now be considered 'naturalized' because they reproduce throughout the river.

Fish as indicators of river health

Measures of fish diversity, abundance, and health (biochemical and physiological measures) are commonly collected as indications of an ecosystem's status or health. Each measure represents different information about the ecosystem. For example, community composition (diversity) may reflect changes that have occurred over months and years, while biochemical indicators reflect more recent changes. Some species are useful as sentinel species (e.g., Doherty et al. 2010). In this review, we examine current and historic data for the indicators:

- *Community*, e.g., diversity and distribution,
- *Populations*, e.g., relative abundance,
- *Sentinel Species*, e.g., survival, growth and reproductive success,
- *Fisheries* (both recreational and commercial), and
- *Invasive Species*.

Community

Fish communities are widely used to assess the status of aquatic ecosystems, and the most common measures or indicators are the numbers of species (richness) and their relative abundance. Species richness can

also be incorporated into several diversity indices that are common in assessments of ecosystem “health” based on the notion that a more diverse community occurs in a healthier ecosystem. Despite the diversity of species in the lower river, the other reaches generally have fewer than 10 common species (Curry and Gautreau 2010), and for most abundances are unknown. We report on the numbers of species and the changes in distributions over time. More information on the Saint John River Basin fish community can be found in other reports (e.g., Curry and Munkittrick 2005; Arens 2007; Casselman 2007; Curry and Gautreau 2010).

Populations

Accurate estimates of fish abundance in a large river system are very challenging and most often only relative abundance can be estimated, e.g., catch per unit effort of sampling (Curry and Munkittrick 2005; Curry et al. 2009). In this report, we use relative abundance which is useful for assessing differences between locations and changes over time. Our estimates are not accurate enough to assess small changes, but the measures do reflect trends in the system.

Sentinel Species

The abilities of a fish to survive, store energy, grow and reproduce are fundamental measures of its health and, by extension, the health of its environment. There are a variety of tools that can measure these physiological endpoints. Changes or differences from reference conditions are used to indicate when a system is stressed, or identify “areas of concern”. Work to develop sentinels for the

Saint John River is an ongoing theme at the CRI.

Fisheries

Commercial and recreational fisheries persist throughout the Saint John River and, consequently, there are a variety of publications and reports available to help us further assess the state of the fish community in the river.

Invasive Species

The fish community can also be significantly impacted by invading, non-native species. Most of the current invasive species issues in New Brunswick fresh waters relate to impacts on important, native fish that support fisheries, e.g., smallmouth bass interactions with Atlantic salmon (Valois et al. 2009; Chaput and Caissie 2009) and muskellunge direct and indirect potential impacts on Atlantic salmon and brook trout (Curry et al. 2007). We will address both the fisheries and fish community issues of invasive species.

Past assessments of fishes in the Saint John River Basin

An assessment of the status of the fishes of the Saint John River was first attempted in the 1960s as New Brunswick prepared to build the last and biggest dam on the main stem at Mactaquac (Meth 1973). The data originated from two sources: historical species records and occurrence data (no standardized sampling); and some collections by Meth (1973) as part of the SJRBB studies during the early 1970s (there was no standardization of sampling which jeopardizes capture efficiency for all species in the river, see Curry et al. 2009).

All the historical records of the fish community, including Meth (1973; **Figure 8.1**), were included in the distributions of fishes presented in Scott and Crossman (1973). All current, known species occurrence records for NB Department of Natural Resources (NB DNR), the State of Maine (including Yoder et al. 2005) and our CRI-based studies were compiled by Curry (2007) and Curry and Gautreau (2010) and are included herein. Our ongoing CRI survey of the main stem follows a standardized method we developed for the Saint John River. The method requires sampling at dusk with seine and gill nets and backpack or boat electrofishing shorelines (Curry and Munkittrick 2005). The main stem has been surveyed from the Maine Northwoods (Moody Bridge) to Fredericton (2000-2003) and downstream to the Reversing Falls at the City of Saint John (2005-2009; **Figure 8.1**). Yoder et al. (2005) sampled the upper reach from Moody Bridge to Edmundston by boat electrofishing (including the Allagash and Aroostook rivers). In addition, information on species distributions has been gathered from over 100 CRI-lead studies throughout the Saint John River Basin.

The river's estuary and harbour were sampled with gillnets (1 hr sets over a 24 hr period - Casselman (2007)) and seine nets in the nearshore areas (Arens 2007; **Figure 8.1**).

DFO began keeping accurate records of some diadromous species returns to the Mactaquac Dam (the numbers of fish captured in their fish trap at the base of the dam) when the dam was completed in the

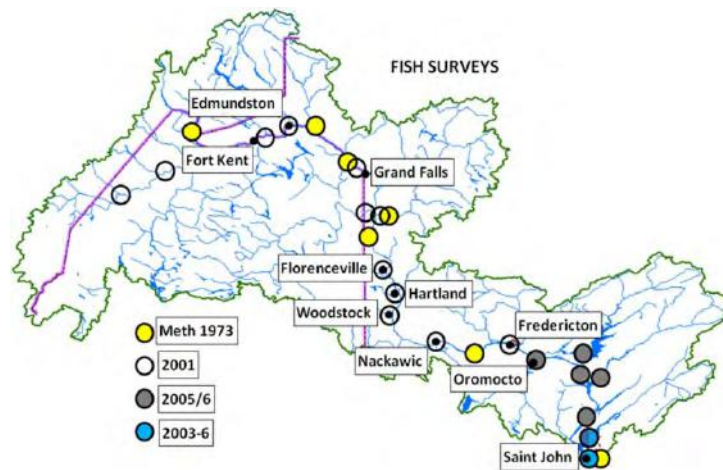


Figure 8.1 Locations of historic and recent sample sites for fish community surveys along the Saint John River.

late 1960s (Atlantic salmon, gaspereau, American eels). These reports are complemented with captures in commercial fisheries for these species as reported in various “stock status reports”. Various efforts lead by DFO and NB DNR have examined relative abundance and fish condition (length and weight) at sites throughout the basin. These are primarily related to Atlantic salmon assessments and occasionally brook trout. Other than species occurrence, these records were not included in the analysis presented here.

8.2 Fish Community

8.2.1 Present status

Fifty-three (53) fish species are reported in the Saint John River Basin (**Table 8.1**). Eleven (11) species are diadromous (some brook, rainbow, and brown trout in the river may also be diadromous). Five (5) species are considered marine species and occur in the river when the high tides of the Bay of Fundy bring them into and trap them in the Kennebecasis Bay, Reach 4A.

Not included in **Table 8.1** are 17 additional species only found in the marine waters.

8.2.2 Comparison with historical communities

Our most complete historical record of fish distributions was Meth's (1973) report for the Saint John River Basin Board. Since that time, there have been species introductions, natural range expansions, and several apparent range reductions (**Table 8.1**). The introductions are most probably human induced. The changes in range of a species can be both natural and/or a reflection of misclassification of species in historical records.

Only one species appears to be new to the Saint John River Basin: the central mudminnow, *Umbra limi*, collected in 2007 downstream of Edmundston (R.A. Curry, unpublished data) and upstream of the Maine border by Yoder et al. (2006). Its origins appear to be the bait fish industry in Maine (M. Gallagher, ME Dept. Inland Fisheries and Wildlife, pers. comm.).

Native species that appear to have changed their range, but most probably occurred and were misclassified in historical records are: (1) the blacknose shiner, *Notropis heterolepis*, that was reported in many locations by Meth (1973), but we have only confirmed the species at Washademoak Lake (Reach 3A) and Yoho Lake (Reach 3B); and (2) the lake chub, *Couesius plumbeus*. The lake chub is common today and easily misclassified as pearl dace (*Margariscus margarita*). Currently, northern red belly dace (*Phoxinus eos*) and finescale dace (*P. neogaeus*) are rare (one red belly dace in the Little River watershed, Reach 2A) or not

found upstream of Reach 2C, and they were rare in the Yoder et al. (2005) survey of Maine waters (just a few samples in the Allagash and Aroostook rivers). Neither of these species is common in larger rivers, preferring still waters. These four species are reported throughout the Saint John River Basin in Maine. In addition, untrained taxonomists often confuse pearl dace, lake chub, red belly dace, and finescale dace and thus interpretation of range changes for these species is difficult.

Interestingly, the greatest changes in range are all expansions by non-native species from both historical and recent introductions. The smallmouth bass, first introduced in the 1800s, is now found from the Kennebecasis River (4B) upstream to the Maine Northwoods (1A). They were introduced by humans upstream into the Tobique River reservoir (date unknown) and recently upstream of Grand Falls (post-2002). They are reported in several CRI and DNR studies and were reported at three stations in Maine by Yoder et al. (2005).

Muskellunge were introduced in a headwater lake in Quebec in the 1970s (Stocek et al. 1999; Curry et al. 2007). This species now appears to be common in the upper basin; we have collected adults at various locations and juveniles in Glazier Lake, and Yoder et al. (2005) reported the species as adults and juveniles in 8 of 13 sites in Maine waters. Adults and sub-adults (individuals greater than 40 cm long) are now regularly caught by anglers downstream to Fredericton and, in 2010, one adult was captured in the Otnabog River (Reach 3B; M. Gautreau, pers. comm.).

Table 8.1 (next page) Fish species and their past and present records of occurrence in the sub-reaches of the Saint John River (see **Figure 2.1**). Yellow lettering is historic records, but not in our current records. Green lettering is current occurrences. Red lettering represents range expansions. (D) are diadromous species, (M) are marine species, and (I) are non-native, introduced species. The listing does not include marine species captured in the river's estuary.

O - Historic records (Meth 1973)

X - CRI's Saint John River Surveys

Y - CRI or DNR studies

Z - Known from tributaries; CRI, DNR, or DFO studies

a - Maine DNR (<http://pearl.maine.edu>)

b - Yoder et al. (2005)

c - rare captures in CRI studies

d - DFO captures at Mactaquac Dam Fishway

Range expansions

¹ these 4 species are often confused

Saint John River: State of the Environment

Common name	1A	1B	2A	2B	2C	2D	2E	3A	3B	4A	4B	4C
3 spine stickleback	aO	XO	ZO	aO	O		O	XO	O	XO		
4 spine stickleback							Y	XO	XO	XO		X
9 spine stickleback	O	XO	O	aO	O	O	O	XO	X	X		X
Alewife (D)				O	O	O	XO	XO	XO	XO	O	X
American eel (D)		O		aO	XO	XO	XO	XO	XO	XO		X
Arctic char	O											
Atlantic menhaden (M)										O	O	
Atlantic salmon (D)	O	O	ZO	O	YO	XO	YO	YO	YO	ZO		Z
Atlantic silverside (M)										O	O	X
Atlantic sturgeon (D)								XO	XO	XO	O	
Atlantic tomcod (D)								YO	O	YO	O	X
Banded killifish	a	XO	O	XO	O	XO	XO	XO	XO	XO	Y	Z
Blacknose dace	XO	XO	ZO	aO	O	O	O	YO	YO	ZO		Z
Blacknose shiner	bO	bO	O	bO	O	O		XO	XO			Z
Blackspotted stickleback												Z
Blueback herring (D)						O	XO	XO	XO	XO	O	X
Brook stickleback												Z
Brook trout	aZO	XO	ZO	ZO	ZO	ZO	ZO	ZOd	ZO	ZO		Z
Brown bullhead	aO	XO	XO	XO	XO	XO	XO	XO	XO	XO		
Brown trout (I)							XO	d				Z
Burbot	XO	YO	O	aO	O	O	O	XO	O	ZO		
Central mudminnow (I)	Y	Y										
Chain pickerel (I)				O	YO	YO	YO	XO	XO	XO		
Common shiner	XO	XO	XO	XO	XO	XO	XO	XO	XO	XO		Z
Creek chub	XO	XO	XO	XO	XO	XO	YO	YO	X	ZO		Z
Fallfish	XO	XO	XO	XO	XO	X	XO	XO	XO			
Fathead minnow	a	O	Z	a		O		O				
Finescale dace ¹	aO	aO		a		O						
Golden shiner	bO	bO	O	bO	XO	XO	XO	XO	XO	XO		Z
Lake chub ¹	X	X	X	a	X	X	X	X	X			
Lake trout	O	O	O	O	ZO							
Lake whitefish	aO	XO	O	O	O	O	O	dO	XO	O	O	
Longnose sucker	XO	XO	XO	XO	O	O	O	O	O	XO		
Mummichog (M)											Y	X
Muskellunge (I)	Y	Y	Y	Y	Y	Y	Y	Y	Y			
Northern redbelly dace ¹	aO	aO	Z	aO	O	XO	YO	O				Z
Pearl dace ¹	aO	aO	O	aO	O	O	YO	O				
Pumpkinseed sunfish				aO	XO	XO	XO	XO	XO	XO		
Rainbow smelt (D)	aO	aO	O	aO	ZO	O	O	YO	YO	XO	X	X
Rainbow trout (I)		X	Z	ZO		ZO		OZ		Z		
Redbreast sunfish				O		O		O	YO	YO		
Round whitefish	aO	YO	O	YO	O							
Sea lamprey (D)			O	O	O	O	O	XO	Z	Z	X	X
Shad (D)				O	O	O	O	dO	O	O	O	
Shortnose sturgeon (D)								XO	XO	XO	O	
Slimy sculpin	XO	XO	ZO	aO	O	O	O	ZO	ZO	ZO		
Smallmouth bass	b	X	X	X	X	XO	XO	XO	XO	XO		
Striped bass (D)				O		O	c	YO	YO	YO	Y	X
White hake (M)										O	O	X
White perch				O	O	XO	XO	XO	XO	XO	X	
White sucker	XO	XO	XO	XO	XO	XO	XO	XO	XO	XO		Z
Yellow perch	aO	XO	XO	XO	XO	XO	XO	XO	XO	XO		Z
Yellowtail flounder (M)										O		
Past	25	27	24	34	31	35	31	39	32	35	10	1
Present	25	26	18	27	16	19	24	36	31	31	6	26

Rainbow trout (*Oncorhynchus mykiss*) are expanding their range. They are believed to have originated as escapees from commercial fish hatcheries in the Woodstock to Florenceville area. Young-of-the-year have been seen in the Salmon River, Whitemarsh Creek, Becaguimec River, Hales Brook, Shikatehawk River, Presque Isle River, Foley Brook, Otter Slide, and Outlet Brook (M. Gautreau, pers. comm.; Smedley 2009). Rainbow trout adults have also been captured at Mactaquac Dam fish trap (Reach 3A; DFO, unpublished data), Nashwaak River (Reach 3A; R.A. Curry, pers. comm.), and the Kennebecasis River (Reach 4A; Curry and Sparks 1997). Captures downstream of the Mactaquac Dam are also believed to be escapees of fish hatcheries.

Splake (brook trout x lake trout hybrid) were introduced and stocked repeatedly in Grand Lake (Reach 3A and B) by NB DNR (Flowers Cove Facility), but stocking stopped around 2003.

A few species appear to have reduced their range. The golden shiner (*Notemigonus crysoleucas*) appeared common upstream of Reach 2B (Aroostook River catchment) in historic records, but it has not been found recently except in the Allagash River of northern Maine (Reach 1A; Yoder et al. 2005). It is reported in Maine lakes of 1A and 2B. The lake whitefish (*Coregonus clupeaformis*) was reported throughout the Saint John River Basin and it occurs in lakes in northern Maine (Reach 1A and 2A), but is not recently reported outside Grand Lake and Swan Creek (Reach 3A and B) in New Brunswick. The source of information used by Meth (1973) for whitefish is not clear, but a range contraction may have occurred. Burbot (*Lota lota*) were reported in much of

the river historically. Today, they are not common downstream of Edmundston, but occasional captures occur in the main stem and tributary systems.

