Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/006

Maritimes Region

Assessment of the Recovery Potential for the Outer Bay of Fundy Population of Atlantic Salmon: Threats to Populations

C.N. Clarke[1], S.M. Ratelle[2], and R.A. Jones[1]

Fisheries and Oceans Canada
Science Branch, Maritimes Region

[1]Gulf Fisheries Centre
P.O. Box 5030
Moncton, NB E1C 9B6

[2]Mactaquac Biodiversity Facility
French Village, NB E3E 2C6

November 2014

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Clarke, C.N., Ratelle, S.M., and Jones, R.A. 2014. Assessment of the Recovery Potential for the Outer Bay of Fundy Population of Atlantic Salmon: Threats to Populations. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/006. v + 103 p.

TABLE OF CONTENTS

Abstract........iv
Résumé........v
Introduction........1
Potential Sources of Mortality........2
Freshwater Water Threats........2
Acidification........3
Climate - Extreme Water Temperature Events........3
Silt and Sediments........4
Pollutants, Chemical, and Wastewater........5
Military Activities........8
Other Power Generation........9
Invasive/Non-native Species Occurrence and Stocking........10
Atlantic Salmon Stocking........12
Other Native Salmonid Stocking........16
Hydro Dams and Obstructions........16
Roads, Culverts and Other Crossing Infrastructure........22
Urbanization........23
Agriculture........24
Forestry........25
Mining........26
Directed Fisheries - Freshwater (Recreational, Aboriginal, Commercial, Illegal)........27
By-catch - Freshwater (Recreational, Aboriginal, Commercial)........28
Freshwater Threats Summary........29
Marine Threats........29
Salmon Aquaculture........29
Shifts in Marine Environment........33
Parasite and Disease........36
Depressed Population Phenomena........38
Shipping Traffic........39
Directed Fisheries and By-catch - Marine/Estuarine........39
Marine Threats Summary........41
Threats Applicable to Freshwater, Estuarine, and Marine Environments........42
Scientific Research........42
Proposed Cumulative Threat Impact Assessment........43
Acknowledgements........44
Literature Cited........44
Tables........63
Figures........82
Appendicies........97
Appendix 1........97
Appendix 2........101

ABSTRACT

This research document provides a compilation of information and review of major threats currently thought to impact the persistence of wild Atlantic Salmon in the Outer Bay of Fundy (OBoF) Designatable Unit (DU). Over 90% of the wild salmon and accessible habitat in this unit lie in the Saint John River (SJR) and its tributaries which, aside from the St. Lawrence, compose the largest river in northeastern North America. Thus, the status of the entire DU population weighs heavily on the status of the SJR. The impacts of threats to Atlantic Salmon vary in dimensions of space, time, and severity. As such, attempts have been made to provide dimensional context for each threat although limitations of available information were encountered. Nearly all threats discussed here have been documented for their effect on salmon populations; however, many have not been directly reported for their effects on OBoF Atlantic Salmon. The information presented here intends to provide only a summary of knowledge on the extent and magnitude each threat poses to this population in either the freshwater or marine environment. Most of this information contributed to the development of a Recovery Potential Assessment (RPA) Science Advisory Report (SAR) for the OBoF Atlantic Salmon population (or DU 16; DFO 2014).

To the extent available data permits, each threat has been assessed a rank of concern relative to other threats to the population. Threats thought to be most limiting population recovery ranked as highest concern. Following past science advice for improving threats assessments for species at risk, a proposed approach is presented for assessing accumulated threat impact on each river.

The threat of highest concern in the freshwater environment, and for the entire DU, stems from the gauntlet of hydro dams facing migrating salmon. The most significant structure is the Mactaquac hydro-generation dam on the SJR, above which lies 36% of the entire DU habitat relying on manual operations to truck salmon above the dam to complete upstream migrations. Aside from the obvious barriers to upstream migration, hydro dams on the SJR affect flow and temperature regimes, which are critical to/for migration cues, alter food web and aquatic community structure, and harbour a growing abundance and diversity of non-native predators to salmon within reservoirs and tailraces. Smolts migrating from systems upstream of Mactaquac Dam have been shown to experience up to 45% additive mortality when passing through three major hydro dams.

Marine threats of highest concern include: depressed population phenomena, salmonid aquaculture operations and shifts in oceanic conditions caused by changes in climate.

Effects of depressed population phenomena are often difficult to quantify but are expected to contribute to the negative effects caused by most other individual threats. Shifts in oceanic conditions may be resulting in unfavorable temperature, current, and predator/prey conditions which contribute to reductions in survival during the salmon’s marine life phase. Aquaculture operations, although less studied in Atlantic Canada than elsewhere, affect wild salmon in several ways including altered pathogen/predator/prey dynamics and through the interactions of wild and escaped farmed salmon.

Évaluation du potentiel de rétablissement de la population du saumon de l'Atlantique de l'extérieur de la baie de Fundy : Menaces à la population

RÉSUMÉ

Le présent document de recherche fournit une compilation de renseignements et un examen des principales menaces que l'on estime aujourd'hui avoir une incidence sur la pérennité du saumon sauvage de l'Atlantique de l'unité désignable (UD) de l'extérieur de la baie de Fundy. Plus de 90 % du saumon sauvage et de l'habitat accessible dans cette unité se trouvent dans la rivière Saint-Jean et ses affluents qui, à l'exception du fleuve Saint-Laurent, constitue la plus grande rivière dans le nord-est de l'Amérique du Nord. Par conséquent, la situation de l'ensemble de la population de l'unité désignable pèse lourdement sur l'état de la rivière Saint-Jean. L'incidence des menaces pesant sur le saumon de l'Atlantique varie selon les dimensions limitées par l'espace, le temps et la gravité. À ce titre, des tentatives ont été faites pour fournir un contexte dimensionnel pour chaque menace, malgré le caractère parfois limité des renseignements disponibles. Presque toutes les menaces évoquées dans ce texte ont été documentées pour leurs effets sur les populations de saumon; toutefois, bon nombre d'entre elles n'ont pas été directement signalées pour leurs effets sur le saumon de l'Atlantique de l'extérieur de la baie de Fundy. L'information présentée ici ne vise qu'à fournir un résumé des connaissances sur l'étendue et l'ampleur de chaque menace posée à cette population dans le milieu d'eau douce ou marin. La plupart de ces informations ont contribué au développement d'une évaluation du potentiel de rétablissement d'un avis scientifique de la population de saumon de l'Atlantique de l'extérieur de la baie de Fundy (ou unité designable 16; MPO 2014).

Dans la mesure où les données disponibles le permettent, chaque menace a été évaluée selon le degré de préoccupation par rapport à d'autres menaces pour la population. Les menaces considérées comme étant les plus limitatives pour le rétablissement des populations ont été classées comme les plus préoccupantes. En suivant les avis scientifiques antérieurs pour améliorer les évaluations des menaces touchant les espèces en péril, une approche proposée est présentée pour évaluer l'incidence, sur chaque rivière, des menaces accumulées.

La menace la plus préoccupante dans le milieu d'eau douce, et pour l'ensemble de l'unité désignable, provient du couloir de barrages hydroélectriques que doit franchir le saumon migrateur. La structure la plus importante est le barrage hydroélectrique Mactaquac sur la rivière Saint-Jean, au-delà duquel se trouve 36 % de l'ensemble de l'habitat du saumon de l'unité désignable; le franchissement de cet obstacle exige de manipuler les saumons pour effectuer leur transfert par camion et leur permettre ainsi de compléter leur migration en amont. À l'exception des obstacles évidents posés à la montaison, les barrages hydroélectriques sur la rivière Saint-Jean ont un effet sur les régimes d'écoulement et de température, lesquels sont cruciaux pour les signaux de migration; ils modifient également le réseau trophique et la structure de la communauté aquatique et abritent une abondance et une diversité croissantes de prédateurs non indigènes au saumon dans les réservoirs et les canaux de fuite. Les saumoneaux migrant des systèmes en amont du barrage de Mactaquac ont présenté jusqu'à 45 % de mortalité ajoutée au moment de traverser trois grands barrages hydroélectriques.

Les menaces en milieu marin les plus préoccupantes comprennent : le phénomène de dépression des populations, les exploitations salmonicoles et les changements dans les conditions océaniques causés par les changements climatiques.

Les effets du phénomène de dépression des populations sont souvent difficiles à quantifier, mais ils devraient contribuer aux effets négatifs causés par la plupart des autres menaces individuelles. Les changements dans les conditions océaniques peuvent entraîner des conditions défavorables de la température et du courant ainsi que des conditions prédateur-proie qui contribuent à la réduction de la survie au cours de la phase de la vie marine du saumon. Les opérations aquacoles, bien qu'elles soient moins étudiées dans le Canada atlantique qu'ailleurs, touchent le saumon sauvage de plusieurs façons, notamment par la modification de la dynamique pathogène/prédateur-proie et par les interactions entre le saumon sauvage et le saumon d'élevage qui s'échappe.

INTRODUCTION

This research document is a follow-up to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designation of the Outer Bay of Fundy [OBoF; Designatable Unit (DU) 16] Atlantic Salmon as ‘endangered’. It presents current understanding of threats to the OBoF salmon and its habitat to support the development of a Science Advisory Report for the recovery potential assessment for OBoF salmon (DFO 2014). This document addresses terms of reference [ToRs] items 9, 16, and 18 (Threats considerations) in Appendix 1 to support the development of the Recovery Potential Assessment (RPA) species advisory report. *Population Status and Trends, Population Viability Analyses, Genetic Considerations, and Habitat Considerations* companion documents address remaining ToRs for the RPA.

In this document, the term “threat” is used in the manner defined by the National Recovery Team (DFO 2010) as “any activity or process (both natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to a species at risk or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur.” COSEWIC (2010) further distinguishes among:

1. actual threats “those that are imminent and can result in harm and population-scale impacts”,
2. threats “that are clearly imminent but the harm to the populations is uncertain”,
3. threats “whose imminence is uncertain but harm is likely if they occur”, as well as,
4. threats “where the imminence and harm are both hypothetical but possible”.

In this document, ‘threats’ will be categorically presented as described by COSEWIC (2010) as they apply to each of the 20 rivers identified within the OBoF or DU 16. This geographic area has been characterized in the past by Fisheries and Oceans Canada (DFO; DFO and MRNF 2008) and labeled Conservation Unit 17 (CU 17). DU labels, assigned by the COSEWIC, are used herein and although some references to CU labels remain, they describe the same area for this population of salmon. The threat categories listed are not presented in order of magnitude or significance.

The possible marine and freshwater threats, to the OBoF salmon, listed by COSEWIC (2010) include: acidification/air pollutants/acid rain, extreme temperature events, chemical contaminants, silt/sediment, waste water treatment, species stocking, dams (hydroelectric and water storage) and obstructions in freshwater, hydro/thermal/nuclear power generation, urbanization, agriculture, forestry, mining, fishing (aboriginal, recreational, commercial and illegal), by-catch in other fisheries, aquaculture effects, disease and parasites, and invasive species.

Atlantic Salmon are an anadromous species with a complex life history that involves residence in both freshwater and marine habitats over a life span of four, five, and six or more years. Adult OBoF salmon spawn in their natal rivers in October and November. Young develop until May or June in gravel nest pits (redds), emerge as fry, and grow as parr feeding on invertebrate drift. Parr ‘smoltify’ mostly after two or three years in fresh water and enter the ocean as post-smolts, where they grow rapidly to maturity. OBoF salmon first return to spawn in their natal rivers after one, two and occasionally three winters at sea. Some survive after reproduction, return to sea the subsequent spring and return again to spawn in consecutive and/or alternating years and are often referred to as ‘previous’ or ‘repeat’ spawners. Salmon returning after one and two winters at sea are called one sea-winter (1SW) and two sea-winter (2SW) salmon, respectively. The term multi-sea winter (MSW) salmon describes those maiden fish returning after two or more winters at sea, as well as repeat spawners.