The fathead minnow (*Pimephales promelas*) was reported in historic records at Edmundston, but only two records are reported recently. We captured one specimen in Power Creek, Reach 2A. Yoder et al. (2005) reported fathead minnows from the Allagash River (below Churchill Lake; Reach 1A) and the Aroostook River below Caribou, upstream of the Tinker Dam (Reach 2B). The lake trout (*Salvelinus namaycush*) reported by Meth (1973) had to be from lakes in the basin (possibly Ayers, Serpentine, Long, First Green, Third Green, Baker, Glasier, and maybe Trousers and Fish in the Aroostook River watershed). These are the only known lakes in the basin that presently and historically are known to support lake trout (C. Doherty, NB DNR, pers. comm.). The Arctic charr (*Salvelinus alpinus*) in Reach 1A reported by Meth (1973) may also be the lake populations known to exist in northern Maine, but otherwise not in the basin. The American eel (*Anguilla rostrata*) reported in Reach 1B by Meth (1973) is uncertain given that eels cannot pass Grand Falls (without human assistance).

The sticklebacks are common throughout the river, but not always susceptible to sampling gear and often misclassified. Slimy sculpin and banded killifish are similarly common in the main stem, tributaries, and lakes. The redbreast sunfish (*Lepomis auritus*) is known from the Aroostook River watershed in Maine, but no captures outside of the Oromocto River catchment and adjacent waters (Reach 3A) have been reported in the Saint John River Basin in

New Brunswick. The origin of the Meth (1973) records is unknown and uncertain. Pumpkinseed sunfish (*Lepomis gibbosus*) are often confused with redbreast sunfish and the pumpkinseed is still found across the historic range.

Striped bass (*Morone saxatilis*) can no longer pass upstream beyond the Mactaquac Dam where they were known to spawn historically (Reach 3A), although they appear to be occasionally transported over the dam with DFO transfers of river herring and are captured in our studies (R.A. Curry, unpublished data). Beach seining surveys over a number of years downstream of Mactaquac Dam by DFO have not found any young-of-the-year striped bass, suggesting spawning no longer occurs in the river (DFO 2007a). Sea lamprey (*Petromyzon marinus*) and American shad (*Alosa sapidissima*) can no longer pass upstream at the Mactaquac Dam. American shad were reported at Grand Falls in the 1920s, at Beechwood Dam from 1957-1971, and as many as 39,000 in the first years of the Macataquac Dam (captured in the fish trap; Chaput and Bradford 2003). The species is thought to still spawn in Grand Lake, Washademoak Lake, the Kennebecasis River, and the Hammond River (Chaput and Bradford 2003).

Meth (1973) reported rainbow smelt (*Osmerus mordax*) from 1A to 4A. Today, an anadromous population is known downstream of Mactaquac Dam (Reach 3A) and various landlocked, lake resident populations are known from 1A to 3A (natural and originally stocked as forage for managed, landlocked Atlantic salmon populations, e.g., Nictau Lake, Glazier Lake). These were the populations most probably

identified and reported by Meth (1973). One population of brown trout persists in the Meduxnekeag River (Reach 2E) since its establishment after being released from a federal hatchery in the mid-1900s. There are two additional, self-sustaining populations in the Little and Mispic Rivers of the Saint John River estuary (Reach 4C; R.A. Curry, unpublished data).

Atlantic salmon in the Saint John River are seriously declining in numbers (see below). They are heavily managed downstream of Grand Falls and their present-day occurrences are reports of juveniles that can be from natural reproduction (only downstream of Mactaquac Dam), stocked fish, fish from parents transported by DFO to specific locations, e.g., Tobique River, or stocked and managed landlocked populations, e.g., Nictau Lake. The historic records would be anadromous salmon as far as the Beechwood Dam (Reach 2D) and the managed, landlocked populations upstream.

Natural upstream migration by the gaspereau (alewife and blueback herring) is halted by the Mactaquac Dam (Reach 3A). Historically, this was believed to be their upstream limit (the original rapids at the site), but the species were captured regularly at the Beechwood Dam from the time of its completion in 1958 until 1967 when the Mactaquac Dam restricted upstream passage (Jessop 1990). Both species are transported upstream of the dam as part of DFO's fisheries management programme and they can be captured upstream to Woodstock at least (Reach 2E; R.A. Curry, unpublished data).

Hake, flounders, and menhaden are occasional captures in Kennebecasis Bay

where salt water intrusions and isolation occur on the high tides from the Bay of Fundy.

8.3 Populations – Relative Abundance

8.3.1 Present status of freshwater species

Methods

The abundance data for all freshwater fishes was collected in three separate programmes. For the NB waters of the main stem, the standardized sampling survey described by Curry and Munkittrick (2005) was applied. In its second phase in the reaches downstream of Fredericton, more gill nets and boat electrofishing were used. Yoder et al. (2005) sampled using boat and raft electrofishing. This current report standardized the data to those from Curry and Munkittrick (2005) to produce relative estimates of abundance; thus the sites are comparable, but estimates are for relative abundance only. The Atlantic salmon abundances are based on the annual stock assessments (most recently in Jones et al. 2010). Only the Atlantic salmon data was conducive to assessing changes in fish abundance in the river over time.

Comparison with historical abundances

As has been seen in other river systems, the general trend is an increase in abundance of fish from headwaters to the estuary (**Figure 8.2**). There are several notable deviations from the trend, the most obvious is in reach 2D

near Florenceville where there is a marked decrease in abundance of fish. This is the reach where others have reported significant negative impacts on the river ecosystem and indicated the most probable factors are the added nutrients from food processing and sewage combined with the highly regulated river discharges (see Chapters 5, 6, and 7). A decline in abundances is also suggested at Reach 3A, downstream of the Mactaquac Dam, where the reach again is highly regulated for flow and there are significant nutrient inputs from sewage (City of Fredericton) and concentrated animal production and other farming (Keswick River).

Changes in the Atlantic salmon populations

There has been a dramatic decline in Atlantic salmon in the river. Adult numbers declined from 18,000 - 30,000 in the capture fisheries prior to 1960 (Dominy 1973; Thomas 2001), to a few hundred in the 1960s as the Mactaquac Dam was

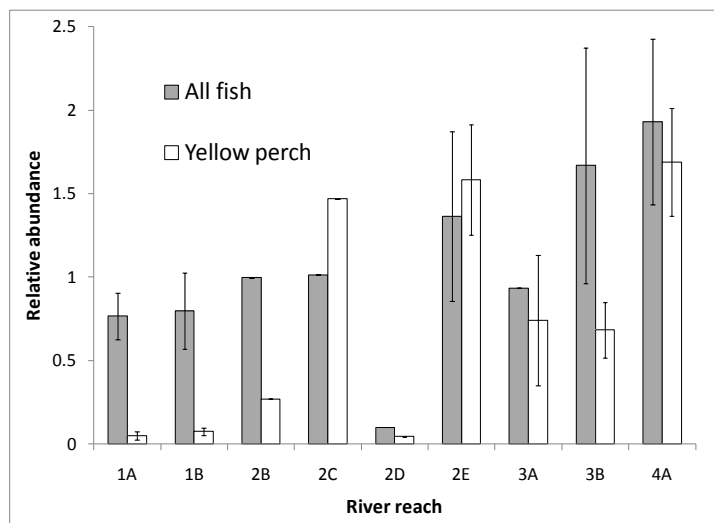


Figure 8.2 Relative abundance of fish along the main stem of the Saint John River (average \pm 1 standard error of the mean; Curry and Munkittrick 2005).

completed (Watt and Penney 1980). Numbers returning to the dam have varied during the intensive management years post-construction of the Mactaquac Dam, and have been averaging 2000 per year since 2000 (**Figure 8.3**). While populations fluctuate in size from year to year naturally, the changes in the Atlantic salmon numbers in the Saint John River Basin appear to be correlated with the history of human activities in the watershed. The first decline in numbers from 1900s to 1960s appears to be related to large harvest (>18,000 adult salmon annually; closed in 1972) and the increasingly poor water quality and habitat in the river (see Chapters 5 and 6; Watt and Penney 1980). For example, Meth (1973) reported that gillnets set in the Grand Falls reservoir/headpond were clogged and unfishable because of trapped “wood fiber, potato eyes, and bacteria and fungi”. Historical water quality was poor (see Chapter 6), but has recovered substantially since the 1960s.

The fishery and pollution were compounded by our activities in the forests of the Saint John River Basin. Early forestry operations polluted smaller streams with sediment and warmed the headwater habitats by removing riparian trees. In larger rivers we removed habitat by straightening banks, and removing large boulders and woody debris to run logs downstream, while polluting the rivers with the bark of cut logs. Finally, we built dams at Tobique, Beechwood, and Mactaquac that blocked passage of fishes up- and downstream. For example, Watt and Penny (1980) estimated that the majority of Atlantic salmon spawning and production of young for the entire basin occurred in the Tobique River. Construction of three dams on the main stem blocked access to and

from that river. Fish passage at these facilities has been managed, but success rates are poor (e.g., Carr 2001; Jones and Flanagan 2007).

The numbers of adult salmon in the river appeared to be recovering in the 1970s; however, this was a period of intensive stocking from the hatchery built to compensate for losses predicted by regulatory agencies from the construction of the Mactaquac Dam. In the 1970s, more than 500,000 parr (fry) were stocked annually (Francis 1980) and the Nashwaak River alone averaged 130,000 stocked parr per year (Jones et al. 2010). These stocked fish most probably increased returns of adults. From 1998 to 2008 the Nashwaak River’s annual average of stocked salmon parr dropped to 21,000.

Water quality post-1970 was improving (Chapter 6) which would have improved survival of juveniles and adults in the river. But the climate was also changing and the Saint John River, like all rivers of the region, was warming. The warmer river

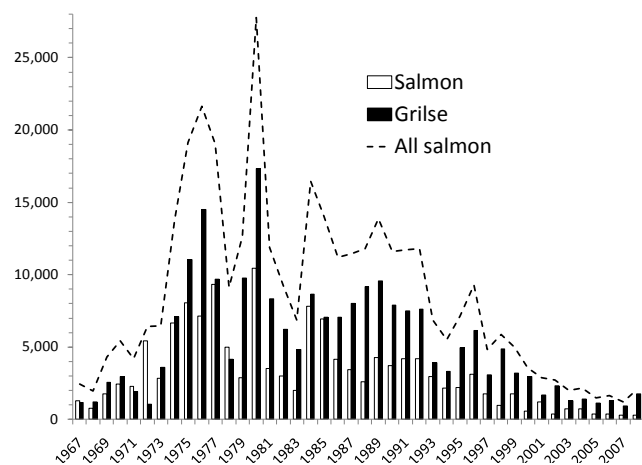


Figure 8.3 Returns of spawning Atlantic salmon to the Mactaquac Dam, 1967-2008 (Jones et al. 2010).

undoubtedly negatively impacted survival and production in the Saint John River, and these negative impacts on the population are predicted to continue (Monk and Curry 2009). Although there were most probably multiple genetic groups within the basin defined by tributaries, there was not any historical separation of those in the count estimates.

The current state of the Atlantic salmon population in the river remains precarious. Most species and populations show resiliency to a single or a few repeated events that reduce numbers. Most populations also have the ability to acclimatize to some level of added and accumulating stressors. In the case of the Saint John River's Atlantic salmon, pressures on the population had begun by 1900 from intensive harvesting, degradation of water quality and habitats, and dams that disconnected fish from their required and best habitats. The population may have demonstrated some resiliency and recovery in the 1970s and 1980s, but we added millions of stocked fish to the system at the same time. Now numbers are extremely low, there are fewer fish artificially added, and our warming climate limits survival and reproductive success. It is highly improbable that Atlantic salmon will ever recover beyond the residual numbers currently in the Saint John River Basin.

8.3.2 Present status of marine species

Methods

Two recent studies have examined the fish assemblage of Saint John Harbour and estuary. Casselman (2007) used multi-panel gillnets set at depth of 5-20 m at three sites in the Harbour and its approaches (Rodney Pier Terminal, Partridge Island, Black's Point). Arens (2007) used a beach seine to sample three sites on the southern side of the harbour in water less than 1.5 m depth. Both studies sampled twice monthly throughout the year for 13 months. Casselman (2007) caught 20 species. Although gillnets sampled the bottom two meters of the water column, 87% of the total number of fish caught were pelagic (open water). Even though low numbers of demersal fish (bottom dwelling) were caught, more demersal species (13 of 20 species) were collected than pelagic species. No species was present during every month of sampling (Casselman 2007).

Relative abundance

A small number of species made up the majority of individuals captured in both environments (**Table 8.2**). Using gillnets, the fish assemblage was dominated by Atlantic herring (*Clupea harengus*) (63.0%) and six additional species that together accounted for 98 % of the total catch. Species richness was significantly higher during summer (May to August, mean 5.3) than winter (January to April, mean 2.9, see **Figure 8.4**). Abundance was also highest during summer (**Figure 8.5**).

Table 8.2 Species found at the mouth of the Saint John River. The locations of capture are marine only (M), marine and fresh water (MF), and only fresh water (F). The relative abundance ranges from no asterisk (<5 individuals in total) to *** (the most abundant).