Compared to their Inner Bay of Fundy (IBoF) counterparts, OBoF salmon differ by: having a higher incidence of maturation as 2SW fish, a lower incidence of females among 1SW fish and they conduct extensive migrations to the North Atlantic. They group separately from IBoF and most other populations at multiple allozyme loci and have therefore been considered a distinct regional grouping (DFO and MRNF 2008). A description of temporal and spatial habitat use for different life stages is provided in the OBoF salmon: Habitat considerations companion document (Marshall et al. 2014).

Outer Bay of Fundy salmon spawn in rivers flowing into the New Brunswick (NB) side of the Bay of Fundy between the USA-Canada border and the city of Saint John (Figure 1). On the basis of DFO and MRNF (2008), COSEWIC (2010), and Chaput (2012), 20 rivers are identified within the OBoF DU in which salmon or parr "are or were present within the last (and last half) century" and which flow into tidal water. Nine rivers flow independently into the Bay of Fundy, the Saint John River (SJR) upriver of Mactaquac Dam is considered one system, and 10 more are within the lower SJR basin where some portion is influenced directly by the incursion of estuarial/tidal waters (Kidd et al. 2011). The head of tide on the SJR is approximately 140 km upstream from the river's mouth to a point between the City of Fredericton and Mactaquac Dam.

This document addresses threats to the salmon populations in the SJR basin and the basins of southwestern New Brunswick discharging directly into the Bay of Fundy between the City of Saint John and the USA-Canada border. Table 1 contains a summary of each threat presented and includes a relative ranking of importance to the persistence of the OBoF salmon population based on presented information. Table 2 presents the estimated productive habitat of rivers considered for this DU and includes major tributary rivers of the Jemseg River and the SJR above Mactaquac Dam. The estimated productive habitat in the SJR comprises over 90% of the entire OBoF DU habitat. Further, over half (57%) of the productive habitat in the SJR occurs below the first major obstruction to fish passage, the Mactaquac Dam.

Because of the natural separation in habitat experienced by salmon during their life cycle, freshwater and marine/estuarine threats are addressed separately in most instances.

POTENTIAL SOURCES OF MORTALITY

FRESHWATER WATER THREATS

Fish are affected by physical habitat loss or degradation, pollution, overfishing and non-native species introduction, which have rendered them one of the most imperiled groups worldwide (Kraft 2009). Atlantic Salmon stocks within rivers, and often within tributaries of large rivers, have adapted to specific environmental conditions within their native rivers, which renders each stock susceptible to localized, and possibly cumulative stresses (Minns et al. 1995).

Habitat quality can be affected by:

- seasonal temperatures,
- stream discharge,
- water chemistry (e.g., pH, nutrient levels, oxygen concentration),
- turbidity,
- invertebrate abundance,
- physical perturbations (e.g., impoundments, deforestation), and
- connectivity, as well as many other factors (Gibson et al. 1993; Armstrong et al. 2003).

Atlantic Salmon streams are generally clean, cool and well oxygenated, characterized by moderately low (2 m/km) to moderately steep (11.5 m/km) gradients (Elson 1975), bottom substrates composed of assorted gravel, cobble and boulder, pH values greater than 5.3 (Amiro 2006), and low (<0.02%) silt loads (Julien and Bergeron 2006). Streams with about 70% riffle area appear to be optimum (Poff and Huryn 1998). Salmon prefer relatively stable stream channels that develop natural riffles, rapids, pools, and flats, which are utilized during different life stages. Low flows have been widely observed to delay entry of returning spawners to freshwater environments (Stasko 1975; Brawn 1982). At high flows, juvenile Salmon were noted to move from pool to riffle habitats (Bult et al. 1999), which is complementary to the noted preference for pools at low discharge (Morantz et al. 1987). This adaptability enables juvenile salmon to occupy extensive sections of streams that experience flow and temperature variation. Further discussion on OBoF salmon habitat is provided in the Habitat Considerations companion document by Marshall et al. (2014).[1]

Acidification

Lowered pH (acidification) in freshwater ecosystems may be a function of natural influences such as the drainage of organic acids from wetlands, or by anthropogenic impacts such as acid rain (Lacoul et al. 2011). Acidification affects aquatic organisms at all trophic levels, which can change productivity and biomass accumulation, as well as cause the extirpation of sensitive species (Lacoul et al. 2011). Although dependent on river conditions such as temperature and nutrient cycling, Atlantic Salmon (including eggs) are sensitive to pH levels below 5.3 (Amiro 2006). There are documented cases of signs of recovery following directed actions to mitigate acidity (Bowlby et al. 2014; Hesthagen et al. 2011).

During the 2007 Water Quality Survey conducted by the NB Department of Environment (NBDOE), which collected samples from throughout several major watersheds of New Brunswick, the Digdeguash, Hammond, Magaguadavic and St. Croix contained samples with acidic pH (<6.5) with the Digdeguash and Magaguadavic samples being the highest (Science and Reporting Branch 2007b; 2007c; 2007e; 2007f). The numbers reported for the Magaguadavic were likely a result of the samples being taken downstream of mill discharges.

The 2009 Conservation Status Report for Atlantic Salmon (DFO and MRNF 2009) did report two areas within the SJR with low pH: Canaan River and Gaspereau River. Hunt et al. (2011) also reported a low pH (5.9) measurement in the Canaan River while investigating the buffering capacity of aquatic systems in New England and New Brunswick rivers.

Extensive provincial testing has revealed some areas in OBoF watersheds with elevated acidity, however, levels are generally low throughout the majority of the DU. Acidification in the SJR does not currently appear to be limiting as pH readings were between 7.2 to 8.1 (slightly alkaline) (Kidd et al. 2011). Additional evidence that pH has not been an issue for Atlantic Salmon in the major tributaries of the SJR can be found in Francis (1980) as he tabled pH readings of ≥ 7.0, in most incidences, at more than 60 electrofishing sites during 1968-78.

Climate - Extreme Water Temperature Events

For Atlantic Salmon of the SJR, temperature stress generally occurs when water temperature reaches 23°C and above (Breau et al. 2011). Parr growth occurs ideally at temperatures above 7°C (Allen 1941), and juveniles feed on invertebrate drift. Freshwater habitat suitability indices for summer (Morantz et al. 1987) and winter (Cunjak 1988) conditions are applicable to OBoF Atlantic Salmon. Amiro (1993) and Amiro et al. (2003) identified stream gradient as a good overall indicator of habitat quality, with suitable gradients being above 0.12%. Smolt migration usually takes place in the spring during night at water temperatures of 8-10°C. Rotary Screw Trap (RST) operations on the Tobique and Nashwaak rivers, during the spring smolt migration period, confirm that peak RST catches generally correspond to mean daily water temperatures of 8-10°C (Jones et al. 2006, Jones et al. 2014).

Effects of climate warming are anticipated in both freshwater and marine environments and will particularly affect northern North America and the North Atlantic (DFO and MRNF 2009).

[1] Text adapted from Amiro et al. (2008).

Western New Brunswick, which contains the majority of OBoF salmon freshwater habitat, is anticipated to experience some of the most drastic increases in surface air temperatures in Atlantic Canada (DFO and MRNF 2009).

Changes in thermal regimes within a river system can affect species survival, invasion rates of new species, and overall diversity of biological communities (Monk and Curry 2009; Minns et al. 1995). Atlantic Salmon are a coldwater species and are predicted to be highly affected by increasing global temperatures, which reduces availability of thermal refuges (Monk and Curry 2009). Within DU 16, Monk and Curry (2009) evaluated the SJR above Mactaquac (including the Tobique River), St. Croix and Waweig rivers which were all deemed intermediate or warm water regions. The authors modeled stream temperatures using global climate models and found that warming summer temperatures are predicted for these rivers, as well as an increase in prolonged duration of temperatures above thermal threshold for Atlantic Salmon.

Major summer cool water refugia within the SJR system occur in four major tributaries; Becaguimec, Salmon (Victoria County), Shikatehawk, and Kennebecasis rivers (Cunjak and Newbury 2005 *in* Kidd et al. 2011). Prior to the construction of a major dam on the Tobique River, cold water sanctuaries were thought to exist near the confluences, which are now likely compromised by the highly regulated flows. With the compromise of cool water refuge due to natural and anthropogenic causes, and their documented importance for the maintenance of physiological processes (Breau et al. 2011), a current inventory of refuges in OBoF rivers would provide critical information for important habitat allocation decisions.

Risk of extreme temperature events increases with riparian zone alteration and water extraction (Caissie 2006). The trend of increasing development along the SJR and its tributaries will place an increased demand on groundwater, which could affect river levels. For the SJR, there have been known losses of cold water refuges on the Tobique River due to storages dams. River level and discharge are monitored on many OBoF rivers by Environment Canada and most data are available online from the Environment Canada website[2]. Clear interpretation of these datasets to characterize true trends in discharge over time can be hindered by the over 200 flow obstructions in DU 16. Temperature has been monitored at select locations in the SJR basin by DFO since 1995 (Figure 2). These data suggest no apparent trends in the frequency of days in the year with minimum water temps above 20°C, a commonly reported metric to describe salmon's ability to recover from extreme temperatures (Caissie et al. 2012).

Silt and Sediments

Soil sediments can negatively impact fish by causing abrasion to skin, eyes and gills (O'Connor and Andrew 1998). Sediments particularly affect salmon spawning habitat if loads are high enough to cover gravelly substrate and smother buried eggs or reduce available suitable spawning area (Soulsby et al. 2001). The United States Environmental Protection Agency (USEPA) deemed sediments as the most important source of pollution in North American rivers (Higgins et al. 2011). Sedimentation impacts result from several activities (e.g., forestry, agriculture, road crossings) and are further discussed below in context of the respective threatening activity.

Flanagan (2003) demonstrated lower survival of Atlantic Salmon eggs with increasing loads of fine sediments near forestry activities in the Miramichi watershed (non-OBoF) in NB. The same study demonstrated lower survival of salmon eggs in the Tobique system where hydro dams manipulated river flow but fine sediments were not the issue effecting the lower survival. Cunjak et al. (2002) found variable results of effects of agricultural-derived sediments on salmonid survival on Prince Edward Island streams. Considering the extensive and long-term occurrence

[2] For more information, please visit Environment Canada's website at http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=894E91BE-1. (Last accessed 14 April 2014).

of forestry, agriculture, industry, and damming activities on the SJR and its tributaries (Kidd et al. 2011), effects of sediments are an important threat for consideration. Tobique and Nashwaak rivers have been affected by extensive historic and current forestry and road crossing activities (Kidd et al. 2011). Both experience low juvenile salmon productivity relative to other maritime DUs and discrepancies have been demonstrated in relative fry and parr abundance within a cohort (Marshall et al. 2014).

Pollutants, Chemical, and Wastewater

In Atlantic Canadian rivers, elevated levels of aluminium are common although the aluminium is often complexed with organic compounds rendering it not bio-available to aquatic life (ISCRWB 2010). In the SJR, aluminium levels are due mainly to the geology rather than to human activity (Kidd et al. 2011). Dennis et al. (2012) surveyed 96 Atlantic Canadian salmon rivers to monitor aluminium levels and none of the three surveyed from the OBoF DU (one each from above and below Mactaquac Dam and from the Outer Fundy complex) were shown to have elevated measurements.

The SJR was/is affected by several other types of pollution including; chemical, toxic and deoxygenating wastes from pulp mills, processing plants, forest spraying and agricultural/industrial run-off (Dominy 1973). An inventory of potential effluent inputs to the SJR watershed (USA and Canada) showed over 70 non-municipal waste water discharges, over 100 municipal waste water discharges, at least 19 fish hatcheries, 21 food processing plants, approximately 40 waste and rock handling facilities, and 15 pulp and paper or lumber mills (Kidd et al. 2011). Exposure to pulp mill effluent has been documented to reduce survival and increase physiological maintenance cost for populations of Atlantic Salmon in the Miramichi River system and in Newfoundland (Melanson et al. 2004; Linton et al. 2005).