Family	Common name	Location	Species	Relative abundance	
				Gillnet	Seine
Ammodytidae	American sandlance	M	<i>Ammodytes americanus</i>		
Anguillidae	American eel	MF	<i>Anguilla rostrata</i>		
Atherinidae	Atlantic silverside	MF	<i>Menidia menidia</i>		***
Clupeidae	Blueback herring	MF	<i>Alosa aestivalis</i>		
Clupeidae	Alewife	MF	<i>Alosa pseudoharengus</i>	**	
Clupeidae	Atlantic herring	MF	<i>Clupea harengus</i>	***	*
Cottidae	Grubby sculpin	M	<i>Myoxocephalus aeneus</i>		
Cottidae	Shorthorn sculpin	M	<i>Myoxocephalus scorpius</i>		*
Cottidae	Longhorn sculpin	M	<i>Myoxocephalus octodecemspinosus</i>	*	
Cryptacanthodidae	Wrymouth	M	<i>Cryptacanthodes maculatus</i>		
Cyprinodontidae	Mummichog	MF	<i>Fundulus heteroclitus</i>		
Gadidae	Atlantic tomcod	MF	<i>Microgadus tomcod</i>	*	*
Gadidae	Pollock	M	<i>Pollachius virens</i>		
Gadidae	White hake	MF	<i>Urophycis tenuis</i>	*	
Gasterosteidae	4 spine stickleback	MF	<i>Apeltes quadracus</i>		
Gasterosteidae	Blackspotted stickleback	F	<i>Gasterosteus wheatlandi</i>		*
Gasterosteidae	3 spine stickleback	MF	<i>Gasterosteus aculeatus</i>		*
Gasterosteidae	9 spine stickleback	MF	<i>Pungitius pungitius</i>		
Hemirhamphidae	Sea raven	M	<i>Hemirhamphus americanus</i>		
Lophiidae	Monkfish	M	<i>Lophius americanus</i>		
Merlucciidae	Silver hake	M	<i>Merluccius bilinearis</i>		
Moronidae	Striped bass	MF	<i>Morone saxatilis</i>		
Osmeridae	Rainbow smelt	MF	<i>Osmerus mordax</i>	**	**
Petromyzontidae	Sea lamprey	MF	<i>Petromyzon marinus</i>		
Pholidae	Rock gunnel	M	<i>Pholis gunnellus</i>		
Pleuronectidae	American plaice	M	<i>Hippoglossoides platessoides</i>		
Pleuronectidae	Yellowtail flounder	F	<i>Limanda ferruginea</i>		
Pleuronectidae	Smooth flounder	M	<i>Liopsetta putnami</i>		
Pleuronectidae	Winter flounder	M	<i>Pseudopleuronectes americanus</i>		*
Rajidae	Winter skate	M	<i>Raja ocellata</i>		
Scophthalmidae	Windowpane	M	<i>Scophthalmus aquosus</i>		
Squalidae	Spiny dogfish	M	<i>Squalus acanthias</i>	*	
Syngnathidae	Northern pipefish	M	<i>Syngnathus fuscus</i>		

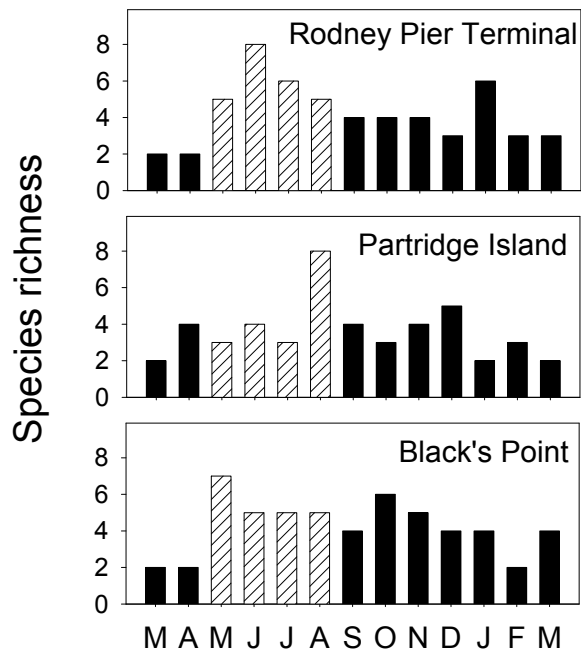


Figure 8.4 Species richness of fish collected using bottom-set gillnets in Saint John Harbour and eastern and western approaches from March 2004 to March 2005 (Casselman 2007).

Fish assemblages were more similar between Partridge Island and Black's Point than the inshore site at Rodney Pier Terminal closest to the termination of the Saint John River. Species ranks and percent composition were more similar between Partridge Island and Black's Point. *Clupea harengus* (Atlantic herring) ranked first (Partridge Island: 84.8%, Black's Point: 73.6%) and *Alosa pseudoharengus* (alewife) second (Partridge Island: 4.7%, Black's Point: 8.3%). At the Rodney Pier terminal, anadromous species *Osmerus mordax* (rainbow smelt; 35.4%, rank 1), *Alosa pseudoharengus* (Atlantic herring; 31.3%, rank 2), and *Microgadus tomcod* (Atlantic tomcod; 14.8%, rank 3) contributed 81.5% of the total number of fish collected.

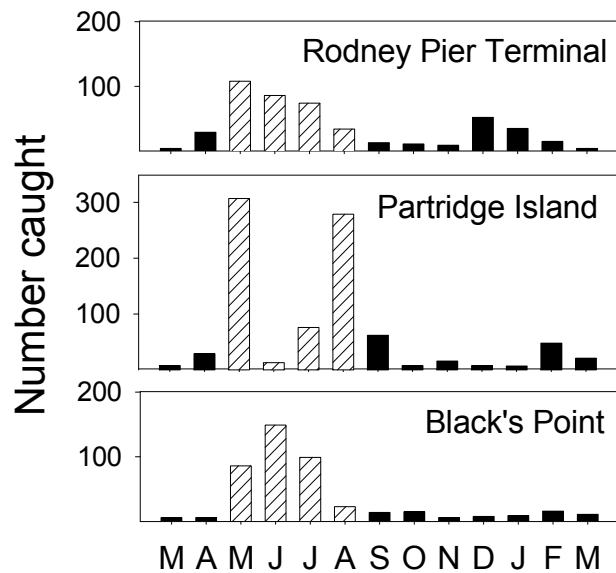


Figure 8.5 Number of fish collected using bottom-set gillnets in Saint John Harbour and eastern and western approaches from March 2004 to March 2005 (Casselman 2007).

Myoxocephalus scorpius (Shorthorn sculpin), *Pseudopleuronectes americanus* (winter flounder) and *Myoxocephalus octodecemspinosus* (longhorn sculpin) have been previously used as sentinel species in Canada and data from Casselman's 2007 study suggest that they can be considered for use in the Saint John Harbour. Although these species were collected at each site, catches were very low.

Arens (2007) sampled fish from onshore (1m depth) with a beach seine at three sites (McLaren's Beach, Bay Shore and Digby ferry terminal) along the western shore of Saint John Harbour every two weeks for 13 months starting in August 2003. Of the eighteen species caught, eight species made

up 98% of the catch. Three highly mobile pelagic species dominated the catch: *Menidia menidia* (Atlantic silversides; 54%), *Osmerus mordax* (rainbow smelt; 19%) and *Clupea harengus* (Atlantic herring; 9%).

Fourteen of the eighteen species were present in Saint John Harbour. Both species richness and total abundance of fish was minimal in the winter months and maximal in summer (**Figure 8.6**).

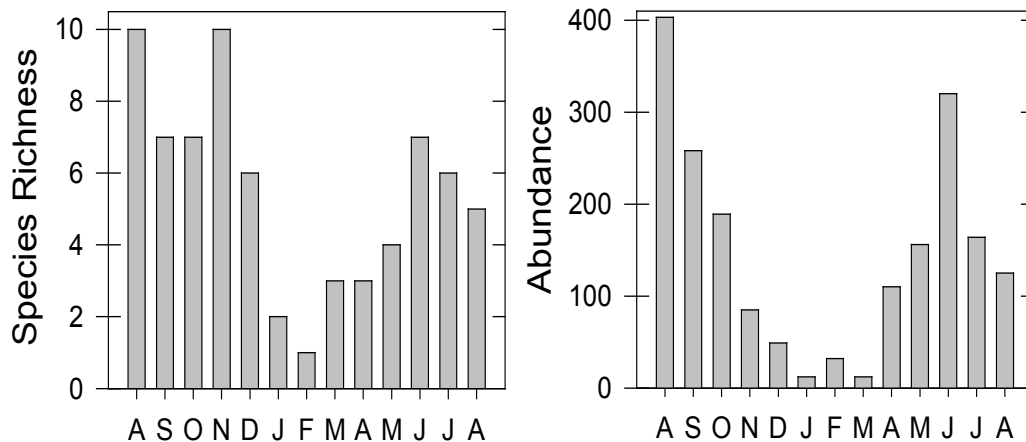


Figure 8.6 Species richness and total abundance of all fish caught by beach seine from August 2003 to August 2004 at three sites in Saint John Harbour: McLaren’s Beach, Bay Shore and Digby Ferry Terminal (Arens 2007).

8.4 Sentinel Species

8.4.1 Present status

Methods

Detailed studies in the Saint John River basin have been used to develop baseline information on potential sentinel species (Barrett and Munkittrick 2009), including detailed seasonal studies on slimy sculpin (Brasfield 2006; Keeler and Cunjak 2007), blacknose dace and golden shiner (Galloway et al. 2004; Galloway and Munkittrick 2006), redbelly dace (Carroll 2007), and in the marine environment with mummichog (McMullin et al. 2009; 2010), rock gunnel (Vallis et al. 2005) and Atlantic silverside (Doyle 2009). Movement of potential sentinel fishes has included studies on slimy sculpin (Gray et al. 2004; Cunjak et al. 2005;

Keeler et al. 2007), white sucker (Doherty et al. 2004 and 2005), muskellunge (Halford 2003; Curry et al. 2007), and brook trout (Curry et al. 2002 and 2010); tagging studies on mummichog in the Miramichi (Skinner et al. 2006) are of relevance to Saint John River harbour studies (McMullin et al. 2009).

There are more specific issues outlined in the cited reports and students theses, but for the purposes of this overview, we will focus on the following sentinel species:

- Yellow perch (*Perca flavescens*)
 - Growth rates (locations along the main stem)
- White sucker (*Catostomus commersoni*)
 - Gonad size, condition (locations along the main stem)

- Slimy sculpin (*Cottus cognatus*)
 - Liver size (upper river only)
 - Nest size and fecundity (in several tributaries with heavy agricultural activities)

Findings by reach

Reach 1

There have been a wide variety of studies in the upper reach, largely focused around Edmundston. These studies have been trying to resolve the relative importance of sewage inputs versus pulp and paper mill inputs, and tributary contributions, using a variety of approaches. Inputs near Edmundston result in an increase in fish condition as much as 45% (Galloway et al.

2003) and a variety of focused studies were conducted to separate the relative contributions of effluents from the sewage facilities at Edmundston from the pulp mill influence (Galloway et al. 2003; Arciszewski 2007), and laboratory exposures using pulp mill effluent (Parrott et al. 2003 and 2004). The dominant influence in this reach is associated with the sewage discharges at Edmundston (Arciszewski 2007), and the headpond downstream of Green River associated with the hydroelectric dam at Grand Falls. Upstream studies indicated some significant contamination associated with the poultry processing facility at Claire during the early years of the studies, resulting in increased liver sizes in fish downstream (Galloway et al. 2003).

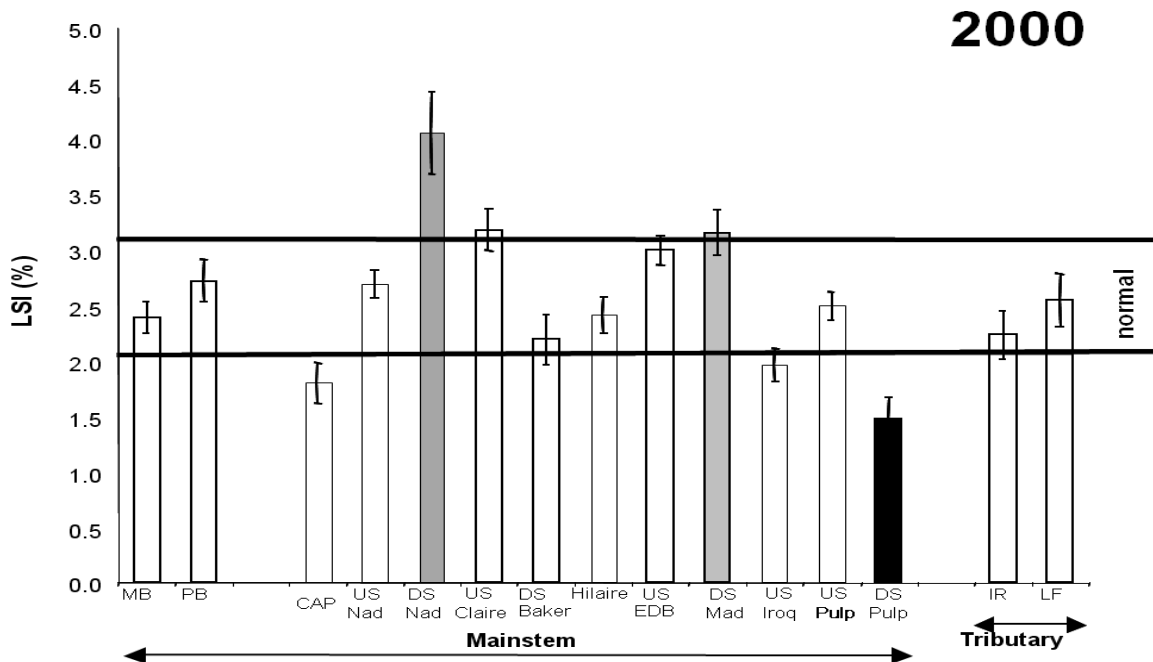


Figure 8.7 Relative liver size (% body weight) of female slimy sculpin in the upper Saint John River from Moody Bridge (MB) downstream to below the pulp mill discharge at Edmundston (DS Pulp) showing the relative responses near the poultry facility at Claire (DS Nad), the sewage discharge in Edmundston (DS Mad), and downstream of the pulp mill in the fall, 2000 (K. Munkittrick, unpubl. data).

Reach 2

Tenzin (2006) studied growth of yellow perch in the main stem of the river in Reaches 1 and 2 and the upper part of 3. The smallest size, lowest condition, oldest fish and slowest growth were observed at two reservoir sites (Tobique and Nackawic), and faster growth was observed at sites with nutrient inputs (Edmundston and Fredericton). The Nackawic site has previously been identified as a site of concern, but this is the first study suggesting that fish in the Tobique reservoir are impacted by stress.

The most dramatic changes in this reach are the decreases in abundance of fish downstream of the Beechwood Dam (**Figure 8.2**; Curry and Munkittrick 2005). Doherty et al. (2003 and 2004) studied fish near effluent outfalls at Florenceville, Hartland and Woodstock and both Doherty et al. (2003) and Freedman (2006) saw evidence of year class failures in the main stem during low flow years. Freedman (2006) suggested that sites exposed to pulp mill and sewage effluents have lower species richness, abundance, condition and

Table 8.3 Relationship of length-at-age for yellow perch showing reduced growth rates at Tobique (the headpond) and Nackawic (Tenzin 2006).

SITES	R ²	Slope	Intercept	n
St Hilaire	0.46	1.78	12.9	23
Edmundston	0.81	1.44	12.8	98
Grand Falls	0.92	2.38	8.6	18
Aroostook	0.91	2.10	9.5	26
Tobique	0.93	0.95	8.2	14
Florenceville	0.95	2.24	8.8	10
Hartland	0.91	1.53	11.3	25
Woodstock	0.90	1.78	9.4	23
Nackawic	0.91	0.98	10.4	45
Fredericton	0.91	1.25	12.4	37

diversity downstream of the Beechwood Dam.

Detailed studies have been conducted in the potato agricultural area in tributaries along the reach from Grand Falls to Woodstock. Studies have shown a variety of impacts in these areas, including reductions in reproductive development and success, year class failures and changes in growth (Gray et al. 2002 and 2005; Gray and Munkittrick 2005; Brasfield 2007; Smedley et al. 2011). The year class strength was negatively correlated with summer (July, August) thunderstorm intensity (Brasfield 2007), and densities were negatively correlated with maximum summer water temperatures (Gray et al. 2005; Smedley et al. 2011).

Finally, there are historic concerns with PCB contamination of the upper Aroostook tributary. Parker and Mallory (2004) examined Canadian sites downstream of the Tinker Dam and did not find evidence of PCB contamination reaching the Canadian side of the dam.

Reach 3

No major issues were identified in this reach during the initial community survey. There was an increase in abundance of fishes in the lower end of the freshwater portion of the river, especially in yellow perch (**Figure 8.8**). Increases in abundance near Grand Lake are largely due to increases in brown bullhead, and lower reaches included increasing numbers of juvenile anadromous species. The most widely distributed and abundant species are white sucker and yellow perch, and future health assessments in these reaches should focus on these species.

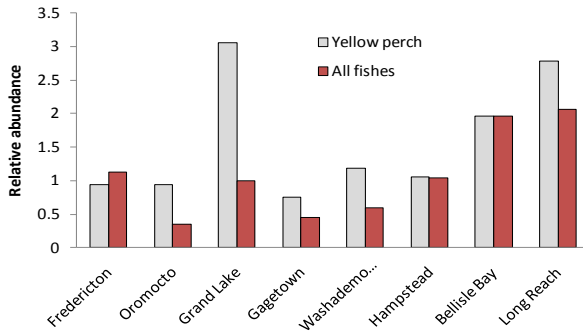


Figure 8.8 Relative abundance of yellow perch and all species combined in Reach 3 of the Saint John River (2005-6).

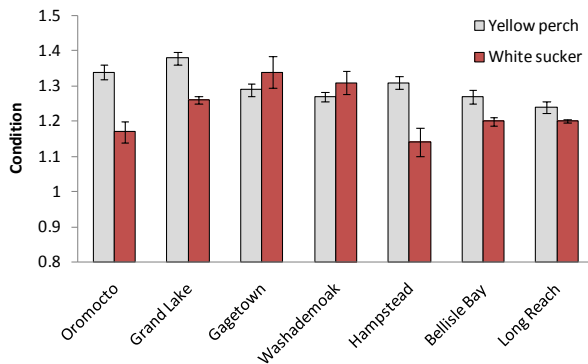


Figure 8.9 Body conditions of yellow perch and white sucker in Reach 3 of the Saint John River (2005-6).

Reach 4

Studies in the lower river have primarily concentrated on evaluating the potential impacts of development, including studies with pulp mill effluents associated with Irving Pulp and Paper (Dubé and MacLachy 2000 and 2001; Hewitt et al. 2003; Belnap et al. 2006; Shaughnessy et al. 2006) and Irving Paper (Bosker et al. 2009), and studies near the oil refinery (Vallieres et al. 2007; Adams 2008) and sewage outfalls (Loomer 2006; McMullin et al. 2010). These studies have expanded and are the focus of a current major research program.

8.5 Fisheries

The term fishery is often confusing, but it is by definition the harvesting of fish or other animals as a commercial enterprise or for recreation. Both commercial and recreational fisheries exist in the Saint John River. The commercial fisheries are currently restricted to the reaches downstream of the Mactaquac Dam; recreational fishing occurs throughout the basin. Species harvested commercially in the river are or have been Atlantic salmon (closed in 1972), American eel, gaspereau (alewife and blueback herring combined), and shortnose and Atlantic sturgeon.

The Atlantic sturgeon has had a recorded annual harvest since 1895 (DFO 2009a). The annual harvest averages 13 metric tonnes (mt), but since 1999 when the most active fisher passed away, the harvest has dropped below 5 mt (~70 adults weighing on average 40 kg). Since 2009, only two licenses have remained active with an annual harvest of <11 mt, which is believed to be sustainable (DFO 2009a). A few adults (<30) are captured for eggs, which are used for spawning, and then released alive in the only sturgeon aquaculture facility on the lower river (Acadian Sturgeon and Caviar Inc., Carters Point). Shortnose sturgeon are rarely captured in the large mesh gillnets of the Atlantic sturgeon fishery. Acadian Sturgeon and Caviar, Inc. collected 15 adult shortnose sturgeon each year for broodstock from 2006 to 2009, and now only these captive fish are used for aquaculture.

Gaspereau, both alewife and blueback herring, are harvested using ~100 licensed trap nets in the river (some gillnets may be used, but mostly in the harbour area; Jessop

2001). Annual harvests averaged ~2000 mt from 1950-2000, but in the late 1990s the harvest was ~1200 mt/year. Jessop (2001) attributed that decline in harvest to overfishing. The fishery exists, in part, because DFO transports returning spawners upstream of the Mactaquac Dam. About 1.5 million (M) gaspereau are moved each year and as many as 4M/year were being moved in the 1980s. These spawn (about 75,000 eggs per female) and the resulting juveniles remain in the headpond until the late summer or fall when they migrate back to the sea.

A commercial fishery for American eel persists in the Saint John River Basin. The reported landings were >100 tonnes/year in the 1990s which was an 8-fold increase from the first records (1980). The American eel is in decline in the St. Lawrence River system as is suggested for many eel species worldwide, but numbers have not yet dropped in the Saint John River Basin and in Atlantic Canada in general (DFO 2010).

Recreational fisheries are worth \$70M annually to New Brunswick. Fisheries in the Saint John River Basin supported 1.2M fish caught annually (50% of the total for New Brunswick) and 290,000 harvested in 2005 (DFO 2007b and C. Doherty, NB DNR, unpublished data). Targeted species are principally brook trout (25% of the catch), smallmouth bass (22%), pumpkinseed and redbreast sunfish (15%), chain pickerel (8%), yellow perch (8%), rainbow trout (5%), and 16 additional species. The recreational fishery for Atlantic salmon has been completely closed since 1998. The majority of the fish harvested (taken home) by anglers are brook trout (56%), rainbow trout (12%), rainbow smelt (11%), smallmouth bass (5%), and brown trout

(5%). There are no trend data for these fisheries, but there has been an overall decline in fish caught by recreational fishers in New Brunswick: 4.4M, 3.2M, 2.8M, and 2.4M in 1990, 1995, 2000, and 2005, respectively (<http://www.dfo-mpo.gc.ca/stats/rec/can/index-eng.htm>). The declining numbers of fish caught reflects local and regional trends in declining numbers of recreational anglers. Harvest rates for the province are also declining from 58% in 1990 to 37% in 2005.

There are currently no major concerns for the recreational fisheries in the Saint John River Basin (K. Collett, NB DNR, pers. comm.). However, a few issues of uncertainty are arising at this time. Somers and Curry (2009) reported a decline in the brook trout population in the Kennebecasis River despite 10 years of a regulated, no-kill zone. Given that the trout harvesting was hypothetically reduced for the river (assuming everyone obeyed the law), the declining population size may be a function of degraded habitat, e.g., loss of groundwater-sustaining baseflow and increased sediment loading from human activities which are both issues in that watershed at this time. There is also uncertainty about the current state and sustainability of the smallmouth bass fisheries in the Saint John River Basin. There are typically over a dozen tournaments targeting smallmouth bass on the river system each year. Three of these tournaments occur prior to spring spawning. During each event 100s of smallmouth may be caught and moved many kilometres from the original catch location. There is currently no active monitoring of this fishery.

8.6 Issues / Concerns

8.6.1 Fish issues

Smallmouth bass

Smallmouth bass (*Micropterus dolomieu*) are not native to New Brunswick. They were introduced in a few waters in the 1800s and early 1900s. Since then, they have moved among waterbodies via natural dispersal and in other cases by humans. In the Saint John River Basin, humans have moved smallmouth bass into at least the Tobique River where they reside in the reservoir (Reach 1C), and, most recently, upstream of Grand Falls (Reach 2C) where they are expanding their range upstream into Maine. The major issue with this species is its voracity and tenacity as a predator and competitor. It has repeatedly altered fish communities when introduced into new waterbodies across North America (Valois et al. 2009). It can occupy the same niches as brook trout and Atlantic salmon and thus displace and/or eliminate these native species. While smallmouth bass support successful and well-enjoyed recreational fisheries, their unauthorized introduction into new waterbodies is a very serious issue as we are now experiencing in the Miramichi River (DFO 2009b). NB DNR continues efforts to educate people that any unauthorized stocking of any fish is an illegal activity that can have serious, negative environmental impacts.

Muskellunge

Muskellunge (*Esox masquinongy*) were introduced into a headwater lake of the Saint John River which resulted in an unintended expansion of a planned

management introduction in the province of Quebec (Stocek et al. 1999). The species is now present from Reach 1A to 3B and reports of expansion downstream occur each year. Other than Glazier Lake, no muskellunge under the age of sub-adults and ~30cm in total length are being reported along the river. No spawning areas are known outside of Glazier Lake at this time, but it is suspected to be occurring in the middle reaches of river. Increasing numbers of individuals were being captured at the Mactaquac Dam into the early 2000s (Curry et al. 2007). Current numbers of captures are not being reported. The potential impacts of this introduced predator on the river's ecosystem was studied by Curry et al. (2007) and indicated that muskellunge are unlikely to consume a significant number of young salmon in the river. There has been no additional support for studies to determine the species' potential impact on the river's ecosystem. The current policy of DFO is to consider muskellunge an invasive species. Specimens captured in the Mactaquac Dam fish trap are counted before being euthanised and specimens >100cm in length are provided for research to the NB DNR (T. Goff, DFO Mactaquac Biodiversity Centre, NB, pers. comm.).

A growing recreational fishery exists along the river (www.muskiescanada.ca/chapters/saint_john_river.php), notably at Glazier and Baker Lakes (ME, Reach 1A), from Hartland to Woodstock (Reach 2D and E), and at Fredericton (Reach 3A). In Reach 1A, there is more retention in this fishery, with an annual catch-kill derby, while it is mostly a catch-and-release fishery in the other reaches. The current NB record catch is a fish of 52" in length caught during the fall of 2009 in the Woodstock area.

The muskellunge is an issue because it has the potential to impact the river ecosystem, but there is a growing recreational fishery with the potential for continuing economic benefits for humans. Currently, there is no agency monitoring this species.

Rainbow trout

Rainbow trout is widely distributed and self-sustaining from Grand Falls to Woodstock (Reach 2A to 2D); it was recently collected upstream of Grand Falls (Reach 1A; Smedley 2009). It was introduced into the Saint John River through escapes from private aquaculture facilities, both production facilities and U-fish/private ponds, and despite provincial regulations designed to ensure zero escapement (Carr 2006). The species is more tolerant of warmer temperatures and sediment, and out-competes native brook trout and Atlantic salmon in these conditions. As a result, the species range will continue to expand in the system wherever it can access new waters, thus representing a potential impact on native species, especially the struggling Atlantic salmon. The current NB Rainbow Trout Aquaculture Policy divides the province into three zones based on potential ecosystem risk (NB DNR 2007).

8.6.2 Reach specific issues

Reach 1

The key issue for upstream reaches of the Saint John River is the expansion of the introduced smallmouth bass and muskellunge. We are not monitoring the fish populations so we have no means to assess how these introduced, top predators are impacting the fish community, river ecosystem, and the recreational fisheries. A

secondary issue is the introduction of other species via the use of live bait in Maine, e.g., the recent discoveries of central mudminnow and most probably the fathead minnow. Use of live bait is illegal in New Brunswick. In Maine, anglers can use live bait in some waters so there is the threat of transporting these fish among watersheds, although it is illegal to release these fish. The live bait industry is managed to control movement of fish among watersheds, but again, insuring adherence to laws and guidelines can be problematic (M. Gallagher, ME Dept. of Inland Fisheries and Wildlife, pers. comm.). In 2011, NB DNR moved to increase the trout harvest by recreational anglers from 5 to 10 fish taken each day in this reach and parts of Reach 2 (NB waters only). There was no science that supported this decision and thus it bodes poorly for sustaining fish populations and the fisheries they support in this region.

Reach 2

The key issue for Reach 2 (Grand Falls to the Mactaquac Dam) is fish passage and river flow management. There are the direct impacts of, at best, poor to non-existent fish passage up- and downstream at the four major dams and through the reservoirs (e.g., Jones and Flannagan 2007). Flow management that is inappropriate for ecosystems combined with wastewater discharges in Reach 2 has led to poor water quality (Chapters 5, 6, and 7) and the lowest fish diversity, abundances, and coincident with three known fish kills (Freedman 2005, Culp et al. 2008, Doherty et al. 2010). A secondary issue is the range expansion of the introduced muskellunge, smallmouth bass, and rainbow trout, including the threat of new introductions. We are not monitoring fish populations and

thus have no means to assess how these introduced species are impacting the fish community, river ecosystem, and the recreational fisheries.

Reach 3

The key issue in Reach 3 is the impact of the Mactaquac Dam on the fish community and fisheries. In addition to stopping upstream fish passage and jeopardizing safe downstream fish passage, its construction is coincident with the significant decline in the river's Atlantic salmon and its location is known as the historical spawning areas of striped bass, which no longer reproduce in the river, American shad (Jessop 1975), and the two sturgeons (current status uncertain). The monitoring of Atlantic salmon in Reach 3 has been ongoing at the Mactaquac Dam and monitoring is improving in the Nashwaak River (e.g., Jones et al. 2010), but there no monitoring of other populations or species except commercial landing reports so we have no means to assess future changes in populations, the fish community, river ecosystem, and the recreational fisheries they support.

Reach 4

Reach 4 issues are specific to the Nerepis River, Kennebecasis River, and the vicinity of the City of Saint John. The Nerepis River flows through CFB Gagetown and it suffers the impacts of active military operations, e.g., sediment loading from vehicles in streams and landscape defoliation requirements (chemical, thermal, and sediment impacts on streams). The Department of National Defence has an active team of environmental officers working to correct and mitigate these

impacts.

In recent years the Kennebecasis River has undergone major development of agricultural lands, two potash mining operations, and multiple natural gas wells. In a move to protect the brook trout population in the river, a no-kill zone was created in 1998 along the reach where many of the largest adults lived during spring to fall. The reach was revisited in 2008-09 and assessments indicated a decline in brook trout numbers and a change in species composition (Somers and Curry 2009). Many homes in this area have lost their wells because groundwater levels have significantly dropped (New Brunswick Beacon 2010); groundwater provides baseflow to the river that sustains coldwater habitats for brook trout in summer, ice-free habitats in winter, and creates the spawning sites in the Kennebecasis River (Curry 2000; Curry et al. 2002).

Studies in the vicinity of the City of Saint John have primarily concentrated on evaluating the potential impacts of pulp mill effluents associated with Irving Pulp and Paper (e.g., Dube and MacLatchy 2000; 2001; Hewitt et al. 2003; Belnap et al. 2006; Shaughnessy et al. 2006), Irving Paper (Bosker et al. 2009), the oil refinery (Vallieres et al. 2007; Adams 2008), and the sewage outfalls (Loomer 2006; McMullin et al. 2010). In the Saint John Harbour, the newly created Environmental Monitoring Partnership will continue to monitor and address issues for fishes.

8.6.3 Species at Risk (www.sararegistry.gc.ca)

Striped bass (*Threatened*)

The striped bass are an enigma in the Saint John River Basin. They were and have been reported in the river since the 1800s. Local knowledge suggests they spawned in several locations, e.g., Belleisle Bay and Grand Lake, but the principle spawning site is believed to be at the head of tide in the vicinity of the Mactaquac Dam and Fredericton (Reach 3A). Since 1967, spawning has been confirmed only once, Belleisle Bay, 1979 (Douglas et al. 2003), and no young-of-the-year have been collected in multiple CRI and DFO surveys (DFO 2007a). The origin of the striped bass in the river today appears to be various rivers along the northeastern USA and the Schubencadie River, Nova Scotia. This has been confirmed by genetic analyses (Douglas et al. 2003; COSEWIC 2004). We assume that juveniles >24 cm in total length begin entering the river from the Bay of Fundy in spring following the gaspereau spawning run (R.A. Curry, unpublished data) and larger adults up to 100 cm total length arrive in the river late in the summer as the gaspereau young-of-the-year begin their downstream migration. Anglers who target striped bass are unconcerned about numbers at this time, although retention is restricted. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is reviewing the current SARA listing for striped bass in the Saint John River.

Redbreast sunfish (*Designated Special Concern 1989. Data Deficient Category 2008*)

This species can be found from Florida to Maine where it is common. In Canada, the only populations occur in the Saint John River Basin, at 16 reported locations, and in the St. Croix River that borders Maine (COSEWIC 2008). There is no evidence these populations are threatened at this time.

Shortnose sturgeon (*Special Concern*)

The shortnose sturgeon is listed as a species of *special concern* by COSEWIC because it is the only population in Canada, but there is no evidence to suggest this population is facing any serious threats at this time (COSEWIC 2005). It is monitored by this committee because populations around the world are listed as vulnerable or threatened, and they are endangered in the USA.