Exposure of Atlantic Salmon to aquatic contaminants such as endocrine-disrupting chemicals and pesticides, especially during the sensitive freshwater stages, affects their survival at sea (Fairchild et al. 2002; Moore et al. 2003). Certain biocides, such as Atrizine (registered pesticide under the Canadian Pest Control Products Act), have been shown to:

- delay and/or inhibit smoltification in parr (Fairchild et al. 2002),
- disrupt growth in saltwater (Nieves-Puigdoller et al. 2007),
- affect the olfactory system, which reduced the ability of the male fish to detect and respond to the female priming pheromone (Moore and Lower 2001),
- affect steroid synthesis of the testes and inhibit male priming response in turn affecting the reproductive success and migration (Moore 2009), and
- directly affect kidney structure, which may affect the release of pheromones in female salmon urine at spawning (Moore 2009).

Furthermore, the pesticides may also act in synergistic, antagonistic or additive manners affecting the aforementioned salmon life stages (Moore and Lower 2001).

In 1972, the International Saint John River Water Quality Committee was formed to address water pollution problems in the system and by 1984, pollutants were reduced by 82% for suspended solids and 88% for biochemical oxygen demand (Carr 2001; Culp et al. 2006). Although a marked improvement, non-point pollution sources such as: agriculture runoff, waste disposal, sewer overflows, leachates from salt piles, acid drainage from abandoned mines, and bacteria and pathogens from livestock, are still affecting water quality (Carr 2001; Gray 2003).

Dutka et al. (1988) used both microbial, biochemical and toxicant screening tests on both sediment and water aliquots at 38 sites throughout the SJR system. The sediment analysis found that the areas of greatest potential concern for biochemical, toxicity and microbial load were:

- five sites above Grand Falls.
- SJR at Florenceville (Highest concern)
- SJR in Grand Bay.
- Little River (City of Saint John).
- SJR at Longs Creek.
- SJR below Nackawic mill.

The Little River, a small estuarine stream entering the Saint John harbour, is affected by oil refinery, newsprint mill (in 1995 redirected to the Saint John Harbour) and power generating station discharges (Vallière 1998; LeBlanc 1995; Dubé and MacLatchy 2001; Dutka et al. 1988).

The upper SJR in NB, from Edmunston to Grand Falls, is affected by several inputs of effluent from; a pulp mill (secondary-treated effluent released), a paper mill (primary-treated effluent released), food processing, three treated sewage discharges and other untreated sewage releases such as poultry processing plants and piggeries (Galloway et al. 2003; Arciszewski et al. 2011; Dutka et al. 1988; Culp et al. 2006; Curry and Munkittrick 2005). Culp et al. (2006) analyzed water quality data taken from this area of the SJR in 2003-2005 and found near threshold levels of total nitrogen (TN) and total phosphorous (TP) to create excessive algal blooms. On the middle SJR, the Beechwood Dam affects effluent impacts as low water discharge reduces effluent dilution and produces high biological oxygen demand (BOD), which reduces dissolved oxygen (Culp et al. 2006). Sub-saturation levels of dissolved oxygen due to high concentrations of organic pollutants and dissolved nitrogen have caused 'fish kill' events in the past on the SJR at the Mactaquac Dam (MacDonald and Hyatt 1973). Atlantic Salmon and American Eel were the species most affected and an estimated 200 salmon died as they approached the Mactaquac Dam tailrace. The main stem of the SJR, near Fredericton, is affected by secondary-treatment sewage inputs (Tenzin 2006).

The McCain food production plant first opened in Florenceville in 1957, with untreated effluent discharge into the river elevating nutrient levels and increasing the BOD until the primary treatment facility was installed for potato-processing wastewater in 1969 (Cocci et al. 1980; Curry and Munkittrick 2005; Culp et al. 2006). In 1996, a tertiary treatment plant with aerobic digesters (Tenzin 2006) began operation. A 2003-2005 water quality monitoring exercise showed the section near Florenceville still received substantial industrial and municipal effluent discharges and was near thresholds for TN and TP to create excessive algal blooms (Culp et al. 2006). On the SJR, the TN and TP concentrations were consistently the highest below effluent influxes and tended to exceed the targets set to prevent significant biological impairment (Culp et al. 2006).

The Aroostook River has a hydroelectric dam 4.8 km from the mouth and has been historically affected by agricultural inputs and PCB discharges from a derelict USA air force base (Tenzin 2006).

The Presquile rivers (Big and Little) also drain agricultural and food processing effluent into the SJR between Florenceville and Hartland (Tenzin 2006). Baum (1982) reported that untreated industrial effluent from two sources significantly impacted the Big Presquile River during the 1960's.

The Meduxnekeag River continues to be impacted by non-point source pollution from surrounding agricultural lands (predominantly potato fields), gravel pits, domestic sewage from Houlton and untreated sewage from Monticello, Maine (Bell et al. 1980; Baum 1982; Peabody and Mitchell 2005; Tenzin 2006). In the past, the river also received leached chlorophenols likely from pressure treated wood at the numerous lumberyards on the system (Prouse and Uthe 1994).

The Nackawic watershed, at the upper most reach of the Mactaquac head pond, is affected by both a bleached kraft hardwood mill and municipal sewage discharges. Although both sources receive secondary treatment prior to water entry (Freedman et al. 2012; Curry and Munkittrick 2005), they have led to hypoxic conditions in the summer around deeper water near Nackawic (Tenzin 2006).

Grand Lake, in the Jemseg River watershed, received effluent from an ash lagoon used by a coal-combustion electric-generating station until 2010 (decommissioned), where concentrations of arsenic at the outfall exceeded the Canadian sediment-quality guidelines for aquatic life (Lalonde et al. 2011).

The Canaan River did not meet the recreational use guidelines (NBDOE Water Quality Index) for *E. coli* levels at several sites possibly as a result of manure spreading on agricultural lands (Science and Reporting Branch 2007a). The Canaan River also had several sites which were deemed as ‘fair’ under the provincial Water Quality Index possibly caused by land disturbance and clearing of riparian vegetation, as well as livestock access to stream (Science and Reporting Branch 2007a).

The Nerepis River flows through the Gagetown military base and is subject to sediment loading from vehicle crossings and landscape defoliation operations (Kidd et al. 2011). Military impacts on OBoF watersheds are discussed in the ‘Military Activities’ section of this document.

The Kennebecasis River has undergone major development in recent years with increased agricultural activity, two potash mines, and several natural gas wells (Kidd et al. 2011). Activities such as removal of riparian vegetation, agricultural operations, municipal and non-municipal sewage discharge, as well as natural events such as ice-jams and ice-melts all affect the sediment supply in the system (Higgins et al. 2011; Science and Reporting Branch 2007d). In addition, *E. coli* level measurements at several sites sampled in 2007 (26% of samples) did not meet the provincial recreational use guidelines (NBDOE Water Quality Index). These measurements were possibly as a result of improper storage of organic waste from point or non-point sources (Science and Reporting Branch 2007d).

In 2007, the Hammond River had several sites which were deemed as ‘fair’ under the provincial Water Quality Index possibly caused by land disturbance and clearing of riparian vegetation, as well as livestock access to stream. Dissolved oxygen and pH did meet the freshwater aquatic life guidelines in 99% and 98% of the samples, respectively (Science and Reporting Branch 2007c).

The Digdeguash River contained only a few water samples indexed as ‘fair’ during the 2007 Water Quality Survey conducted by the NBDOE although these sites were not influenced by any industrial or municipal sources of pollution and may be a result of riparian zone alteration/removal (Science and Reporting Branch 2007b).

Treated waste water from the New River Beach Provincial Park is discharged near the mouth of New River (Troy Lyons, NB Department of Environment and Local Government, pers. comm., 2013).

The Magaguadavic River has multiple fish hatcheries, a yarn factory and an inactive mine on the system which have contributed to relatively poor Water Quality indexing by the NBDOE (Science and Reporting Branch 2007e). Effluent from wastewater facilities and a shellfish processing plant also flow into the Magaguadavic estuary (Troy Lyons, NB Department of Environment and Local Government, pers. comm., 2013).

The Dennis Stream receives treated municipal and industrial waste water from an aerated lagoon system in the town of St. Stephen which is within the provincial requirements for total suspended solids and BOD levels (ISCRWB 2010).

In 2007, the St. Croix River Water Quality Survey by the NBDOE found some fair and marginal index ratings which may be explained by the sites possibly being impacted by industrial effluent, urban development and municipal/non-municipal sewage discharges (Science and Reporting Branch 2007f). The fair and marginal samples were mostly collected around the Woodland and Cotton Mill dams near the St. Stephen area. The Woodland Dam was bought by the International Grand Investment Company in 2010. New ownership subsequently increased pulp production, constructed a gas pipeline to the plant, repaired their chip line and improved the wastewater treatment facility to reduce high BOD liquor losses to the sewers (ISCRWB 2010). Other sources of effluent in the St. Croix system stem from (ISCRWB 2010):

- The municipal wastewater treatment facility in Baileyville.
- The sewer overflow in the City of Calais (good compliance in 2010).
- The wastewater treatment facility in McAdam.
- The treated domestic and industrial wastewater from the Champlain Industrial Park.
- The treated domestic wastewater from mobile homes on Meadow Brook.
- The treated domestic wastewater from Oak Bay Park.

Military Activities

General effects of terrestrial military activities on Atlantic Salmon were recently described in DFO and MRNF (2009):

> "Military training activities conducted by the Department of National Defence, as well as those activities in support of training (construction and maintenance of infrastructure), can have varied effects on fish, including Atlantic Salmon. Training activities have the potential to directly harm fish through such actions as the crossing of watercourses (fording), whereby a vehicle driving on the substrate could crush and kill eggs or juveniles present in the substrate. This outcome could also occur during an exercise that would require a large scale crossing of soldiers on foot. Military exercises using explosives could lead to direct mortality if used too close to watercourses with fish present. The same is possible for unknown experimental chemicals, which in the past included 'Agent Orange'. Support activities also have the potential for impact. Many military training areas have numerous roadways, and these roadways would require bridge or culvert installations and maintenance, ditching, and road resurfacing and grading. These activities could lead to the deposit of sediment into nearby watercourses."

The Canadian Department of National Defence (DND) operates Canadian Forces Base (CFB) Gagetown outside Gagetown, NB. CFB Gagetown is located 30 km southeast of Fredericton and includes parts of the Oromocto and the majority of the Nerepis river drainages. Established in 1958, Gagetown is Canada's second largest training centre at 11,000 km^2.

CFB Gagetown uses herbicides to control vegetation (Andy Smith, DFO-CFB Gagetown Unit, pers. comm., 2013). The application is conducted by contracted licensed applicators. All products are registered and approved by Health Canada's Pest Management Regulator Agency (PMRA). Products are also approved for use in NB by the NBDOE. Herbicide application must comply with DND Policy and all applicable Federal and Provincial acts and regulations governing the use, storage, handling and application of herbicides. A third party monitor is hired to ensure adherence to environmental regulations and the proper storage, handling, mixing and loading of herbicide. The monitor is also responsible to verify the correct calibration of application equipment and to collect water and vegetation samples (pre- and post-operations).

Training at CFB Gagetown does include live fire using: small arms, heavy artillery, aerial bombing, and other combat weapons (Andy Smith, DFO-CFB Gagetown Unit, pers. comm., 2013). Chemicals could be released to the environment from ordnance such as ammunition, shells or bombs. To mitigate potential effects to aquatic environments, targets are installed 100 m or further from watercourses. Water samples are collected and analyzed for chemicals found in ordnance as part of a water quality monitoring program. DFO and DND initiated a partnership in 1996 to monitor and mitigate training operations effects on watersheds.

Significant sedimentation impacts have been recorded on the Nerepis River basin (Shane Heartz, DFO-CFB Gagetown Unit, pers. comm., 2013). Mitigation of sedimentation appears to be reducing impacts and focuses on road infrastructure improvements and maintenance. Turbidity monitoring and mitigation on combat training centre (CTC) streams largely began in 1998 and indicates reductions in sedimentation since then.

Other Power Generation

Non-hydro generating stations in the OBoF DU are summarized in Table 3. The Lepreau Nuclear Generating Station (NGS) is located west of the City of Saint John on the Bay of Fundy coast. This NGS returned to service in 2012 following four years of shut down for refurbishing. Lepreau uses seawater from the Bay of Fundy to cool reactor components and continuously circulates more than 300 gallons per minute.

In their environmental monitoring report for the Lepreau NGS, Nelson et al. (2001) reported that:

> "Emissions of concern from the Point Lepreau NGS into the Bay of Fundy include: the release of radioactive fission and activation products in liquid and gaseous effluent, the discharge of cooling water at temperatures of up to 20°C higher than ambient temperature, and the introduction of biocides when these organic substances are required to reduce fouling in the cooling system."

The same report concluded that:

> "No environmental increases in 137Cs [cesium 137] activities have been observed as a result of releases from the NGS. Levels of 137Cs measured in the Bay of Fundy result from atmospheric fallout from the nuclear weapons testing [of the year they were tested] and have decreased to an average of 2.55 mBq/l due to radioactive decay and gradual dilution with Atlantic [Ocean] water and freshwater. Levels of 137Cs measured in terrestrial and freshwater plants have decreased as a result of radioactive decay of previously deposited material and decreased inputs from atmospheric testing...;
> ...Tritium remains the only radionuclide released from the Point Lepreau NGS, which can be detected in vegetation, water, and air, although levels are significantly below those considered harmful to organisms. Small increases in the tritium activity in air for the air monitoring station (AMS) five located in Digby N.S. indicate that there is some transport of radioactivity across the Bay of Fundy of no ecological or human health risk."

Colson Cove thermal generating station, near the city of Saint John, is fuelled mainly by petroleum products and is not currently in operation due mainly to production costs. Despite improvements in reducing emissions, the Colson Cove Generating Station remains the largest thermal generating station in Atlantic Canada and has been cited by the New Brunswick Environmental Network and the Clean Energy Coalition of New Brunswick as the largest single point source of air pollution and greenhouse gases in the region. Two other thermal generating stations, Grand Lake and Courtney Bay, have recently been decommissioned although these are likely still impacting the surrounding environment.

The generation of hydro power from the eight meter tides of the Bay of Fundy has been the subject of various proposals and feasibility studies recently. In 2010, the US Federal Energy Regulatory Commission (FERC) awarded a preliminary permit to Tidewalker Associates to study the feasibility of tidal power generation in Half Moon Cove, in Cobscook Bay, Maine. The focus of the proposal was to construct a primary tidal barrage (similar to the principle of hydro dams) and install current driven devices (similar to principle of a windmill) as a supplementary means to generate tidal power. Decisions on project direction as a result of the feasibility study were expected in 2012, however, updates are not yet published. Similar to the effects of hydro power generation dams, the use of tidal barrages has been shown to affect fish migration were facilities exist in the Bay of Fundy at Annapolis Royal, NS (Gibson and Myers 2002). Generally, the study of tidal barrages in the Bay of Fundy and elsewhere indicate significant adverse environmental effects on fish, birds, and sedimentation (Isaacman and Lee 2010). Although tidal generation of any type is not currently being developed in the Passamaquoddy Bay, past study has demonstrated that this activity is likely to negatively affect migratory fish if present.

Invasive/Non-native Species Occurrence and Stocking

Invasive species are one of the most commonly cited causes of biodiversity loss around the world (Hermoso et al. 2011; Blanchet et al. 2007; Roberge et al. 2008). Competition with exotic species has ecological and evolutionary consequences, which may lead to environmental and economic shifts (Blanchet et al. 2007). Thomas et al. (2009) describes the major sources of non-indigenous invasive species in North America as being from aquaculture operations, the live fish trade and the pet/aquarium fish trade.

Freshwater stages of Atlantic Salmon are vulnerable to predation by several species of native and non-native fish including: Brown Trout (*Salmo trutta)*, Brook Trout (*Salvelinus fontinalis)*, Common Carp (*Cyprinus carpio*), Slimy Sculpin (*Cottus cognatus*), Largemouth Bass (*Micropterus salmoides)*, Smallmouth Bass (*Micropterus dolomieu*), Chain Pickerel (*Esox niger)*, Burbot (*Lota lota*), and Yellow Perch (*Percida flavencens*) (Valois et al. 2009). The creation of headponds results in lower water velocities and migratory delays rendering smolts more vulnerable to predation by piscivorous birds and fishes. Predation on emigrating smolts by Smallmouth Bass, Striped Bass (*Morone saxitalis)*, Muskellunge (*Esox masquinongy)*, Chain Pickerel, Yellow Perch, Mergansers, and Cormorants has been observed in areas such as dam tailraces where fish may become disoriented after they pass through the turbines or spill gates (Carr 2001; Blackwell and Juanes 1998). Thus, the threat of predation by invasive species can be exacerbated by the presence of dams or obstructions.

Smallmouth Bass slowly expanded its natural range into the SJR system both by natural and unauthorized human introductions (Curry and Munkittrick 2005). They were initially introduced into western New Brunswick (Lake Chiputneticook, St. Croix drainage) around 1869 as a sport fish and are now a dominant species in the system (Mary Sabine, NB Department of Natural Resources (NBDNR), pers. comm.; Fletcher and Meister 1982). These fish are of particular concern as they can occupy and thrive in Atlantic Salmon habitat, as well as predate on juveniles (Bostick et al. 2005: Kircheis and Liebich 2007; Valois et al. 2009). Historically, their natural range was the Great Lake Basin and Mississippi River drainage (Scott and Crossman 1998). Smallmouth Bass have been detected in the following OBoF systems:

- Magaguadavic (Carr and Whoriskey 2002; Mary Sabine, NBDNR, pers. comm.; Carr and Whoriskey 2009).
- St. Croix (Dudley et al. 2011; Valois et al. 2009; Wilson 1956; Willis 2006; Science and Reporting Branch 2007f).
- Musquash (Valois et al. 2009).
- Bocabec (Chaput and Caissie 2010).
- Lepreau (Chaput and Caissie 2010).
- Digdeguash (Chaput and Caissie 2010).
- SJR lakes and river system (Mary Sabine, NBDNR, pers. comm.; Baum 1982).

In addition, juvenile Smallmouth Bass have been captured in RSTs operated during the spring on the Nashwaak and Tobique rivers (Marshall et al. 1999; Chaput and Jones 2004). Table 4a summarizes Smallmouth Bass observations by DFO at monitoring facilities on the SJR. The presence of juveniles on the Tobique during the spring is evidence that young-of-the-year (YOY) are able to find suitable winter habitat on this northern tributary. More recently, juvenile Smallmouth Bass were captured in the following tributaries or rivers during an electrofishing survey that visited 189 sites within most of the rivers or tributaries within the OBoF DU: Monquart, Big and Little Presquile, Gibson Creek, Meduxnekeag, Eel, Shogomoc, Pokiok, Nackawic and Dennis Stream (Table 4b). Smallmouth Bass have also been captured in the Canaan and Hammond rivers (Science and Reporting Branch 2007a, 2007c).

Chain Pickerel are now established in several OBoF rivers in southwestern NB including: SJR, St. Croix River, and recently, the Magaguadavic River (Hoyle and Lake 2011; Curry and Munkittrick 2005; Fletcher and Meister 1982; Baum 1982). Its natural home range was the southern United States but was introduced in the early 1800's to New Brunswick. The Chain Pickerel is a predator of juvenile salmon (Barr 1962; Warner et al. 1968; Bostick et al. 2005; Kircheis and Liebich 2007). Chain Pickerel have been captured in Eel River, Cumberland Bay, Youngs Creek, and Canaan systems during an electrofishing survey of rivers within the OBoF region (Table 4b; Science and Reporting Branch 2007a; Lalonde et al. 2011).

Rainbow Trout is one of the most widely introduced fish species in the world and in eastern Canada. Stocking of Rainbow Trout dates back to the 1890's, which has led to some naturalized populations (Thibault et al. 2009). The Invasive Species Specialist Group (ISSG), in 2008, listed the Rainbow Trout as one of the 'Top 100- World's Worst Invasive Alien Species' (Schröder and Garcia de Leaniz 2011). Researchers found that, in competition with Rainbow Trout, Atlantic Salmon exhibited disrupted behaviour patterns and dominance hierarchies, as well as depressed growth rates (Blanchet et al. 2007; Roberge et al. 2008).

The Rainbow Trout were first introduced to NB rivers in the early 1900's as a sport fish. The only self-sustaining population in NB is thought to occur in the Shepody River watershed in the IBoF DU (Carr and Felice 2006; Thibault et al. 2009) although juveniles (Flanagan et al. 2006) and adults (Jones et al. 2006) have been annually observed on the Big Salmon River (an IBoF river).

Carr and Felice (2006) reported that Rainbow Trout were found on several occasions (electrofishing, angling, fishways or fences) in the following rivers or sub-drainages of the SJR within OBoF region: Magaguadavic, Big Presquile, Becaguimec, Shikatehawk, Tobique, Whitemarsh Creek, Muniac, and on main stem of the SJR in Mactaquac Dam and Beechwood Dam fishways. An extensive electrofishing survey of the OBoF region in 2009 revealed that juvenile Rainbow Trout were present in the Muniac, Monquart, Stickney Brook, Shikatehawk, and Becaguimec systems (Table 4b). Rainbow Trout are believed to have reproducing populations on the Big Presquile, Shikatehawk, and Becaguimec (Kathryn Collet, NBDNR, pers. comm., 2013). These individuals could have originated from escapes from licensed freshwater aquaculture sites in the upper SJR watershed as identified in Carr and Felice (2006). In addition to behavioural effects and depressed growth rates, other potential effects of Rainbow Trout on Atlantic Salmon include: predation, competition for food, transfer of disease and parasites, and reduction in breeding success.

In addition to the rivers noted in Carr and Felice (2006), Rainbow Trout have also been reported in the Kennebecasis (Science and Reporting Branch 2007d) and St. Croix rivers (Science and Reporting Branch 2007f).

Muskellunge were introduced in the headwater lake of the SJR system in the 1970's as part of a planned management introduction in the province of Quebec (Stocek et al. 1999). Now, the Muskellunge is present throughout 500 km of the SJR watershed. This invasive species appears to be a potential threat to Atlantic Salmon stocks although impact, as determined in two models, was variable (Curry et al. 2007). The bio-energetics model estimated Muskellunge predation on smolts migrating past Mactaquac Dam to be 7,400 fish while the isotope mixing model estimated between 73,000 and 154,000 smolts would be consumed annually (Curry et al.

2007). Even the lower estimate is a concern given the low juvenile densities in tributaries upriver of Mactaquac Dam (Jones et al. 2014). With no safe downstream passage, the predation is likely greatest in the tailrace and spillway area of the Mactaquac Hydroelectric Dam as smolts would be concentrated and potentially stressed as they fall over or pass through the turbines (Curry et al. 2007; Carr 2001). Since Muskellunge numbers in the SJR system are still low and temporal habitats minimally overlap with salmon, Curry et al. (2007) concluded that it was improbable that Muskellunge were having a significant impact on salmon population in that area of the SJR.

Curry et al. (2007) reported that one large (89.5 cm) radio tagged Muskellunge migrated downstream past Mactaquac Dam and then into the lower Nashwaak River.