American eel (*Special Concern*)

The American eel populations of the Great Lakes system have been on the decline, but the population appears healthy in the Saint John River Basin and in Atlantic Canada in general (DFO 2010).

Atlantic salmon (*Endangered*)

COSEWIC classified the salmon populations in the Saint John River and rivers west to the USA as endangered (criteria A2b, >%50 reduction in abundance) in 2010. While the evidence of the decline is obvious, there are no COSEWIC reports on the designation process, status reports, or schedule and status currently available.

8.7 Conclusion

Throughout the Saint John River Basin, there are many stable, healthy populations and communities of fishes. Some other areas and reaches are demonstrating signs of stress in the fishes, which is an indicator of an unhealthy state of the river environment. Where there are issues, it appears the key problems are poor wastewater management, poor river flow management, and poor fish passage (**Table 8.4**). Secondary issues are climate change that is warming and altering flow regimes in the river, and a lack of detailed monitoring and assessment programmes which limits our ability to detect changes in populations and communities both along the river and over time. Most of the issues, major or secondary, can be overcome. This requires a plan. It requires: 1) that all stakeholders in the Saint John River Basin agree to some basic fish population and community

objectives, e.g., the free-swim of fishes past existing dams and improved water quality in stressed reaches; 2) designing an appropriate monitoring and assessment programme which will require additional research, e.g., what is impact of non-native fish on the river's ecosystem and what is the appropriate minimum flow to protect all species; and 3) commitment by regulatory agencies to the implementation and sustained long-term monitoring and assessment, including reporting.

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Table 8.4 Summary of changes, current population and fisheries status, and future issues for fishes of the Saint John River.

Category	Change since 1960s	Current status	Future Issues
Community/ Biodiversity	No species lost; 2 introductions (muskellunge and central mudminnow); Range reduction of native species: Mactaquac Dam construction; Range expansion of introduced species: smallmouth bass, rainbow trout, muskellunge	Stable	<ol style="list-style-type: none"> 1. New species introductions: <ol style="list-style-type: none"> a) live bait from Maine waters b) additional introductions from aquaculture operations, i.e., rainbow trout; 2. Range expansions of introduced species: <ol style="list-style-type: none"> a) smallmouth bass b) rainbow trout c) muskellunge 3. Unauthorized human introductions of smallmouth bass 4. Lack of detailed monitoring and assessment programmes limits ability to detect change in the community.
Populations/ Abundances	Only data for Atlantic salmon – abundances dramatically reduced	Stable for all species, except Atlantic salmon	<ol style="list-style-type: none"> 1. Lack of detailed monitoring and assessment programmes limits ability to detect change in the populations.
Fisheries	Atlantic salmon - closed in 1972 (commercial) and late 1990s (recreational); gaspereau - increasing harvests (sustained by Mactaquac Dam reservoir); Atlantic sturgeon – declining harvests	Stable – all recreational and commercial fisheries appear to be sustainable	<ol style="list-style-type: none"> 1. Recreational Fisheries - Lack of detailed monitoring and assessment programmes limits ability to detect change in fish populations resulting from recreational fisheries. 2. Potential to close recreational fishery for striped bass.
Species at risk	5 species officially listed at risk.	All species appear to have stable, secure populations except Atlantic salmon	<ol style="list-style-type: none"> 1. No issues are on the horizon. 2. Lack of detailed monitoring and assessment programmes limits ability to detect change in these fish populations.

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9. Traditional Ecological Knowledge and the State of the Saint John River Basin

Samaqan Nuhkmoss (Water Grandmother): my experience and perspective as a Wolastoqew returning to Wolastoq (the Saint John River Valley)

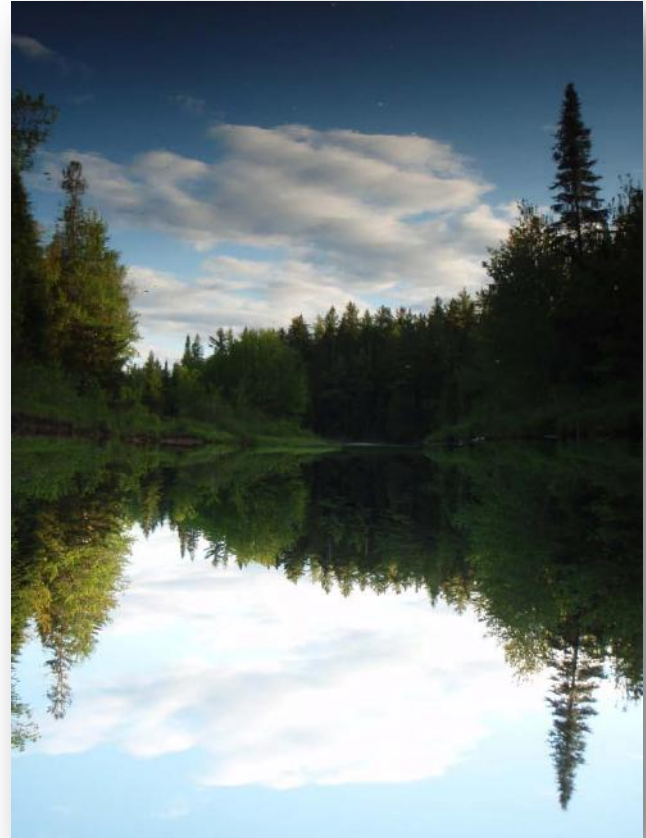
Cecelia Brooks
with Luke deMarsh

Editors' note

This chapter marks the first time in the editors' experiences that a state of the environment report brings together traditional ecological knowledge (TEK) and "western science" to provide information on the condition of freshwater environmental indicators. Inset boxes are used throughout the chapter to highlight instances where TEK and findings in other chapters are mutually supportive.

9.1 Introduction

This chapter is an oral history narrative of my experience as Samaqan Nuhkmoss (Water Grandmother) for the Canadian Rivers Institute (CRI), and as a Wolastoqew (Maliseet person) returning to the place of my people, Wolastoq (the Saint John River Valley). Wolastoqiyik are a nation of



indigenous people who have lived throughout Wolastoq for thousands of years (Leavitt 1997). Wolastoqiyik translates to mean 'the people of the beautiful bountiful river'. I draw on Wolastoqiyik traditional ecological knowledge (TEK) and history in reflecting on the environmental state of Wolastoq.

The concept of TEK has emerged from the environmental impact assessment (EIA) process for developments and projects in Canada. TEK refers to traditional knowledge held by indigenous peoples about their local environment (Berkes 2008). The time-sensitive nature of the EIA process has resulted in TEK being recorded as if it is a uniform system of knowledge based in the past (Cruikshank 2005). In fact TEK is a fluid, diverse system of knowledge based in the ongoing relationships of indigenous peoples

with their environment. I believe scientific knowledge and traditional ecological knowledge are parallel systems that benefit from informing one another. One is not greater than the other. Combining these two systems will create a more complete assessment of what is happening and has happened in an ecosystem, such as Wolastoq.

Recording the oral history of indigenous peoples is part of a more nuanced understanding of our history and knowledge of the environment. Indigenous people have an intimate relationship with the natural environment. This relationship is embedded in TEK and is vital to the cultural and social survival of indigenous people. Life history has re-emerged as a culturally appropriate methodology for TEK research (Cruikshank et al. 1990; Cruikshank 2005). Recording the narratives of indigenous people reveals an alternative picture of the past as well as the present, gives a dignified voice to the once voiceless, and contributes to the empowerment of indigenous peoples. The flow of this chapter like the flow of the Wolastoq and the flow of oral history is in the form of a conversation; based on an exchange with my friend and colleague Luke deMarsh.

LD: What is your connection to Wolastoq River?

CB: My connection to Wolastoq River comes from my father Louis Brooks who grew up at what is now known as Sitansisk (St. Mary's old reserve). This is the small plot of land adjacent to Union Street in Fredericton, on the north bank of Wolastoq River. He lived there with his extended family and remembers fourteen houses on that little plot. Some community members

maintained small vegetable gardens between the small houses. Birch bark canoes were rare but nearly everyone had a canvas canoe. Canoes were used to travel up and down the river to hunt, fish, and collect other foods and medicines. My father's generation transitioned from living completely off the land to making a small living off the land through the collection of wild foods for consumption, trade and resale. Black ash (*Fraxinus nigra*) baskets were also made by many to trade for food and supplies. Hunting and fishing provided food to share with family and friends to supplement the rations provided by Indian Agents (a position title mandated by the *Indian Act* to administer Indian affairs in a jurisdiction). Food was often scarce to the point that my father and many others suffered from malnutrition. My father was unable to walk until the age of four due to rickets, caused by a dietary deficiency in vitamin D.

My father's fondest memories during these challenging times revolved around travelling by canoe with family to the islands of Wolastoq above the old reserve. While on the islands my father remembers gathering traditional plant foods, fishing, and sharing stories around a campfire. Fireside stories at these gatherings were a source of entertainment and a time for Wolastoqiyik from the different communities to share information with one another.

The stories my father shared with me about his life on Wolastoq were the impetus for my return to Wolastoq five years ago. My path back to Wolastoq has been filled with dreams, visions and other adventures. One dream in particular led me to connect with my Elder, Dr. Charles Solomon, a Wolastoqiyik Elder from Pilick (Kingsclear

First Nation). When I relayed the dream to Elder Charles he advised me to follow the path of medicine because this dream was a message to inform me of my true calling. My educational experience in medical chemistry helped me decide that my values were not in line with the practices of allopathic i.e., conventional, medicine. I had already developed a keen interest in the use of medicinal plants. Elder Charles' instructions sparked a deeper passion to learn as much I could about medicinal plants, their identification, constituents, preparation and application.

Throughout the 1990's I worked in an environmental laboratory in Nashville, Tennessee, that analyzed water, wastewater, soil, and air samples. After nearly ten years of working in this lab I became conflicted with the irony in my efforts to have a positive impact on the environment. I realized that the lab was emitting thousands of liters of organic waste in order to identify environmental contaminants. I knew that more could be done to prevent contamination in the first place. I was also aware that all contaminants could eventually impact our water supply. These realizations helped me decide to leave the laboratory position in order to focus on water science issues.

During this transitional period in my life the May 2000 water crisis occurred in Walkerton, Ontario. I knew this tragedy could have been prevented because of my experience in water science. This led me to shift my efforts to drinking water. I was able to acquire a position in the water lab with the Clarksville, Tennessee municipal water treatment facility. I gained valuable experience in the water lab and I knew that an operational position in the plant was

integral to understanding the process.

Once I received my Grade IV Water Treatment license from the State of Tennessee I began to visit the wastewater treatment facility to learn about that system and eventually acquired certification for the operation of that facility as well. During my work at the two treatment facilities I gained an understanding of the inner workings of these systems and their potential shortfalls.

Throughout this time I kept abreast of the ongoing water quality crisis facing Canadian First Nations' communities. The crisis appeared to stem from a lack of capacity within First Nations to control their water systems because they lacked training and education. I felt compelled to return to Canada in order to share my knowledge of drinking water with Wolastoqiyik people. In the summer of 2006 I moved back home.

In the autumn of 2007 I became the Science Director for the Maliseet Nation Conservation Council (MNCC) based in my home community of Sitsansisk (St. Mary's). MNCC's mandate was to create a Wolastoq River watershed management plan with core funding from the Department of Fisheries and Oceans (DFO) and to find ways to bridge the educational gap for Wolastoqiyik youth in the sciences. This opportunity allowed me to start addressing the water quality problems of Wolastoqiyik people through training and education. I knew this position was a good first step toward my goal of building First Nations' environmental capacity, enabling Wolastoqiyik to take better care of Wolastoq River and all the life she cares for.

During my time with MNCC I met and

worked with many organizations and people who were working toward building bridges with Wolastoqiyik communities. The CRI was one of the key organizations with whom I collaborated given its focused work on the health of rivers, including Wolastoq. After many discussions with Dr. Allen Curry, the Director of CRI, we decided to develop and collaborate on Samaqan Nuhkmoss (the Water Grandmother Project). My efforts with Samaqan Nuhkmoss required me to leave MNCC in order to work more closely with science educators. I continue to work with MNCC on the development of a sound research protocol in the collection of TEK by serving on their Ethics Review Board.

I made many connections during my first year in Canada. One of these connections was with Luke deMarsh, an anthropology graduate student at UNB. I discovered that we shared a connection with Elder Charles Solomon because of Luke's interest in medicinal plants. Luke was also working on the research project Mesq Kpihikonol (Before The Dam); documenting Wolastoqiyik memories of Wolastoq before the dams were built on the river. I was invited by Imelda and Dave Perley of the Wolastoq Language and Culture Centre and Evie Plaice, the principle investigator of Mesq Kpihikonol, to work with them. Our fieldwork took us to several Wolastoqiyik communities to meet with Elders. Luke and I focused our interview efforts with Elder Charles because of my special connection with him as well as Luke's thesis work on Elder Charles' traditional medicinal plant knowledge. We continued to spend time with Elder Charles, both formally and informally after our core work with Mesq Kpihikonol was complete. Sadly, Elder Charles passed away during the writing of this chapter.

Our interviews and field trips with Elder Charles to the medicinal plant gathering sites demonstrated to me the great importance of sharing the stories of Wolastoq and Wolastoqiyik. The traditional knowledge Elder Charles shared with us about Wolastoq was missing from the volumes of data being generated about our river. The CRI recognized this deficit and it resulted in the inclusion of a Wolastoqiyik perspective in this report.

LD: Why are you interested in the state of the environment of Wolastoq River?

CB: Environmental health has a direct effect on human health and many times the connection between these areas is lost. The nature of science is to reduce and synthesize conclusions down to the sub-molecular level. This being said, Western scientists are gaining an understanding of the relationships between the parts of the environment, as seen in the discoveries made within the discipline of ecology. But even ecology does not offer a complete picture of Wolastoq River. Wolastoqiyik peoples' TEK offers a complementary perspective to the Western scientific perspective. Wolastoqiyik TEK is based on an immemorial amount of time spent on the land and in the waters throughout the four seasons. The inclusion of Wolastoqiyik TEK is necessary when seeking solutions to the complex environmental and human health issues in Wolastoq.

Wolastoqiyik people have been impacted physically, emotionally and spiritually by the degradation of the environment (Paul 2000). To heal the river and its ecosystem will in turn help heal the Wolastoqiyik and all others who live in the watershed and depend on the river. Wolastoqiyik peoples'

dependence on Wolastoq River is a reflection of the cultural importance she has to the people who have lived here for thousands of years. There is now scientific evidence that the harm that has come to the Wolastoq is harming the health of the Wolastoqiyik (Getty 2009). This evidence needs to be explored further with the inclusion of Wolastoqiyik people in future research so that we may contribute to the solutions.

9.2 Traditional Ecological Knowledge and the Saint John River Basin

LD: Is there historical literature that contributes to an understanding of Wolastoq River and her environmental state?

CB: Sure. In 1689 John Gyles was nine years old, a Puritan from what is now Maine. He was captured and taken prisoner along with his parents by Wolastoqiyik and taken to Meductic (Gyles 1736). He lived with Wolastoqiyik people until his release at the age of nineteen and his account of the time in captivity is a very interesting story. Although interesting, we must also keep in mind that he was a hostile observer and his account was published as popular literature. One point that is important in his account is the location of Meductic. It was one of several Wolastoqiyik communities. I think the fact that the location of the place called Meductic has changed is a prime example of how we have changed the environment of Wolastoq. The Meductic of John Gyles' time is now submerged in the head pond of the Mactaquac Dam. Meductic has a sign on the highway but the original Meductic is under water. What is

now called Meductic is the shore off of where it used to be (see also Kenny and Secord 2010).