Largemouth Bass were deliberately introduced and the first occurrence was detected in the Magaguadavic River in 2006 (Brown et al. 2009). These can be voracious predators on native fish populations including juvenile salmonids. Through illegal introduction activity, Largemouth Bass have recently been confirmed to be present and reproducing in the St. Croix[3] (MDIFW 2012).

Brown Trout were introduced into New Brunswick as a sport fish in 1921 (Scott and Crossman 1998). Populations of Brown Trout are localized and can be found within the SJR on the Meduxnekeag and Presquile rivers (Marshall et al. 2000; Baum 1982), as well as other rivers within the OBoF region including: East Musquash River, Craig Lake, Birney Lake and Lock Lomond. The Digdeguash River was reported to have a sea-run Brown Trout population in the late 1970’s, which still persists (Peterson 1978; Science and Reporting Branch 2007b). Brown Trout have been documented to be more aggressive than salmon at juvenile stages and to adversely affect salmon feeding behaviour (Jonsson and Jonsson 2011b).

There is evidence that competitive interactions between Atlantic Salmon and introduced Brown or Rainbow Trout can alter behaviour in salmon making them more vulnerable to predation (Harwood et al. 2002; Blanchet et al. 2006). There is currently no authorized stocking of non-native fish species in the OBoF DU.

Didymosphenia geminata (Didymo) is an introduced algae that creates dense, woolly, smothering brownish mats on rocks and the bottoms of streams and is believed to impact ecosystems by changing the distribution and abundance of organisms at the base of the food web (Gillis and Chalifour 2010). The first major bloom of Didymo documented in North America was in the late 1980’s on Vancouver Island, British Columbia (Gillis and Chalifour 2010). The impact of Didymo has been reported as minimal (in western Europe) to high in some salmon rivers where it smothers redds built by trout and other species (in New Zealand). The presence of Didymo has been confirmed in the Shikatehawk Stream and the Tobique River although full impact on salmon is unknown.

Atlantic Salmon Stocking

There is an established body of literature linking wild population manipulation through supplementation programs to various measures of depressed population fitness (Fraser 2008). Past and present stocking strategies on the SJR system upriver of Mactaquac Dam are outlined below and the recent ‘Revisions to the Mactaquac Fish Culture Program’ and justifications have been previously documented in Jones et al. (2010). To serve the purpose of this document (describing extent and severity of threats to OBoF salmon) while remaining as concise as possible, the following discussion covers only the general strategy, numbers of fish, and time periods, to provide context on the magnitude of program components. This discussion presents

[3] Maine Department of Inland Fisheries and Wildlife press release. June 28, 2012. For more information, contact Doug Rafferty, (207) 287-5248.

neither exhaustive detail of stocking since 1967 from Mactaquac nor details of stocking between 1880 and 1967, when more than 150 million age-0+ (mostly 'fry') and some age-1+ salmon of Saint John harbour, the Miramichi, Restigouche, possibly Serpentine and a very few non-New Brunswick river origins were widely distributed through the entire SJR system (Larry Marshall, DFO, pers. comm., 2013). Jones et al. (2014) provide more comprehensive details of Atlantic Salmon collected (juveniles since 2001) and released for the SJR upriver of Mactaquac Dam (including Tobique River), Nashwaak, St. Croix and Magaguadavic rivers. The following discussion focuses on the long-term DFO stocking and manipulation of the OBoF population above Mactaquac Dam as a threat to the population's persistence, however, where similar stocking methods have occurred, impact severity is expected to be positively related to duration and extent of stocking in the system. Generally, 'Past' stocking actions refers to those which collect and spawn wild adults, rear eggs in captivity and release juveniles at a later stage (mostly as smolts in this case). Current practice generally refers to those which capture juveniles from the wild, rear to maturity in captivity and release adults to the wild to spawn naturally.

Past (1967-2004)

Stocking actions occurred on the SJR through the DFO Mactaquac Biodiversity Facilities (formerly Fish Culture Station), which largely became operational in 1968 (Smith 1979) and to a lesser degree, the Saint John Hatchery (located near the City of Saint John). Initially, the Mactaquac Biodiversity Facility's production target was set at 500,000 smolts annually to compensate for loss from hydro-power dam infrastructure (Marshall et al. 2014). This level of smolt production was assumed to be more than adequate to compensate for the mortality of wild smolts associated with Mactaquac Dam operations, flooding of productive habitat and the suspected reduced fitness of hatchery-reared smolts (Smith 1969; Marshall et al. 2014). Annual releases of smolts, mostly below Mactaquac Dam, averaged about 225,000 and ranged from approximately 90,000-337,000 from 1974-2004 (Jones et al. 2014). Coinciding with the construction of the Early Rearing Facility and switch-over to the age-1 smolt program in the early 1980's, the reduction in smolt releases was augmented by the release of age-0 unfed fry and fall parr. On average from 1983 to 2004, about 325,000 fall parr (max = 540,000 in 1994) were released to upriver tributaries but mainly to the Tobique River (Jones et al. 2014). Annual unfed fry releases peaked at just over one million in 1994 and averaged about 447,000 from 1987 to 2000. The large numbers of younger fish that were released during this period helped to compensate for below 'production target' numbers of smolts released below Mactaquac.

With the construction of Mactaquac Dam, annually from 1967 to 1971, 800-1,100 wild sea-run adults (majority MSW salmon) were collected from the fish collection facility and randomly mated at the Fish Culture Station (Smith 1979). From 1972 to 2003, DFO staff collected approximately 200-500 wild run adults for the compensation program (Ingram 1980, 1985; Ingram and Ensor 1990; Marshall and Cameron 1995; Marshall et al. 1997, 2000; Jones et al. 2004). From 1968 until the mid-1990's, broodstock were retained from spring, summer and fall season runs (Smith 1979; Trevor Goff, DFO, pers. comm., 2013) but tributary of origin was unknown (i.e., an adult destined for the Tobique River versus Shikatehawk River). As a result, tributary specific adaptations, if present, could have been homogenized or lost. After the mid-1990's until 2004, no fall (late) returns were retained for broodstock.

To produce smolt for release below the dam, broodstock were spawned 1:1 (i.e., each parent contributing to only one brood) within their seasonal run group (Trevor Goff, DFO, pers. comm., 2013). All other adults from the fish collection facilities at Mactaquac Dam were trucked upstream predominantly to two release locations, one near Woodstock, NB (approximately 100 km upriver of the Mactaquac Dam), and the other near the top of Tobique Narrows Dam head pond (approximately 200 km upriver of Mactaquac Dam and upriver of both Beechwood and Tobique dams) (Ingram 1980). Assuming the earliest returning fish were bound for the furthest upstream, the earliest migrating adults were predominately trucked furthest upstream to the Tobique River release site while late summer and fall running fish were trucked and released near the top of the Mactaquac head pond near Woodstock (Ingram 1980, 1985; Ingram and Ensor 1990).

Other than natural migration to and from Mactaquac Dam, the smolt release strategy circumvented the entire natural freshwater life stages for program fish (spawning-to-smolt stages occurred completely in captivity). The egg to smolt stages includes periods in which Atlantic Salmon develop important characteristics for homing, as well as experience more than 90% natural mortality from the egg stage (Jonsson and Jonsson 2011a; Cunjak and Therrien 1998). Freshwater production was modelled by Gibson et al. (2009) where they estimated egg mortality (to fry stage) on the Tobique River to be 96.2%.

Studies on population effects from captive rearing show that selective forces act rapidly on salmon through survival of environmentally matched genotypes and phenotypes (Fraser 2008). In captivity, survival from egg-smolt was at least 10% and sometimes higher than 30% (DFO, unpublished data[4]), while estimated wild egg to smolt survival is less than 1% for all cohorts but one on the Nashwaak River from 1995 until 2008 (Jones et al. 2014). Hatchery operations thus relax and may re-direct natural selective pressure (i.e., certainly more, and maybe different fish survive in captivity than in the wild). Hatchery smolts exposure to less and possibly different selective pressure could have led to decreased fitness in future generations as individuals which would not have survived egg-smolt stages in the wild survive to contribute to future generations. Araki et al. (2009) reported decreased fitness in wild-hatched salmonid offspring from captive hatched parents compared to those from wild hatched parents. This work suggests further potential for past strategies to lower fitness in future generations.

In addition to the effects of altered selective regimes, artificially spawning fish has been shown to reduce fitness in offspring due to lack of natural mate selection (Neff et al. 2011). Current research has demonstrated local adaptations can occur at scales both larger and smaller than the 'river' (Fraser et al. 2011). 'Mixed stock' adults collected at the dam were presumably bound for tributaries upstream and thus, no released smolt migrated from its naturally intended tributary from 1968-2005. This could have contributed to a loss of local adaptations possibly important for population sustenance.

Finally, a lack of passive upstream fish passage measures at Mactaquac Dam requires that each individual migrating adult be trapped, handled and transported to reach upstream spawning locations. Trapping, handling and transport stress induced by such activities contributes to known and likely unknown compromises to survival and reproduction (Burnley et al. 2012). DFO staff at handling facilities observe and record suspected damage to fish (Figure 3). These handling stresses are expected to be compounded for adults released at Woodstock and destined for the Tobique or Aroostook rivers, as they must navigate the fish lift at Beechwood Dam and another fishway on those rivers.

Despite the preceding discussion, with no passive upstream fish passage at the Mactaquac Dam, trapping and trucking operations provided the only means for salmon to reach upstream spawning areas (Marshall et al. 1995). Also, measures were taken to maintain presumed local adaptations by spawning within seasonal run groups and adjusting adult release sites above the dam according to migration timing under the assumption that earliest migrants were bound for furthest upstream. Although these strategies could be considered appropriate for the available resources and state of knowledge of the day, their effects on OBoF population fitness remain un-documented.

[4] Egg survival data provided by Ross Jones (DFO Assessment Biologist), Moncton, NB.

Present (2001-2012)

Adult broodstock collection and artificial spawning largely ended in 2004 except for the Serpentine River program (Serpentine program described below). From 2001 to 2012, between 1,200 and 3,400 juvenile salmon (predominately wild migrating pre-smolts or smolts) were collected using RSTs on the Tobique River or gatewells in the Beechwood Dam and reared to adult stage in captivity (Jones et al. 2014). Upon maturity, approximately 100 matings are still carried out for production of smolts for release downriver of Mactaquac Dam and fall parr (age-0+) to release to the Tobique River. These captive matings would be subject to the same population effects described above although perhaps less severe due to the relative increased exposure of age-0+ juveniles to wild selective pressure between release and smolt stages. Aside from those retained for the 100 matings, the majority of captive-reared adults collected as smolts from the Tobique were distributed back to the river to spawn naturally with the potential to make significant contributions to the estimated egg depositions upriver of Mactaquac Dam (Jones et al. 2014). Further, since 2005, all naturally returning sea-run adults collected from fish collection facilities have all been released either near Perth (Beechwood head pond) or near Woodstock (top of Mactaquac head pond) to allow for a 'free swim' back to tributaries. The 'free-swim' strategy assumes the transferred adults could be from mixed stocks and generally avoids the potential for transferring adults to release sites above their naturally intended tributary. Exceptions to the 'free swim' strategy occurred in 2009 and 2010 because of a dispute between Tobique First Nation and NB Power (in 2009) and lack of DFO Conservation and Protection officers to adequately protect the wild sea-run adults in the vicinity of the Tobique Narrows Dam (in 2010).

Based on recent studies, current DFO practices of 'free-swim' transfers, tributary specific smolt collection, rearing to adult and releasing back to the wild to spawn is more likely to maintain wild fitness than previous strategies of captive spawning adults of mixed stock origin and juvenile rearing (Fraser 2008; Fraser et al. 2011; Neff et al. 2011). Fleming et al. (1996) found that adult males deprived of wild experience as a juvenile and released to the wild as a smolt "obtained 51% the spawning success of wild males" in their experiments. Kihslinger et al. (2006) found that even rudimentary naturalization of juvenile captive environments resulted in substantial improvements in fitness-related traits in salmonids; this work underscores the apparent importance of early natural exposure. DFO staff have been collecting smolt from, and releasing as adults back to, the Tobique River since 2005. This has likely reduced the loss of local adaptation for that system (compared to past strategies) since then as mating and juvenile survival/mortality is occurring in the wild. O'Reilly and Jones (2014) demonstrated significant genetic signature clustering of Tobique samples from those collected from other OBoF rivers. Although the Tobique River has the most accessible productive habitat for salmon upriver of the Mactaquac Dam (Marshall et al. 2014), there are other systems that no longer receive juveniles from stocking programs. Therefore, unique or important families in these smaller tributaries could be at increased risk of loss.

The Unique 'Serpentine Stock'

In addition to operations described above, an annual broodstock collection program exists where a portion of the earliest migrating adults to Mactaquac Dam are retained. In years where the Serpentine broodstock target is not achieved, the fish are released above the dam to spawn naturally. These fish, based on their distinct phenotypic characteristics (early return migration and dark and deep body), are referred to as the 'Serpentine Stock'. This stock was presumed to be destined for the Serpentine River, one of the highest tributary rivers to the Tobique. The 'Serpentine Stock' is unique from most Atlantic Salmon in Canada as it returns to the estuary in November and then ascends the river the following May/June before spawning in the fall (Huntsman 1933a, 1933b; Saunders 1978). The 'Serpentine' 2SW salmon are an intermediate size, generally between 64 and 72 cm, larger than a typical 1SW salmon but smaller than a typical 2SW salmon. Interpretation of scales is also used, along with the phenotypic characteristics and run timing to make the final designation as a ‘Serpentine’ fish (Leroy Anderson, DFO, pers. comm., 2013). Generally, since the construction of Mactaquac Dam to present day, most of these earliest returning adults were collected and have been part of an annual breeding program. Progeny of these crosses were generally released as fall parr to the Serpentine River and were also used to initiate the ‘Restoration Program’ on the Aroostook River in the mid-1980’s. Starting in 2011, DFO Science decided to alternate between a ‘Free Swim’ and ‘Captive Program’ to ensure some wild sea-run returning ‘Serpentine’ adults were released to spawn in their natal river. This program would be expected to have similar effects on the persistence of ‘Serpentine Stock’ salmon as other programs which collect wild adults, artificially spawn and release offspring after captive rearing. Because the Serpentine is a smaller population in the Tobique River basin, collections of Serpentine salmon made up a higher proportion of whole population and thus, negative effects caused by captive spawning and rearing would affect a larger portion (if not all) of the Serpentine population.

Other Native Salmonid Stocking

There is evidence (see ‘Invasive Species Occurrence and Stocking’ section) that competitive interactions between Atlantic Salmon and introduced Brown or Rainbow Trout can alter behaviour in salmon making them more vulnerable to predation (Harwood et al. 2002; Blanchet et al. 2006). Gibson (1973) suggested competition between salmon and native Brook Trout could also be detrimental to salmon populations as larger Brook Trout are known to predate stocked juvenile salmon fry (Henderson and Letcher 2003). Other studies have demonstrated varying degrees of compatibility for Atlantic Salmon and Brook Trout (Gibson et al. 1993; Mookerji et al. 2004).

It is not clear whether the extensive stocking of non-anadromous salmonids has or continues to impact OBoF salmon populations. Predation impacts are expected to be higher when Brook Trout outnumber salmon in the watershed, which could be a concern as salmon populations continue to decline (Ward et al. 2008). Examining the catches of Atlantic Salmon versus Brook Trout during an extensive electrofishing survey in 2009 would indicate that Atlantic Salmon outnumber Brook Trout in most incidences (Table 4b; Jones et al. 2014).

The NBDNR carries out regular stocking of various life stages of Brook Trout and Landlocked Salmon in waters of New Brunswick. Several of the stocked systems connect to OBoF river watersheds, including through the Grand Lake (Jemseg River). Recent stocking efforts for NB counties which contain OBoF rivers are summarized by species and year in Figure 4 (Krista DeBouver, NBDNR, pers. comm., 2012). Only native genetic strains are stocked and all fish are fin clipped and tested to be free of known disease prior to release to the wild.

Recent observations of suspected adult Landlock Salmon have been made by sorting facility staff at the Mactaquac Biodiversity Facility (Sean Dolan, DFO, pers. comm., 2013). The origin and migration tendency of these fish are unknown although could be of concern if Landlocked Salmon are being passed upstream and/or are reproducing with sea-run Atlantic Salmon.

Hydro Dams and Obstructions

Based on available information, hydro-power dams and other obstructions (and threats stemming from them) are the most limiting threat to OBoF salmon population persistence. In general, dams can alter the river flow, temperature, hydraulics, the stability and availability of substrate, channel morphology, and riparian vegetation which affects the structure and function of the aquatic communities although the disruption of the water level fluctuations can aid in sustaining biodiversity (Culp et al. 2008). Hydroelectric dams, even those equipped with upstream fish passage facilities, reduce the connectivity and production of salmon habitat by restricting/ delaying mature fish from reaching spawning grounds, e.g., Beechwood fishway could not be operated from October 2 until October 19, 2010, due to extremely high water. Most dams in the OBoF DU lack downstream passage, which causes migration delays in head pond reservoirs above dams, mortality in descending spillways or through turbines, and predation in head ponds during migration (Ruggles and Watt 1975; Carr 2001; Marshall et al. 2014). Most obstructions less than 3.4 m are surmountable by adult salmon as are waterfalls less than five meters in height that have a vertical drop into a plunge pool with a depth 1.25 times the height (Powers and Orsborn 1985; Shearer 1992).

Although population declines of Atlantic Salmon are not yet specifically associated with declines of other diadromous species because of impeded upstream access and nutrient cycling, restoration of Atlantic Salmon populations will be favored by restoring access to upstream habitat for all diadromous species and the food webs they contribute to. There is increasing evidence that the restoration of diadromous fish populations, including Atlantic Salmon, may well depend on the restoration of the entire biotic community that co-evolved in those watersheds prior to compromise by flow regulation (Stanford et al. 1996). Important diadromous interactions include:

- The transport of marine-derived nutrients (reproductive products, excretion, decomposition of carcasses) into freshwater during their upstream spawning and recruitment migrations,
- the influence on habitat by species, that construct redds in the spring, which can improve the habitat for salmon at later dates and improve the abundance and diversity of aquatic insects, and
- the predator-prey interactions during overlapping migration of diadromous fishes (e.g., upstream Gaspereau migrations in spring may reduce predation pressure on smolts migrating downstream).

Prior to the construction of the Mactaquac Dam, American Shad (*Alosa sapidissima*), Striped Bass, Alewife (*Alosa pseudoharengus*), Blueback Herring (*Alosa aestivalis*), Atlantic Sturgeon (*Acipenser oxyrhynchus*), Shortnose Sturgeon (*Acipencer brevirostrum*), American Eel (*Anguilla rostrata*), and Sea Lamprey (*Petromyzon marinus*) had access to the headwater areas of the Saint John (Smith 1979, 1969). Leim (1924) indicated that American Shad historically ascended the SJR up to Grand Falls (320 km from the mouth of the river) but that the bulk of the catch was taken in the lower 200 km of river. In the SJR system, Shad were observed at the Tobique Narrows fishway, over 180 km above the head of tide prior to the construction of the downstream dams (Smith 1979). Since the construction of Mactaquac Dam, access to upstream areas has only been provided for Atlantic Salmon and Gaspereau, the latter according to a management plan's annual objective of 800,000 Alewife and 200,000 Blueback Herring (both referred to as Gaspereau). The surplus Gaspereau arriving at the fishway are harvested. American Eel and Sea Lamprey have only had accidental access to the waters above Mactaquac Dam.

Gaspereau and Shad fisheries still occur in a number of rivers below Mactaquac (DFO 2001) and American Eel and Sea Lamprey are present in rivers below Mactaquac (Table 4b). A large in-river fishery for Shad was once reported to have existed on the St. Croix River (Perley 1852). Gaspereau access to the St. Croix River has been deliberately impeded in the past decades.

There are more than 200 dams on the SJR system, which impede fish migration to various extents (Kidd et al. 2011). Reservoirs cause deviation from natural hydrologic cycles, which can stress the aquatic biota exposed to high and low water events in short periods of time (days or seasons) (Kidd et al. 2011). Carr (2001) tabulated all the major power generating dams in the SJR system. This table has been modified to include the other major generating dams located within the DU (Table 5).

Head pond reservoirs are an especially noteworthy threat on the SJR where the reservoir area created by the Mactaquac, Beechwood, and Tobique Narrows hydro dams alone totals more than 11,000 ha (Carr 2001). Over 145 km of river, used primarily for migration by adult Atlantic Salmon, has been compromised by flooding by head pond reservoirs of Mactaquac, Beechwood and Tobique Narrows hydro dams. The largest of these reservoirs, at the Mactaquac dam, is 100 km in length and covers an area of approximately 8700 ha (Carr 2001; Tenzin 2006). Head ponds are a threat to salmonids due to their impacts on seasonal flows (spring highs and winter lows), and temperatures (Rosenberg et al. 1997), both of which are environmental cues for migration (Jonsson and Jonsson 2011b). Head ponds reduce thermal refuge and the capacity to decompose organic wastes resulting in reduced oxygen levels (Kidd et al. 2011; Culp et al. 2006). The most severe cases are found in the Tobique and Mactaquac head ponds where the rate of downstream movement has been up to nine times slower than in other sections of the river (Carr 2001). The relative mortality rate for Tobique River smolts (DFO lead coded wire tagging study from 1989-1991) is 45% as they pass through three major dams (Washburn and Gillis Associates Limited 1996; Carr 2001; Gibson et al. 2009).

Construction of the Mactaquac Dam, owned by NB Power, began in 1965 and was completed in 1968 (Carr 2001). The dam is located on the main SJR, approximately 17 km north of Fredericton, and completely obstructs upstream fish migration. As a result, a combined fish collection and trucking facility, as well as a Fish Culture Station (hatchery) was built to ensure salmon persistence above the dam. Initial reasoning for the additional hatchery production of smolts included: loss of extensive spawning and rearing habitat by head pond inundation, suspected migration difficulties of adult salmon (upstream) and smolts (downstream), ability to navigate the head pond, and the likely high turbine mortality to smolts while descending the dam (Smith 1969; Marshall et al. 1995).

The NB Power owned and operated Beechwood Dam, constructed in 1956-1957, is located on the SJR, at the village of Beechwood approximately 130 km upstream of Mactaquac Dam. Fish passage facilities consist of a collection gallery and mechanical skip hoist to pass salmon and a number of other species (Smith 1969). The skip carries the fish in water and releases them directly into the head pond. Prior to construction, this site was not a barrier to migrating salmon (Smith 1969).

The Tobique Narrows Dam, built between 1951-1952 by NB Power, is located one km from the mouth of the Tobique River (Smith 1979). As this river holds some of the best salmon rearing and spawning waters in the SJR system, a 274 m concrete fishway was constructed consisting of 75 pools (Smith 1969; Francis 1984). The Sisson Dam was built in 1965 at the foot of Sisson Lake, on the Sisson River, a headwater tributary of the Tobique River. The dam is built at the site of a natural falls barrier therefore fish passage was never provided (Smith 1969). Other obstructions in the Tobique River as described by Smith (1969) included:

- Mill dam, a wood construction, driving dam, built on Pokiok Brook in 1895, which obstructed fish passage.
- Mill dam on Odellach Brook (1886), a complete barrier to fish passage.
- Mill dam on the main Tobique did provide satisfactory fish passage.
- Dam on Haley Brook operated by the DFO was used to provide water for salmon rearing ponds and was a complete barrier to fish.
- Multiple natural falls on the Odell River and Britt Brook also are obstructions to upstream migration.
- There are also three major water storage dams (Serpentine, Trousers and Long) on the 'Right Hand Branch' of the Tobique River with a combined water storage capacity of 130 million m^3 (Carr 2001).