“It is well established that many islands were flooded (lost) when the Mactaquac Dam’s reservoir was created.”

Chapter 5 River Habitats, p. 67

Other things that Gyles talks about in his memoirs are also indicators of environmental change. He talks about hunting and gathering with Wolastoqiyik during that time and some of the activities that he was able to participate in. I also think it is important to note what Meductic means. I asked my father, “What does it mean? And he said it means the end of the road or end of the journey. And I said, “Like home?” And he said, “Yeah like end of the journey, home.” This means we lost a piece of our homeland to the head pond of the Mactaquac Dam. One may say that we could simply move and we did, but the profound impact of permanently losing a long connection to a land cannot be denied.

LD: Are there other historical or ethnographic pieces that you think are relevant to the state of the environment of Wolastoq River?

CB: You could go all the way back to the diaries of Champlain (1910) where he documented the many islands in the Wolastoq. Some islands are no longer there because the river system has changed. All river systems change over time but with the installation of dams the flooding of Wolastoq has been exacerbated in the

spring. I am not so sure new islands are being formed. Some islands are being destroyed (Anon., pers. comm.) because of the unnatural fluctuations of the water. Ekpahok Island (old name was Savage

“Impounded reaches have few islands. Submerged islands may still provide some structure representing habitat.”

Chapter 5 River Habitats, p. 71

Island, changed in 2010 by Wolastoqiyik) is one of those places. Currently there are efforts being made by the Keswick Farmers Association to reinforce the banks of the island so the land they now farm doesn't continue to erode into the river. Ekpahok Island was another one of the major settlements of Wolastoqiyik people. It was a summer gathering place where our ancestors held council meetings to discuss family hunting areas and to simply gather and commune with each other and the land. There was even a racetrack there that was used for foot race competitions. Again, we have lost another connection to our ancestral homeland. First to agriculture, then to the erosion caused by the unnatural fluctuations in water levels.

Father Pierre Biard (1897), a Jesuit priest and missionary from France, echoes the sentiments of many past New Brunswickers that there were too many trees and the forest was depressingly thick with cedar and pine growing right down to the water. These recorded observations are all significant indicators of the health of the environment during these early times. The settlers viewed the abundance of forest as a barrier to agriculture, while this abundance was necessary for the livelihood of

Wolastoqiyik people and the health of Wolastoq River. Agriculture has now replaced much of the forest. In Carleton County, the hub of the world's largest french fry manufacturer, the farmland goes right down to the water's edge. Carleton County used to be covered with forest, an old and diverse forest that we no longer have (Simpson 2008).

“Land was also being cleared for agriculture throughout this period, so much so that “by the 1890s, there were already reminiscences about the region's former appearance. By that time, cleared agricultural land extended almost completely from Grand Falls to Meductic, a stretch of river that was described only 90 years earlier as “dark wilderness””.

Chapter 3 Development in the Saint John River Basin, p. 30

In the ethnographic literature Mechling (1959) documented life among Wolastoqiyik beginning in the twentieth century. He determined that many of the traditional social and economic practices had been eroded. Nonetheless, traditional knowledge of Wolastoq River, including use of her many plants and animals for food, medicine, shelter and tools, continued. The resilience of Wolastoqiyik people in the face of drastic change is an indicator that culture has a way of contributing to the survival of the people. Our culture is what connects us to the land and the more this connection is broken the more broken our culture becomes. I understand that this concept is difficult for those who do not have a culture deeply embedded in a land but I would

hope that they can still see the correlation.

LD: Are there examples from Wolastoqiyik oral history that are relevant to an understanding of the present environmental state of Wolastoq River?

CB: Absolutely. I think all the stories that I have heard are not only relevant but also necessary for understanding the present conditions. Many Wolastoqiyik Elders have fond memories and they love to tell the stories of their observations, which are indicative of the state of the environment of Wolastoq River. Elder Spike (Donald) Moulton from Neqotkuk (Tobique First Nation) shared with me one of the stories that highlights the dramatic changes that have occurred on Wolastoq.

Elder Moulton told me this story as we were standing outside his home along the river in Neqotkuk. He was pointing to Wolastoq River where significant bank erosion was occurring. The erosion is a source of anxiety for people living in the homes along the road that runs adjacent to the river. He said the river was more narrow and shallow before the dam was installed. Pointing out 100 feet beyond the present shore Elder Moulton recalled the land, people and homes that used to be there. That land has eroded into the river. He named the people who lived there and said that many were fishing families. He said, "Early in the morning just as dawn was breaking you could walk out and see the people paddling out in their canoes to go fishing." He said, "Then in the evening you would see them returning with their bounty. On those days everyone would know they were getting some fish that day for supper or for breakfast the next day." I said, "I don't see any fisherman out there now." He said, "Oh

no, all the fish are gone." This statement alone conveys the perceptions of Wolastoqiyik people. These conclusions are not based on fish population density studies but on Elders' prior knowledge of the abundance compared to the sparse numbers of fish that are now observed. It does not take studies to realize there are not enough fish to warrant going fishing for the community.

"Finally, we built dams at Tobique, Beechwood, and Mactaquac that blocked passage of fishes up- and downstream. ...the majority of Atlantic salmon spawning and production of young for the entire basin occurred in the Tobique River. Construction of three dams on the main stem blocked access to and from that river. Fish passage at these facilities has been managed, but success rates are poor."

Chapter 8 Fishes of the Saint John River, p. 121

Another story that tells of the changes that have occurred is one my father told me many times over the years. This story is about the islands on Wolastoq River just above Fredericton, and the abundance of fish that used to inhabit this area. There is an island down from what is now called Ekpahok Island (aka Savage Island) called Mollie's Island by the Elders of Sitansisk (Mollie Etawol is Wolastoq for Mary Edward). The reason they called it Mollie's Island is she was left behind on one of their expeditions to this island. The story is that she was gathering berries when everyone else was loading the canoes. Somehow they

did not notice she was missing until they heard her hollering for them as they paddled away. Luckily they heard her and turned around to retrieve her. It's a fun story that tells how it came to be called Mollie's Island.

A few families, including my fathers', would travel to Mollie's Island, to fish striped (black) bass (*Morone saxatilis*). There were so many fish that you could walk on the backs of fish. That is how I've heard the story told by several Elders, through the years. Dad said that what they mean is the fish would come out of the water because the ones on the bottom would push them up out of the water. "Esqapesasicik" (waiting to be pushed up), that's what we would say. Striped (black) bass are a very large fish that came up each summer to spawn and would be so thick in the water that they were literally pushing each other out of the water.

During that time they were making the shafts for spear fishing but using manufactured metal spearheads. They

"Striped bass can no longer pass upstream beyond Mactaquac Dam where they were known to spawn historically ... Beach seining surveys over a number of years downstream of Mactaquac Dam by DFO have not found any young-of-the-year striped bass, suggesting spawning no longer occurs in the river."

Chapter 8 Fishes of the Saint John River, p. 119

would make these spears to fish the striped (black) bass at night. Often times he [Dad] said it was a full moon so you could see the shine coming off of the fish, glistening in the moonlight. They would build fires, play music and sing. He said, "It was like a party out there." They would spear the fish and have twine tied to the spears so that when the fish eventually tired and died they could find the fish. Everyone notched the spears or used colored twine so they could identify their spears. "There were many fish, so many fish you couldn't begin to get them all" he said. "You just got what you could. We would stay out there two or three days fishing and feasting on fish. Then take what was left back to the community and everybody would get a little bit".

There are elements of an indicator of freshwater quality in that story. I asked my Dad why there were so many fish in that location. He said, "The bass were moving up river to spawn." Now the scientific community is studying whether striped (black) bass are even still spawning in Wolastoq River (Allen Curry, pers. comm.). When I asked my father why he thought the bass were not spawning and why they were not as abundant he said, "No place to spawn. They need the same things as salmon: pebbly bottoms, the nice sandy bottoms and clear water." He added that the dam (Mactaquac) is a problem for the bass, by creating a barrier into the upper reaches of Wolastoq River. My father used this example and other stories of abundance to explain the reason why we were able to fish the way they did in past, but also why we should not do this now. When I told him that some Wolastoqiyik people are still fishing with gill nets, because it is their treaty right, he does not agree with this practice. He said it may be a treaty right but beyond our rights we have a

responsibility to the earth not to take what is no longer in abundance. He added that although we have the “right”, our responsibility supersedes all else. It is our way and that is why we as a people have succeeded in surviving for thousands of years on Wolastoq River.

Another teaching that came out of another story explains my father’s concern that Wolastoq River fish may no longer be healthy for us to eat. He recalls the sewage pipes that dumped raw sewage into Wolastoq River not far from the Old Saint Mary’s Reserve. He said that they used to swim there until they started seeing human waste floating beside them after the sewer pipes were put in. Dad laughed while he recalled how they would tease one another as they quickly got out of the water to avoid coming into contact with the floating waste. Dad also talked about the city landfill, which was located where Dairy Queen now sits on Union Street. Some in the community would tease Tom Brooks about having first pick of the garbage because his house was closest to the dump. They would holler in Wolastoq, “Hey here comes (ehckuyat) the red truck” when the red dump truck carrying the city’s garbage would arrive. I asked my father how close the dump was to the river and he said that it was right on the river. The dump was so close to the river that during the spring flood the dump would wash into and down Wolastoq River. It’s disheartening to think that a better location could not have been found for the city dump. For these reasons my father and other Elders are concerned that Wolastoqiyik people still fish striped (black) bass. Fortunately and rightfully these fishermen question contaminants they know are impacting the quality of the fish as a food source (Maine Govt. undated).

Another story Dad told me is about the water quality. I asked if the water was clean enough to drink when he was a kid. He replied, “Oh yeah it was just so clear. When we were paddling up to the islands and got to the shallows my mother would be in the front of the canoe, my father was in the

“The river section below Mactaquac Dam was classified as mesotrophic largely based on consistently high levels of algal biomass. No distinct peaks in [total phosphorus] or [total nitrogen] were noted in this stretch of river, but nutrient and algal biomass levels were higher than reservoir values or reference condition values...”

Chapter 7 Primary Production, p. 106

back. He was poling us through because it was so shallow. We [the children] were in the middle. My mother would dip a cup into the river and get everybody a drink. There was no sediment, just sand and gravel, clear to the bottom. Nobody got sick. It was good tasty water”. This would have been the late-thirties, even then as indicated by my father’s account it was perceived to be clean.

Some other Wolastoqiyik TEK stories that come to mind concern medicinal plants of Wolastoq. Elder Charles [Solomon] told me he first collected sweetgrass (*Hierochloa odorata*) in East Saint John. He would travel down with his uncle from Pilick (Kingsclear). He said the sweetgrass was so thick you could pick it by the handful. But there was a factory built right there in Red Head (Marsh), so he had to find another spot to pick.

“Edmundston and downstream into the Grand Falls reservoir have poorer water quality because of the intensity of industrial, municipal, and animal waste (farming and food processing) entering the river in addition to the reservoir effect. The Florenceville to Woodstock reach has poorer water quality because of the organic waste discharged from three food processors and numerous municipal sewage treatment facilities.”

Chapter 6 Water Quality, p. 91

Elder Charles also told me about his favorite medicine kilhuswasq (*Acorus americanus*). He said they used to be able to pick kilhuswasq right below Pilick, but when the Mactaquac Dam was built it destroyed the ponds where the kilhuswasq grew. Elder Charles then had to travel to Maine to collect kilhuswasq and many others from the Wolastoqiyik communities go to the same place. Some have expressed concern about using this medicine because it is located near potato fields. The concern is that the agro-chemicals may be contaminating the medicine. If this is true then using kilhuswasq from that site could be harmful to our health. It is important for those studying health and the environment to know that Wolastoqiyik people are still living off the land; to the extent it may be impacting our health. There need to be assurances that our wild harvesting practices are protected from contamination. Most of the foods found in the grocery stores are tested and monitored but our wild foods are not. Triggered by concerns expressed to me by Wolastoqiyik and Mi'gmaq people I am currently working with researchers at CRI

and the University of New Brunswick (UNB) to initiate a study of the environmental contaminants found in traditional foods and medicines of all New Brunswick First Nations. This monitoring is necessary to protect the health of First Nations and the general New Brunswick citizenry, especially in the case of fiddleheads (*Matteuccia struthiopteris*), a wild food enjoyed by many in the province. Wolastoqiyik people introduced the initial settlers to fiddleheads and the newcomers came to recognize this food as a delicacy. Grocery stores sell this wild floodplain vegetable after the spring freshet. The spring freshet waters contain a toxic cocktail of contaminants, which means this Wolastoqiyik food could be a health concern.

LD: Is there a common perspective within Wolastoqiyik communities about the state of the environment of Wolastoq River?

CB: I think the perspective is that it is ruined by pollution. They understand that run off going into the river is carrying pollutants. I think the perception is best illustrated in their confidence in the foods and the medicines they are collecting. Many have said that they won't eat some of the plants from the river. Some still eat foods from some areas, but they caution and they question. I have been repeatedly asked during my travels as Water Grandmother to test the water and the plant foods and medicines. Many community members have expressed a concern that the pollutants in the water and the associated plants and animals are the cause of the high rates of cancer in their communities. A 2009 study conducted by the UNB Nursing Department in collaboration with the Union of New Brunswick Indians (UNBI) found that a

sample of New Brunswick First Nations people, in known areas of contamination, have a cancer rate of nearly 10% compared to the overall New Brunswick's cancer rate of 2% (Getty 2009). This study was focused on the health of New Brunswick First Nations and the possible contamination of specific wild foods by environmental pollutants. Many people have a sense that Wolastoq River has changed. This perception is correct, however the studies that confirm the changes are not reaching the ears and eyes of the people who continue to rely on Wolastoq River as a source of food.

I think the perception is very clear that Wolastoq River is not the way she used to be. Wolastoqiyik people understand this because their parents and grandparents have shared stories similar to the ones my father has shared about the vibrant state of the environment in the past.

LD: What concerns have Wolastoqiyik people shared with you as Nuhkmoss Samaqan about the environmental state of Wolastoq River?

CB: I have repeatedly heard the Wolastoqiyik cultural teaching that everything we do to the land will eventually impact our waters and as a result will impact all living things. Without water we cannot live and activities that are contradictory to this understanding are occurring. Wolastoqiyik people want to be a part of the solution.

Many of the concerns that have been shared with me so far by Wolastoqiyik community members are about the source waters of Wolastoq that provide drinking water and the effect this has on the quality

“The authors believe that while ecosystem health can be measured quantitatively, i.e., scientifically, you cannot do so without first listening to what Saint John River communities and stakeholders value or see as being important determinants of ecosystem health.

Chapter 12 Next Steps, p. 165

of the drinking water. Although the goal for the Water Grandmother project in the first year was to build awareness about drinking water quality issues in FN communities I quickly learned that many are aware of the issues and want to know what will be done to alleviate these problems. They are also aware that the contaminants introduced to the source waters are not removed in the treatment process. They expressed a desire to have more input on the policies and activities that effect our environment so that our way of thinking becomes a part of the decision making process. Kidney disease, obesity and cancers are attributed to diet and lifestyle, but they are also caused by environmental contamination (Getty 2009). Our lifestyle has been greatly affected by what has happened to the lands and waters we depend upon to maintain the traditional lifestyle.