The Grand Falls hydroelectric dam is located on the SJR in the town of Grand Falls. It was built in 1925 without a fish passage facility as upstream migration prior to construction was completely obstructed by a natural falls (Smith 1969). The falls (23 m vertical drop) at Grand

Falls are the only natural barrier to upstream fish movement on the main-stem of the SJR (Kidd et al. 2011).

A headwater tributary (Barney Brook) of the Salmon River historically had a small barrier with by-pass channels, which did not impede fish movement and another dam used for fishing which was an obstruction (Smith 1969).

The Aroostook River has three power dams (Squapan, Caribou and Tinker dams) and two storage dams (Millinocket and Squapan dams) (Smith 1969). The Squapan (1941) dam is the only complete barrier to fish. Fish passage was not provided at the time due to high cost and low priority of the fishery (Smith 1969; Kidd et al. 2011). The Caribou Dam (1890) is located 24 km above the Aroostook falls and fish passage is provided (Smith 1969). The Tinker Dam was originally built in 1906 at the Aroostook falls which was an obstacle to fish migration but not impassable (Smith 1969). The dam was rebuilt in 1923 although the fishway was not installed until 1936. This fishway was inefficient in low water flows and was replaced in the 1980's with a trap and truck facility (Marshall et al. 1997). Limestone River, a tributary of the Aroostook River below Tinker Dam, has a series of natural falls and a dam built at the mouth of Pirie Lake, which impedes fish movement (Smith 1969).

The Monquart Stream (Hargrove) Dam, completed in 1966 as a private venture, is located 0.5 km from the mouth. Initial fishway construction was limited by both availability of water and cost, which prompted a netting and tank-truck transfer operation (Smith 1969). Fish passage was only facilitated at irregular intervals for a decade and since then the dam has been a complete barrier to fish movement. Hatchery juvenile salmon have been stocked intermittently since the late 1960's (Carr 2001) and possibly before dam construction (Larry Marshall, DFO, pers. comm., 2013). Prior to 1966, upstream fish passage was not impeded in Monquart River (Kidd et al. 2011; Carr 2001). Relatively high densities of juveniles were detected in the 500 m of habitat below the dam on the Monquart in 2009 (Jones et al. 2014).

Historically, the Shikatehawk River had a low (less than one meter) wooden dam considered to be a partial obstruction during low water events. This dam was used for recreational purposes although gates were open to permit fish movement in the past.

There are five impoundments in the Big Presquile River watershed. The uppermost dam is at the Christiana Reservoir in Fort Fairfield, followed by an impoundment in Easton Maine (McCain Food processing plant), Presquile, Westfield, and the lower most is at Mars Hill (FB Environmental Associates 2010b). The only impoundment that is a complete barrier to fish movement is at the town of Easton (Baum 1982). The Tracey Mills Dam built on the Big Presquile River was a complete barrier to fish passage (Smith 1969) but washed out in 1973, and juvenile salmon are again found in the system (Baum 1982; Jones et al. 2014).

Smith (1969) had reported fish passage issues at the Waterville Dam (near mouth of the Little Presquile River) and the Lakeville Dam in Williamstown Lake. The Waterville Dam was located 4.3 km above the mouth of the river and was built to store water in order to operate the mill (Smith 1969). The sawmill operations stopped in the mid-1960's but the remaining concrete structure, old turbine and woody debris were a partial to complete obstruction to fish passage (Clowater and Philips 2008). The abandoned sawmill dam was removed and the low-flow channel excavated in 2008 to open the stream to fish movement and 5.2 ha of habitat is now fully accessible (Philips and Clowater 2008). In a 2009 electrofishing survey, high juvenile salmon abundance was detected in the Little Presquile River above the old Waterville dam site demonstrating the success of the removal of the dam by the NB Department of Transportation (Jones et al. 2014). The Lakeville dam found at the outlet of Williamstown Lake resembles a weir dam with a vertical slot creating a short waterfall. This structure would only be an impediment to salmon migration during low water events. The area above the Lakeville Dam consists of a large head pond lake with minor rearing habitat tributaries around the lake. A

1.3 m-high dam downstream of Williamstown Lake (town of Avondale) may present an obstacle for salmon migration. This small dam does not appear to prevent salmon passage as juveniles were found above this site in the 2009 electrofishing survey (Jones et al. 2014).

The Meduxnekeag River, in the town of Woodstock, historically had a storage dam that was constructed in the early 1880's (Baum 1982) and was either a partial or complete obstruction depending on the water levels (Smith 1969) but was flooded with the construction of Mactaquac Dam (Baum 1982). An inventory of obstructions to fish passage was conducted in 1957 and found 19 man-made obstructions throughout the Meduxnekeag watershed although 11 no longer existed by 1982 (Baum 1982). It is believed that the remaining obstructions on the South Branch of the Meduxnekeag would not have any appreciable effect on the potential for salmon restoration (Baum 1982). However, the North Branch has a natural obstruction at Oakville and five m-high dam at Briggs Mills (Warner 1957), which are both barriers to upstream migration (Baum 1982).

The Eel River, between the mouth of the river and Benton, has a 4.3 m natural falls, which is only passable during very high water events. Although Marshall et al. (1997) and Marshall and Penny (1983) do not report any productive salmon habitat, a 2009 electrofishing survey of rivers within the OBoF region detected juvenile salmon presence, albeit at low densities, in the Eel River (Jones et al. 2014).

A series of 2.7 m natural falls over a 1.6 km stretch of the Shogomoc River was a complete barrier to fish passage before Mactaquac Dam construction (Smith 1969). A 2009 electrofishing survey did detect juvenile salmon presence, indicating some recent spawning of returning sea-run adults, in the Shogomoc River (Jones et al. 2014).

Near the mouth of Pokiok Stream lies Pokiok Falls, a series of falls, that historically obstructed all fish passage (Smith 1969). The Mactaquac head pond partially flooded the area and provided access to some previously inaccessible spawning and rearing habitat. The 2009 electrofishing survey also detected juvenile salmon presence in the Pokiok Stream (Jones et al. 2014), likely progeny of recent salmon returns released upriver of Mactaquac Dam.

The Pinder Dam was constructed on the East Branch of the Nackawic River approximately 24 km from the mouth. This dam was built to operate the Corey's Mill and is a complete obstruction to fish passage (Smith 1969). There are approximately 5,104 units of potential spawning and rearing habitat above Pinder Dam if upstream fish passage was provided. This habitat is potentially very valuable to recovery, if equally productive (based on gradient) as the existing accessible habitat within the Nackawic River (Marshall et al. 2014).

Historically, the Mactaquac River at Wiggins Mill (approximately 24 km from the mouth) had a dam for mill operations in the spring months although it did have a gate and was not believed to obstruct fish passage (Smith 1969). Washburn and Gillis (1986), during a fish habitat improvement opportunity survey, did not outline any fish habitat issues within the Mactaquac River.

The East Branch of the Nashwaaksis has a 2.4 m high natural falls, which may be a partial obstruction to salmon during low water events (Smith 1969). Juvenile salmon were caught at one of the two electrofishing sites surveyed in 2009 but accessibility of the habitat above the falls is still uncertain as neither site was upriver of this natural obstruction (Jones et al. 2014).

Until its removal in 2012, Nashwaak River had a stream driving dam (Barker Dam) below Nashwaak Lake preventing fish passage for two to three months of the year (Smith 1969; Washburn and Gillis 1986). Historically a log driving dam (Irving Dam) was operated on the main stem of the Nashwaak just below the "Narrows" but it was not considered to be a barrier to fish passage. An impassable falls on the Dunbar Stream, approximately 0.8 km from the confluence, is a natural barrier to salmon migration. Marshall et al. (1997) identified an additional four barriers to salmon migration although the one identified at the mouth of Mackenzie (Young) Brook is no longer considered a barrier as wild juvenile salmon have been captured during electrofishing surveys above the barrier (Jones et al. 2004).

Smith (1969) reported two dams in the Oromocto River system, which may have affected salmon movement in the past. Dams were built at the outlet of the Oromocto Lake and South Oromocto Lake by fishing clubs to increase angling opportunity. Neither Washburn and Gillis (1986) or Smith (1969) reports any fish passage issues on the Oromocto River. Connor and Gabor (2006) reported that the Oromocto River is also affected by impoundments built by Ducks Unlimited to increase waterfowl brood-rearing area. Since 1976, Ducks Unlimited has improved habitat for brood-rearing waterfowl and wetland obligate birds in the SJR floodplain mainly through impoundments (Connor and Gabor 2006). The SJR floodplain is composed of 13% impounded floodplain and 50% seasonally flooded emergent wetlands totalling 1872 ha (Connor and Gabor 2006). The creation of impoundments results in ideal waterfowl brood-rearing areas with stable water conditions. However, a decrease in stream access and/or stream habitat types such as pools, riffles and backwater areas will either preclude or displace certain migratory fish species such as Atlantic Salmon (Bunn and Arthington 2002). OBoF rivers affected by impoundments are: Portobello Creek (Grand Lake Meadows/Portobello National Wildlife area), Oromocto River, Kennebecasis River and Canaan River (Connor and Gabor 2006).

Smith (1969) reported a wooden dam located on the Burpee Mill Stream (Jemseg complex) at the Acadia Forestry Station built in 1965 as a fire protection reservoir. It was thought to be an obstruction when the gates were closed in July and August. This structure is suspected to no longer be present.

Historically, substantial runs of salmon spawned in the Musquash River supporting a weir and gill-net fishery (Thompson 2001). Water powered mills and dams were built at the mouth of every suitable stream although fish passage for salmon was provided and maintained until the NB Power Commission built its first hydro generating station with two dams on the East and West Branch of the Musquash River. The project was completed in 1922 although the West Branch dam burst in the spring and was rebuilt in the fall of 1923. No fish passage was provided at the dams, which effectively ended the Atlantic Salmon run in the Musquash River (Thompson 2001). Currently the hydro station on the Musquash River is remotely operated by the Department of Natural Resources and the structures remain an impediment to fish passage (Thompson 2001; Wells 1999). Approximately 2,750 productive habitat units (Marshall et al. 2014) are available to Atlantic Salmon in the Musquash, if upstream and downstream fish passage were to be provided at these barriers.

The Pocologan River has a causeway with culvert under the main highway (1960), which was presumed to be an impediment to fish passage (Wells 1999). Recently, an electrofishing survey at one site above the culvert detected juvenile salmon (Jones et al. 2014). Similarly, Carr and Whoriskey (2002) and Dalziel (1956) both report that salmon utilize the first 9.6 km of river from the mouth. The area above Pocologan Station, where the low-gradient, swampy woodland/barrens area with the river bottom composed of sand, silt, and mud with little gravel, is not ideal for salmon rearing (Dalziel 1956). The section of river upriver of the Keyhole Falls is also a natural obstruction during low water events. The Pocologan River has the smallest drainage area (57 km^2) and productive habitat estimate (226 units) within the DU (Marshall et al. 2014).

The Magaguadavic River at St. George, NB, had a 13.4 m-high dam and 3.7 megawatt hydroelectric station (with four Francis turbines) located at the head-of-tide, which was replaced with a 15 megawatt hydroelectric station (with two Kaplan turbines) in 2004 (Jones et al. 2010). Upstream passage is provided by a pool and weir fishway and a downstream bypass with an assessment facility that was constructed in the new hydroelectric station (Jones et al. 2010). The assessment of anadromous fish using the fishway is done with a trap in the third pool from the top of the fishway. Historically, Washburn and Gillis (1986) reported that the dam (Briggs and Little Mill built in early 1900's) presented a problem for salmon movement, as well as insufficient attraction water to get salmon to move into fishway. It is also reported that there is a water storage dam with a fishway (Wells 1999) and a five meter high natural fall on the Piskahegan River (tributary to the Magaguadavic) (Martin 1984). Marshall et al. (2014) present evidence that Atlantic Salmon were absolutely unable to navigate the natural falls, and it has been the construction of the fishway combined with stocking of juvenile salmon upstream by DFO that has permitted Atlantic Salmon (and other anadromous fish species) to utilize the Magaguadavic watershed.