The sensory taste of water may be viewed as a subjective trait that is dependent on many variables. At the same time it is a tool that many Elders have used to describe what they have noticed about the changes in their water. I heard one particularly memorable story from an Elder in a community that had been using well water until quite recently. The community has now installed a water treatment system.

This Elder told me that he does not drink the water straight out of the tap anymore because of the taste. He added that the taste is not as noticeable if he boils the water to make tea. This Elder asked me why they switched from the wells when there was nothing wrong with the water before. Now the water has a chemical flavor. I explained that chlorine is added to the water to keep it free of microbes. He responded that this must be because of all the waste that was being introduced into the source water. The Elders' understanding of the change in water access and treatment illustrates two things: the first is a sense and concern about the possible negative effects of adding chemicals to the drinking water, the second point is a concern that these chemical additives are now necessary because of the contaminated state of Wolastoq River today.

Wolastoqiyik people, like most New Brunswickers, would prefer contaminants were not entering the source water of Wolastoq River. They however recognize that it is too late to prevent what has already occurred. At the same time they hope that the future will bring about changes that will mitigate further damage to this precious resource, a key part of their identity as their namesake.

“Generally, water was of poorer quality in the 1960s but it has improved in recent years, especially since 2000. ... The improvement since the 1960s is most likely the result of more and better treatment of municipal and industrial wastewaters”.

Chapter 6 Water Quality, p. 89

LD: How can Wolastoqiyik contribute to a better understanding of the state of the environment of the Wolastoq?

CB: There is a long history of mistrust between First Nations and various governments and I think it is therefore very important that Wolastoqiyik are involved directly with environmental monitoring. For example, in many communities where Health Canada or Environment Canada or the New Brunswick Departments of Environment or Natural Resources have come in and completed testing, say on water quality, and published reports the validity of the information is not trusted. The reason for this is typically because community members were not the ones doing the testing.

On the other hand, I have heard some community members say that they don't think the levels of pollutants are that bad.

“Despite these changes, there are still several stretches of the river near our urban centres, industries, and agricultural lands that should concern us. Consequently, there remains a need to continue to improve how we manage our activities that can and do impact the river's water quality and thus its environmental condition.”

Chapter 11 Conclusions, p. 159

When their traditional foods are highly contaminated, they are told by government agencies not to eat that food. However, they believe the dominant society is trying to stop them from being Wolastoqiyik. Being Wolastoqiyik means being able to go out and fish and hunt and collect food, and

sustain themselves off the land. Again, if Wolastoqiyik were involved directly with environmental monitoring perhaps this mistrust would be lessened

This cycle of mistrust can be fixed by including Wolastoqiyik in finding solutions. Relationships need to be mended and new ones need to be made. The foundation of that relationship could be the shared interest of the scientific community and the First Nations in environmental concerns. Cooperation through the inclusion of First Nations, in finding solutions, would be a great starting point. TEK needs to be honoured and this can be achieved through involving more First Nations people in the process. This shows respect for our way of life.

LD: What steps does the scientific community need to take in order to get a better understanding of the Wolastoqiyik perspective on the state of the environment of Wolastoq River?

CB: The scientific community is the trusted authority in this society when it comes to understanding what is happening to our environment. Increasingly First Nation TEK is being acknowledged as a valid and reputable perspective in relation to the use and treatment of the lands and waters. The time is right to link the two in a mutually respectful way for the greater good of society. Initial steps can be taken by the scientific community in the areas of education and outreach. The CRI is currently taking this step through the Water Grandmother project. Our goals for the project are to build awareness of water quality issues in the First Nations communities and to provide a window of opportunity in water science education. In

2010, the first year of the project, we succeeded in introducing the goals of the project to the communities and continuing to develop educational initiatives that will provide opportunities for youth in New Brunswick, including First Nations youth, in the area of environmental management.

9.3 Conclusion

I have chosen to share my perspective on the environmental state of Wolastoq River as a conversation. My people, Wolastoqiyik, have shared and continue to share their traditional ecological knowledge of Wolastoq through stories and experience on the land and in the water. The TEK stories of my Elders provide a complementary picture of Wolastoq River to those expressed by the various scientific perspectives in this manuscript. My role as Samaqan Nuhkmoss (Water Grandmother) for the CRI will allow me to build respect and understanding between Wolastoqiyik traditional knowledge holders and the

“... everything we do to the land will eventually impact our waters and as a result will impact all living things. Without water we cannot live”.

Chapter 9 Traditional Ecological Knowledge, p. 153

scientific community; and in so doing achieve and promote a greater depth and breadth of knowledge about Wolastoq and how to take better care of her and the land around her.

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10. Looking to the Future: Climate Change

Scott Kidd

Near-future climate change has the potential to alter the environmental conditions of the Saint John River Basin, which will in turn alter the state of the Saint John River. Any additional impacts of our activities, such as more wastewater from an increasing population or more runoff from the impervious cover in expanding urban areas, will only add to this change.

Natural Resources Canada (NRCAN; 2010) predicts that western New Brunswick will have a 2 to 4°C increase in summer temperatures in addition to an approximate 2°C increase in winter temperatures by 2050. There will likely be more very hot days and fewer very cold ones. The amount of precipitation is also expected to increase in the Saint John River Basin. With these projected changes in climate, there will also be higher rates of summer evapotranspiration, which is the transfer of water from the ground to the atmosphere by evaporation from waterbodies and transpiration by plants. In winter, the amount of precipitation that falls as rain versus snow will increase. Finally, precipitation events are expected to be more intense, i.e., more rain will fall in shorter periods of time.

Some of the more dramatic predicted impacts the new environmental conditions will have on the underlying state of the Saint John River Basin follow below.



Decline in summer stream flows

It is predicted that by 2050 there will be less water flowing through the Saint John River and its tributaries during the summer months than there is today (NRCAN 2010). One main cause of this will be the higher evapotranspiration rate which will more than offset the increase in precipitation. In addition, the reduced snowpack will lead to less snowmelt replenishing groundwater and basin streams in the late spring and early summer.

There is already evidence of a decline in annual water flow in the Saint John River associated with warming temperatures. Bruce et al. (2003) reported that from 1900 to 2000 the average annual temperature in the basin rose by 1°C, with much of this increase occurring after 1970. They also noted a corresponding 13% decrease in the average annual flow of the Saint John River Basin at Fort Kent near Grand Falls from 1970 to 2000.

This decrease in summer flows will need to be considered by decision-makers when they determine the minimum flow-through

requirements of dams in the basin. As discussed earlier in this report, the state of the river has already been negatively impacted by how its flow regime is presently managed. Not compensating for lower stream flows caused by climate change will only worsen the situation.

Increase in stream temperatures

Monk and Curry (2009), based upon two climate change scenarios, predict that warmer air temperatures in the region will be accompanied by an increase in stream temperatures. This is projected to lead to an increase in the number of weeks these streams experience temperatures that exceed 20°C, which they propose as the threshold of thermal stress for Atlantic salmon. This could cause a reduction in cold-water refuges in the river for fish like Atlantic salmon and brook trout, and more habitat available for warm-water fishes like yellow perch. It also emphasizes the importance of maintaining or increasing present amounts of groundwater contributions to cold water habitats. As such, the future diversity and abundance of the river's fishes will likely be different.

Other predicted impacts of climate change

NRCAN (2010) predicts there will be fewer wetlands in the Maritimes because of changing land use and more droughts. Forests, which play a pivotal role in their streams' ecology, will be different in the basin. The distribution of forest types will change because of warmer temperatures, greater potential for and likely more forest fires, and more and different pests. More intense storms will lead to increased runoff from agricultural and urban areas because rainwater will have less time to infiltrate

the ground. More sediments and pollutants will be carried into streams with this increased runoff.

To conclude, the few of the many predicted impacts of climate change on the Saint John River Basin discussed in this chapter make it clear that future management of the river must take climate change into account. Failing to do so will result in the river declining from its present state even if our other impacts on it do not increase.

References

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11. Conclusions

R. Allen Curry
Scott Kidd

Since the last extensive surveys in the 1960s and 70s, there have been improvements in various indicators of environmental quality along the Saint John River, a few fundamental changes in its physical conditions and associated biological processes and communities, and some stretches where the river continues to be negatively impacted by our developments, land use, and other activities (see **Figure 11.1**).

The overall quality of water in the river has improved in the last 40 years. Some areas in the river have experienced decreases in nutrients, metals, and bacteria and increases in dissolved oxygen. The improvements have occurred because communities and industries are doing a better job of treating wastewater before discharging it to the river, there are more stringent regulations and laws, and there is better monitoring by the regulatory agencies in Canada and the USA. This improved water quality benefits the ecosystem as well as reducing risks to human health associated with drinking water and recreational use of the river.

Despite these changes, there are still several stretches of the river near our urban centres, industries, and agricultural lands that should concern us. Consequently, there remains a need to continue to improve how we manage our activities that can and do impact the river's water quality and thus its



environmental condition. The state of the river continues to be far from ideal in the Edmundston area and in the middle reach downstream of the Beechwood Dam. We continue to discharge poorly treated and sometimes untreated sewage into the river, which increases both bacterial counts and the potential risk to humans, and nutrient levels that accelerate algal growth and overload the river's natural equilibrium. After this excessive algal growth dies off, it and the organic wastes from municipalities decrease the river's dissolved oxygen when they are broken down by bacteria. Agriculture increases sediment loads to the river, and these sediments can also carry pesticides and nutrients to the aquatic environment. Forestry in the tributaries also adds sediments and alters temperatures by opening streams to sunlight and altering groundwater flows. Compounding these

effects are the sustained periods of low flow downstream of the Beechwood Dam. This situation exacerbates the problems of low oxygen and high primary production.

The Beechwood and Mactaquac Dams themselves have had a major impact on the river. These structures and their extensive headponds have changed the physical nature of the river. In addition to the change from a river to lake environment, many islands that are a defining feature of the Saint John River and that provide valuable habitat were submerged when the headponds were filled. Flow downstream of the dams is highly controlled because water is released almost exclusively to meet current or potential energy production demands. The dams are barriers to fish movement along the river. These physical changes in turn alter the biology of the river. Fish are unable to access upstream habitats, often the most critical areas of reproduction and rearing for several species, e.g., Atlantic salmon, American eels, and brook trout. Fish moving downstream have poor survival through the dam's turbines or when they fall over the dam itself, e.g., salmon smolts and adults. The creation of headpond reservoirs behind the dams also changed the fish community living there: more warmwater (e.g., yellow perch) and fewer coldwater (e.g., trout and salmon) fishes survive in these areas; non-native species that prefer lake-like environments are spreading (e.g., smallmouth bass, chain pickerel, muskellunge); more gaspereau (alewife and blueback herring) are found upstream of Mactaquac Dam now because they are trucked to and released in the headpond; and, species that used to spawn at the Mactaquac Dam location or upstream have not sustained successful reproduction since

the dam was built, e.g., striped bass and possibly Atlantic sturgeon. And in addition to the major hydroelectric dams, there are approximately 200 other dams in the Saint John River Basin that may be having similar impacts.

This report used the existing and accessible data that goes back to the 1950s to assess the state of the Saint John River and changes over time. There are still many areas of the river where data are sparse or missing or, if data exist, it is difficult to compare them because the collection methods were not the same over time or between sites. The assessment process can be improved to insure we can detect changes from the expected, natural conditions, but that requires the comprehensive spatial and temporal monitoring of the river's condition. This type of programme would also support regular reporting of the state of the environment, or a river report card. Such monitoring combined with this report's summary of our best current understanding and some directed research will be the cornerstones of successful future state of the environment reports for the Saint John River.

The Saint John River will continue to face a number of challenges. However, it is also important to realize that we have the knowledge and technology to better manage our wastewaters, river flows, and fish passage and, thus, overcome these challenges and significantly reduce our impacts on Wolastoq, the Beautiful Bountiful River.

Table 11.1 Saint John River reaches in the main stem where indicators of ecosystem status exhibit a condition that is different from the predicted natural state.

SOE chapter and environmental indicator	Reach											
	1A	1B	1C	2A	2B	2C	2D	2E	3A	3B	4A	4B
5 River habitats												
5.2 Hydrologic regime							X	X	X	X		
5.3 River gradient			X	X	X	X	X	X				
5.4.1 Temperature refuge from tributaries		X	X				X				X	
5.4.2 Edge habitats of islands			X			X		X				
5.5 Benthic invertebrates ^a		X					X					
6 Water quality												
6.2 pH							X	X				
6.3 Dissolved oxygen												
6.4.1 Metals - aluminum	X						X	X	X			
6.4.2 Metals - iron												
6.4.3 Metals - other												
6.5 Coliform bacteria		X	X	X	X	X	X	X	X	X	X	X
7 Primary production												
7.3 Total nitrogen	X		X	X	---	---	X	X	X	---	---	---
7.3 Total phosphorous	X	X	X	X	---	---	X	X	X	---	---	---
8 Fishes^c												
8.2 Fish community ^d	X	X	X	X	X	X	X	X				
8.3 Relative abundance							X					
8.4 Sentinel species		X	X		X	X	X					
8.5 Present fisheries									X	X	X	
9 Traditional knowledge												
9.2 Historical use of the river ^e					X	X		X	X			X

^a Conclusion is preliminary due to limited data.

^b No data were available.

^c Issues regarding the state of Atlantic salmon are not included, but discussed in Chapter 8.

^d Mactaquac Dam (border between Reaches 2E and 3A) restricts upstream fish passage.

^e Based primarily on the traditional ecological knowledge of residents of Pilick (Kingsclear First Nation) and Sitansisk (St. Mary's old reserve - Fredericton) in Reach 3A.

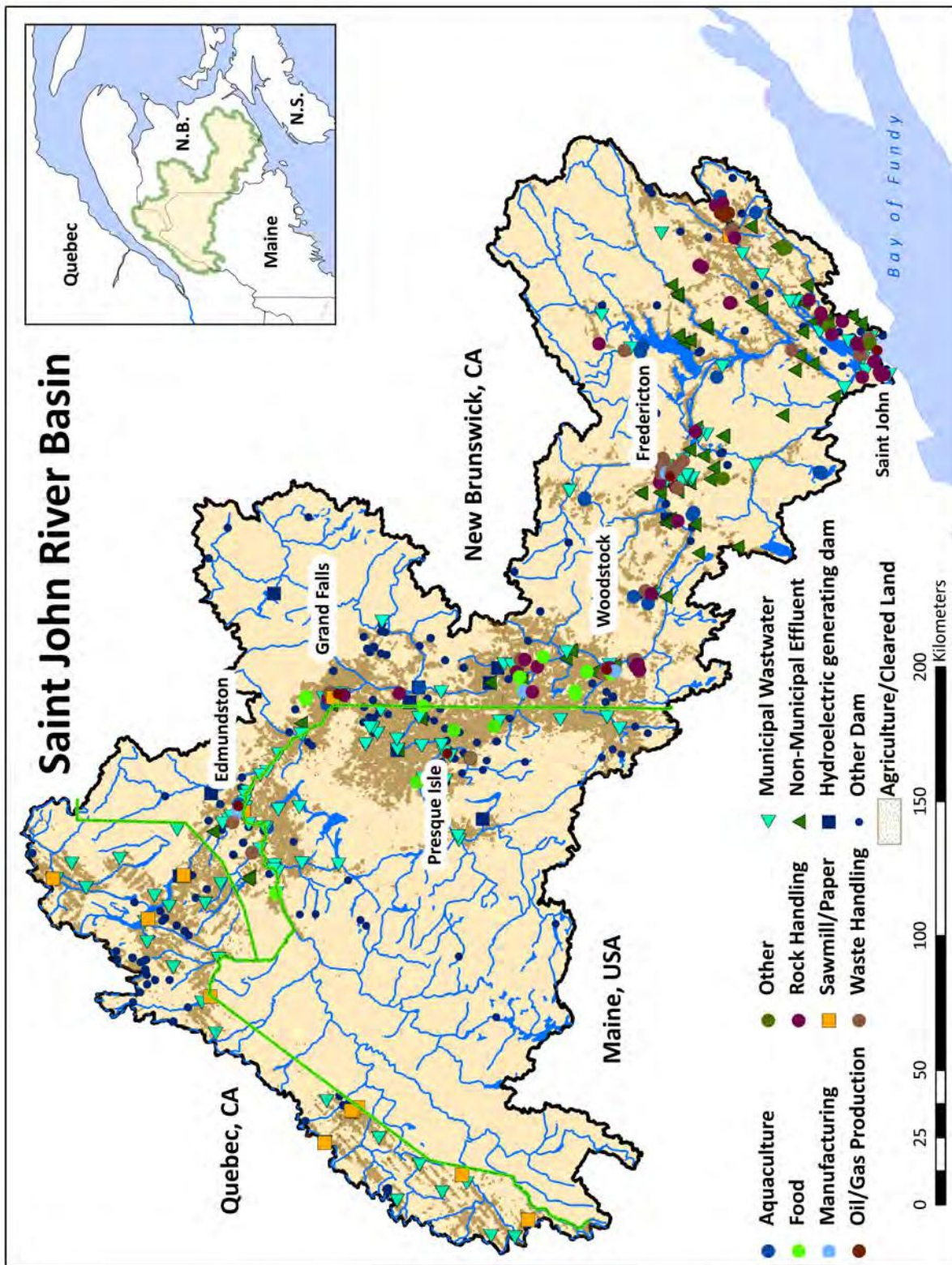


Figure 11.1 Known activities and operations potentially impacting the state of the Saint John River.

12. Next Steps

Scott Kidd
 Kelly R. Munkittrick
 R. Allen Curry

12.1 Future Research

The preparation of this report has illuminated that, while there is much we now know about the state of the Saint John River, there continues to be some large and glaring gaps in our knowledge. Some of the missing information, such as details regarding the river's benthic invertebrate community, is needed to address basic questions about the river's ecosystem. Other information, such as how much and the fate of effluents and runoff entering the, would help answer the more complex questions about our impact on its state. What follows below, in no particular order, are examples of future studies and work that should be undertaken to help improve our understanding of the state of the Saint John River.

- Comprehensive spatial and temporal monitoring of the river's condition: Establish a series of sampling sites along the main stem of the river and in its tributaries at which a suite of common measures of the physical (e.g., temperature and water levels), biological (e.g., fish and benthic invertebrate communities), and chemical (e.g., water quality parameters) states of these waterways are collected on a regular basis and in a manner that insures we can statistically detect changes from natural conditions.



- Improve our understanding of the effect of dams on the ecosystem, e.g., fish passage success for all species, the seasonal minimum flow requirements to protect the ecosystem, and the impacts of the headpond reservoirs on the ecosystem.
- Better monitoring and assessment of pollutants entering the river from currently unregulated and non-point sources.
- Improve our understanding of the real and potential impacts of land-use and land-clearing on the state of the river.
- Studying the cumulative effects of multiple inputs and activities along the river.
- Monitoring and assessment of the river's species at risk.
- Continuing to study the role of invasive species in the river's ecosystem.
- Studying the fate of sediments and contaminants in the Saint John Harbour that are carried upstream with the tide.
- Evaluating the impact of local sources of air pollution on the river.

All of these together demonstrate the need for a comprehensive monitoring

programme, one that considers the spatial and temporal characteristics of the river's ecosystem including all human activities and inputs.

12.2 Advancing Cumulative Effects Assessment

We need to also use our improved understanding of the state of the Saint John River to make environmental assessments more effective and better predictors of what impacts future developments and other human activities will have on the river. In multi-use river systems such as the Saint John, the most effective approach is a cumulative effects assessment (CEA). A CEA determines the response to accumulating stressors along a river and it is critical for understanding how adding new stressors will impact a system. An effective CEA requires a good understanding of an ecosystem's environmental state which we have now presented for the Saint John River.

How to conduct a CEA is an evolving discussion in environmental assessment and management. The Canadian Rivers Institute (CRI) in collaboration with its partners is investigating best approaches and we are using the Saint John River to test some hypotheses.

Much of the focus of the CRI's work on the Saint John River over the last decade has been on testing and developing new methods and approaches for looking at both the cumulative effects in the river (accumulated state of the environment) and the river's assimilative capacity (a prediction of whether more development

will surpass a threshold and create problems). Regardless of the approach taken, there are a number of concerns that affect interpretation of data, including what to use for a reference site, how much natural variability there is between sites, between months and between years, and how big a difference from normal should be considered important. These questions have been the foundation of much of the CEA work that has gone on, in addition to trying to understand what organisms make the best sentinels for detecting environmental impacts, when to sample them, how to sample them, and what to measure on them.

We have learned a great deal over the last decade working in the basin but, as we demonstrate in this report, there is still more to do. There are several steps that need to be taken, including returning to priority areas of concern for further study, establishing long term monitoring sites to track the state of the river, and extending the studies down to the estuarine, harbour and nearshore areas off the river mouth. There is a group of studies already starting focused on developing a regional monitoring framework for the harbour, and identifying indicators, reference sites and triggers to develop an adaptive monitoring framework. It is one of five nodes established by the Canadian Water Network in a national consortium program focused on developing regional monitoring frameworks for cumulative effects assessment (www.cwn-rce.ca). Building on this work and the past research described in this report will advance our understanding and practice of cumulative effects assessment and will, in turn, lead to better

environmental assessments and decision-making in the Saint John River Basin and across Canada.

12.3 Developing a Report Card for the Saint John River

Now that we have a better understanding of the state of the environment for the Saint John River, it would be logical to continue monitoring and reporting on its health. Across Canada and around the world, this is often done using a watershed or river *report card*. These present an easy-to-understand snapshot of a watershed to the public and decision-makers. The report card assesses the state of various indicators in a watershed and then gives a score or grade to each indicator. River communities and stakeholders typically choose to assess environmental, social, cultural, and economic indicators of the things they value, such as the status of recreational fisheries. These scores are combined and final grades are assigned for individual sites along a river and the entire river. Report cards are prepared every 1-2 years, allowing everyone along a river to monitor changes, good or bad, and thus they help drive how a river is managed over time.

This state of the environment report for the Saint John River is *not* a report card. Care has been taken in the writing of this report to not detail, describe, or reach conclusions regarding the overall “health” of the Saint John River. The authors believe that while ecosystem health can be measured quantitatively, i.e., scientifically, you cannot do so without first listening to what Saint John River communities and stakeholders value or see as being important

determinants of ecosystem health. Science with its data, such as those we report here, can provide guidance, but deciding upon indicators and the weight to be given to them requires input from communities and stakeholders before a report card on the health of the Saint John River can be presented.

Appendix

Canadian Rivers Institute Publications: Saint John River

The Canadian Rivers Institute (CRI) has conducted >100 studies on the Saint John River since 2001, including graduate student theses and projects (>40), scientific publications and reports (60), and a variety of ongoing research projects (>20).

Theses Related to Saint John River: Ph.D.

1. Curry, C. Factors determining odonate biodiversity and distribution as well as the functional role of predaceous invertebrates in benthic food webs. *In progress*
2. Noel, L. Community resilience in regulated rivers. *In progress*
3. Barrett, T. Sentinel fish species suitability in the Saint John River. *In progress*
4. Loomer, H. Effects of agriculture on nutrient storage within the food webs of headwater streams. *In progress*
5. Bosker, T. 2009. Short-term adult fish reproductive tests: evaluation, refinement and application.
6. Jardine, T. 2008. Development of tools to trace organic matter and assess mercury bioaccumulation in streams and rivers.
7. Brasfield, S. 2006. Evaluation of multiple stressors associated with potato farming and their potential impacts on fish populations.
8. Galloway, B. 2005. Evaluating the suitability of fish species for environmental monitoring programs.
9. Gray, M. 2003. Assessing non-point source pollution in agricultural regions of the upper St. John River basin using the slimy sculpin.

Theses Related to Saint John River: M.Sc.

10. Somers, G. Land use and riparian zones in the Kennebecasis River. *In progress*
11. Higgins, H. 2011. Suspended sediment dynamics in a tributary of the Saint John River, New Brunswick.
12. Foster, E. 2010. Nutrient status variability in the Kennebecasis and Nashwaak watersheds.
13. Sollows, M. 2010. Size, age distribution and conservation status of the freshwater pearl mussel *Margaritifera margaritifera* (L.) in the Kennebecasis River, New Brunswick, Canada.
14. Grace, L. 2009. The effects of agricultural practices on metabolic rates in stream environments.
15. Merrill, S. 2009. Social-psychological indicators of private land management in the Canaan-Washademoak watershed, New Brunswick.
16. Smedley, R. 2009. Fish condition and community structure in an agricultural landscape.
17. Adams, J. 2008. Response of fish populations to mitigation at an oil refinery.
18. Melvin, S. 2008. Reproductive endocrine response of two small-bodied fish, the mummichog and the fathead minnow, exposed to pulp mill effluent.

19. McMullin, V. 2008. An investigation of temporal and spatial reproductive variability associated with northern mummichog spawning activity in the lower Saint John River.
20. Arciszewski, T. 2007. Stable isotope signatures and condition indices in fish and invertebrate populations in the Upper Saint John River.
21. Arens, C. 2007. Nearshore fish community structure in the Southern Bay of Fundy.
22. Casselman, J. 2007. Fish communities in Saint John Harbour.
23. Tenzin, K. 2006. The design of a non-lethal fish monitoring program for rivers in Bhutan.
24. Goldschneider, A. 2006. River sediment and flow characteristics near a bank filtration water supply: Implications for riverbed clogging.
25. Dawe, M. 2006. Assessing infiltration velocities during riverbank filtration.
26. Keeler, R. 2005. Development and application of passive integrated transponder technology to investigate the movement and reproductive ecology of adult slimy sculpin in small New Brunswick streams.
27. Freedman, J. 2005. Movement patterns and trophic structure of a reservoir fish community assessed using stable isotope analysis.
28. Vallieres, G. 2005. An effects-based assessment of the health of fish in a small estuarine stream receiving effluent from an oil refinery.
29. Doherty, C. 2004. Movement patterns and biology of white sucker in a riverine environment exposed to multiple stresses.
30. Flanagan, J. 2003. The impacts of fine sediments and variable flow regimes on the habitat and survival of Atlantic salmon (*Salmo salar*) eggs.
31. Vallis, L. 2003. The potential use of rock gunnel (*Pholis gunnellus*) as a bioindicator in Saint John Harbour, New Brunswick, Canada.
32. Hanson, S. 2002. Size structure and trophic interactions of age-0 river herring and age-0 smallmouth bass in the Mactaquac reservoir and Oromocto Lake, New Brunswick.
33. Petrunic, B. 2002. Reductive dissolution of manganese oxides in river-recharged aquifers: Laboratory-scale investigations.

B.Sc. Honours Theses Projects

34. Doyle, M. 2009. Use of Atlantic silverside for assessing inputs to Saint John Harbour.
35. Hanson-Lee, M. 2007. Development of a fish caging protocol for environmental effects monitoring in the Saint John Harbour.
36. Carroll, L. 2007. The reproductive cycle of the redbelly dace (*Phoxinus eos*).
37. Loomer, H. 2006. Swimming in sewage: indicators of faecal waste on fish in Saint John, New Brunswick.
38. Young, D. 2006. Assessing the variability in testosterone production in the slimy sculpin.
39. Mitchell, C. 2004. A histological comparison of mummichog (*Fundulus heteroclitus*) in contaminated streams entering the Saint John Harbour.
40. Hodder, M. 2004. Assessing the occurrence of bank filtration and selected municipal well fields in New Brunswick.
41. Halford, A. 2003. Tracking of muskellunge in the Saint John River.

Research Papers Related to the Saint John River

2011

1. Jardine, T.D., and Kidd, K.A. 2011. Low concentrations of selenium in stream food webs of eastern Canada. *Sci. Total Environ.* 409: 785-791.
2. Higgins, H., St-Hilaire, A., Courtenay, S.C., et al. 2011. Suspended sediment dynamics in a tributary of the Saint John River, New Brunswick. *Can. J. Civil Engin.* 38: 221-232.
3. Smedley, R.A., and Curry, R.A. 2011. Testing the severity of ill effects model for predicting fish abundance and condition. *N. Am. J. Fish. Mgt.* (in press).

2010

4. Curry, R.A., and Gautreau, M.G. 2010. Fishes of the Atlantic Maritime Ecozone. In: (Eds., D.F. McAlpine and I.M. Smith) *Assessment of Species Diversity in the Atlantic Maritime Ecozone*. NRC Research Press, Ottawa, Canada.
5. Curry, R.A., Bernatchez, L., Whoriskey, F., et al. 2010. The origins and persistence of anadromy in brook charr. *Rev. Fish. Biol. Fisheries* 20: 557-570.
6. Doherty, C.A., Curry, R.A., and Munkittrick, K.R. 2010. Spatial and temporal movements of white sucker: implications for use as a sentinel species. *Trans. Amer. Fish. Soc.* 139: 1818-1827.
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8. McMullin, V.A., Munkittrick, K.R., and Methven, D.A. 2010. Spatial variability of reproductive and size characteristics of the northern mummichog (*Fundulus heteroclitus macrolepidotus*) collected near municipal wastewater discharges. *Water Qual. Res. J. Can.* 45: 25-34.
9. Barrett, T.J., and Munkittrick, K.R. 2010. Seasonal reproductive patterns and recommended sampling times for sentinel fish species used in environmental effects monitoring programs in Canada. *Environ. Rev.* 18: 115-135.

2009

10. Bosker T., Hewitt, L.M., Munkittrick, K.R., Melvin, S.D., and MacLatchy, D.L. 2009. The effects of final treated effluent and in-mill waste streams from a Canadian thermomechanical pulp and paper mill on mummichog (*Fundulus heteroclitus*) reproduction. *Water Qual. Res. J. Can.* 44: 333-344.
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Current Studies on the Saint John River

<u>Research Lead</u>	<u>Topic</u>
1. Baird	Nashwaak, Canaan, Little River and Grand Lake Meadows
2. Benoy	Sediment impacts
3. Courtenay	Estuarine nutrient issues
4. Culp	Food web structure/function, Edmundston, Florenceville
5. Culp	Nutrient status headwaters to Fredericton
6. Culp	Nutrient status Nashwaak & Kennebecasis
7. Cunjak	Salmonid egg hatching, tributaries
8. Curry	Downriver fish community
9. Curry and Cowie	NB Aquatic Data Warehouse
10. Dalton	Canaan-Washademoak, Nashwaak /F'ton watersheds
11. Haralampides and MacQuarrie	Riverbed sediment studies, Fredericton
12. Hewitt	Pesticides, Little River
13. Kidd	Food web studies
14. Methven	Estuarine species/reversing falls
15. Moir	Economic perspectives on environmental issues
16. Munkittrick	Assimilative capacity studies
17. Munkittrick	Sentinel species Kennebecasis/Rockwood
18. Munkittrick	Poultry plant impacts
19. Teather	Sediments from agricultural areas