The Digdeguash River has a falls at the mouth of the river that is impassable at low-tide conditions (Washburn and Gillis 1986) but access is possible during high tide conditions and salmon were detected during 2009 electrofishing surveys (Jones et al. 2014). Wells (1999) noted that the natural barrier has blasted fishway-type pools at the mouth of river. The Digdeguash River is relatively pristine with little industry or major human settlements (Wildish et al. 1980) and has more productive habitat per drainage area in relation to the larger Magaguadavic watershed (Marshall et al. 2014).

The first dam was built on the St. Croix River in 1860. There are three power dams; Milltown (Cotton Mill), Woodland, and Grand Falls (Kellyland), and three others to control water levels (Vanceboro Dam, Forest City Dam, West Grand Lake Dam). There is also a causeway on the river at Oak Bay. All dams provide fish passage although pulp mill effluent affects fish in the system (Wells 1999; Washburn and Gillis 1986). Exclusively in Maine, 48 dams have been erected since 1780 and as of 2006, 20 dams (includes dams with fish passage and those more recently removed or breached) remain in the system negatively affecting the migration of anadromous fish species (Hall et al. 2011).

Roads, Culverts and Other Crossing Infrastructure

Bowlby et al. (2014) described the impacts roads and crossings can have on salmon-bearing streams:

> "Roads and road crossings can have substantial impacts on freshwater habitat of Atlantic Salmon, so much so that the National Research Council (2003) ranked roads as the second most significant impediment to Atlantic Salmon recovery. Every road crossing has the potential to be a barrier to fish movement (total, seasonal, or specific to certain life stages) and a chronic source of pollutants (e.g., petroleum products, road salt) and sediments, particularly during storm events when water is directed along ditches. Such issues become more severe in situations where the road is damaged (e.g., washouts, plugged culverts, bank erosion) or when vehicle accidents result in acute chemical spills into the adjacent waterway. Increased human access to areas has been linked to alteration of aquatic habitats and the spread of non-native species (Trombulak and Frissell 2000). Road density has been used as an index of development or as a proxy for cumulative impacts within a watershed, and has been found to be inversely correlated with salmon and trout density in the Pacific Northwest (Cedarholm et al. 1981). Presence of roads has also been correlated with changes to species composition, population sizes, and the hydrological processes that shape aquatic habitats (Gucinski et al. 2001)."

Analyses of roads and watershed spatial data tallied intersections of NB provincial roads (NBDNR[5] 2013) with OBoF streams by watershed basin. Based on NBDNR classification, road

[5] Spatial data provided by NBDNR and analyses carried out by Mojo Mapping Inc., Dorchester, NB, (2013).

surface was stratified by paved and unpaved as unpaved roads are reported to significantly increase sedimentation to adjacent waterways (Ramos-Scharron and MacDonald 2007). Class one and two roads were considered as ‘paved’ surfaces and all others (including roads trails and railway) as ‘unpaved’. Although not intended to explicitly capture each possible crossing of any type of road or trail, these analyses allow a reasonable index of crossings by road surface type for each OBoF basin. Density of roads (km road/km^2 basin) and crossings (per 10 km of stream) are presented for each basin by road surface type for OBoF rivers and SJR tributaries upstream of Mactaquac Dam (Table 6 and figures 5 and 6). ‘Comp.’ suffixes included in basin names indicate ‘composite’ areas that were not part of provincial watershed basin data and were manually delineated and tallied for increased accuracy in accounting road and crossing density.

Road crossing density for OBoF systems is shown in Figure 5 and ordered by density of unpaved crossings as they have been shown to contribute significantly to sediment input to streams. The Nashwaak, Keswick and Tobique are among the rivers in the OBoF with highest unpaved road crossing densities, due in part to the extensive history of forestry operations there.

Urbanization

Urbanization results in many threats to the aquatic ecosystem through land development, which can have negative effects on aquatic life (Booth et al. 2002). Several studies broadly evaluating salmon populations have documented more severe declines where natal rivers are more urbanized although declines have been observed on less developed systems as well (Chaput 2012; Ford and Myers 2008).

The most intense urban development in the SJR basin is occurring around the cities of Fredericton and Saint John (Kidd et al. 2011). Salmon mortality from contaminant input, habitat loss and or river usage (recreational and industrial) is unknown. Approximately 513,000 people live in SJR basin alone comprising 43% of NB’s total population (Kidd et al. 2011).

Notable urban development above the Mactaquac Dam in the SJR basin includes; Edmundston (~16,000 residents, SJR), Presque Isle (~9,700 on Aroostook River, Maine) and Caribou (~8,200 on Aroostook River, Maine), and smaller communities: Woodstock (~5,200, Meduxnekeag/SJR), Grand Falls (~5,700, SJR), Houlton (~6,100 on Meduxnekeag River, Maine), Perth-Andover (~1,800, SJR), Nackawic (~1,050, Nackawic River), Plaster Rock (~1,150, Tobique River), Hartland (~950, SJR), and Bath (~500, SJR).

Urban development below the Mactaquac Dam includes; Saint John (~128,000 including greater Saint John Area, SJR), Fredericton (~94,000 including greater Fredericton Area, Nashwaaksis Stream/Nashwaak River/Keswick River), Quispamsis (~18,000, Kennebecasis River), Rothesay (~12,000, Kennebecasis River), Grand Bay-Westfield (~5,000, SJR), Oromocto (~8,400, SJR/Oromocto River), Sussex (~4,300, Kennebecasis River), Hampton (~4,000, Kennebecasis River), and Penobsquis (~1,800, Kennebecasis River). The majority of the effects would be concentrated in the Saint John, Fredericton and Kennebecasis River Valley. Adult salmon must negotiate heavy pollution from industrial, commercial and residential sources when entering the Saint John Harbour.

Urban development in rivers of the Outer Fundy complex is limited to the towns of St. Stephen (~4,800 in 2011), Calais, Maine (~3,120 in 2010), St. George (~1,300 in 2006) and St. Andrews (~1,900 in 2011).

As mentioned above, road density can be used as a proxy for development in watersheds and has been shown to be negatively related to salmon and trout densities. Figure 6 shows the density of roads for each OBoF watershed (km of roads / basin area) ordered from highest total density. The density of paved roads in each basin is used as a measure for the relative magnitude of urbanization (see Cumulative Threat Impacts section).

Agriculture

The major environmental concern associated with the agricultural sector is the impact of suspended sediment and agrochemicals on the surrounding water quality (Chow et al. 2011). Proportions of YOY fish in agricultural regions are reduced as a function of reproductive dysfunction, increased mortality or a combination of both (Gray 2003). Intensive farming operations may lead to severe soil erosion, chemical runoff and nutrient leaching from farmland to both surface and groundwater which has been recognized as a threat to ecosystems and aquatic life (Yang et al. 2011; Brasfield 2007).

Approximately 6% of the land in the SJR basin is used for agriculture although 25% of the area around St. Leonard, Grand Falls and up/down stream of Florenceville is occupied by agriculture operations (Kidd et al. 2011). Agricultural practices, mostly related to potato farming, are prevalent in several sections of the SJR (above Mactaquac) from Woodstock to Grand Falls (Welch et al. 1977). Potato crops are a poor soil binding crop and, therefore, the land is susceptible to erosion. In addition, these conventional crops receive relatively large amounts of biocides annually (Welch et al. 1977). The area between Grand Falls and Hartland is one of the largest potato-producing regions in Atlantic Canada (Brasfield 2007). Curry and Munkittrick (2005) further describe the potato production areas and processing plants in the SJR basin above the Mactaquac dam to include the Grand Falls area, Florenceville, Hartland, Presquile, and Woodstock.

Although not considered an OBoF salmon river, approximately 65% of the Little River (draining to the SJR near Grand Falls) watershed is dominated by agricultural fields of predominantly potatoes but also including peas, grain and hay (Gray 2003; Yang et al. 2009). Black Brook, a tributary of the Little, was described as one of the most intensively farmed watersheds in eastern Canada (Brasfield 2007).

The Salmon River was used to study the effects of agricultural practices on aquatic organisms (fish and invertebrates) as approximately half of the watershed was affected by intense agriculture (Welch et al. 1977).

One of the Presquile stream’s headwater tributaries, Dudley Brook, did not meet Maine’s water quality standards and is in violation of Maine’s standards for aquatic life due to the high nutrient and sediment load attributed to agricultural practices (predominantly potato) in the sub-watershed (FB Environmental Associates 2010a).

The Meduxnekeag watershed consists mostly of potato crop fields on rolling topography, which has led to erosion and consequently siltation of the streams and pesticide and nutrient contamination (Baum 1982).

The Nashwaak River is affected by forestry and agriculture, which have prompted stream channelization, unstable river banks, and increases in beaver dam activity. All of these changes in the river likely affect habitat productivity and fish passage depending on the water flow regimes.

Agriculture represents 3.2% of the land use in the Canaan River, where forested land and wetlands are the predominant land uses in the watershed (Science and Reporting Branch 2007a).

Land use in the Kennebecasis River is similar to the rest of the SJR basin although agriculture occupies a greater proportion in this area than the average in the rest of the SJR basin (15.4% versus 6%) (Higgins et al. 2011).

Agriculture represents 7% of the land use in the Hammond River and forested land (83%) is the predominant use in the watershed (Science and Reporting Branch 2007c).

Agriculture represents 2.6% of the Digdeguash watershed where forest (85%) and wetland (9.5%) remain the predominant land uses (Science and Reporting Branch 2007b).

Forestry

Forestry remains the dominant land-use of the SJR basin at >80% (Kidd et al. 2011). The forest industry was the first major anthropogenic impact on the SJR and large-scale log driving was prevalent during the 1700's (Culp et al. 2006). By 1850, nearly all major SJR tributary basins had been logged with some described as the most heavily felled areas in the province (Kidd et al. 2011). With an extensive history of logging and milling in the OBoF DU, historical effects (e.g., submerged sawdust covering river bottoms) may be as, or more, concerning than current operations (Kidd et al. 2011). Failure, as recently as August 1989, of forest harvest operators to comply with the then 60 m buffer zones between clear cutting and water ways, as well as containing run-off from new road construction, resulted in the heavy silt compaction of more than five km (including two index electrofishing sites) of previously pristine gravel/cobble habitat on the headwaters of the Salmon River, Victoria Co. (Larry Marshall, DFO, pers. comm.). In conjunction with land-clearing, the use of pesticides is/was common practice. Dichlorodiphenyltrichloroethane (DDT) was used heavily between 1952 and 1967, but was banned for use in Canada in 1972. The use of DDT has been shown to have significant negative effects on aquatic and terrestrial life (Welch et al. 1977; Yule and Tomlin 1971).

Per capita, New Brunswick is Canada's largest producer of forest products (New Brunswick Crown Land Task Force 2011). Productive forest land is defined by NBDNR as 'land capable of producing a merchantable stand within a defined time period'. New Brunswick is composed of 84% productive forest land and ownership is generally subdivided into four categories; Crown Land (51%), Private Woodlot Owners (29%), Industrial Freeholds (18%), and Federal Lands (2%) (DNR Staff Review 2004).

New Brunswick's approximately 3.3 million hectares (ha) of crown forests are divided into 10 commercial leases to large forestry-based companies (Figure 7). Threats due to forestry operations could be significant for salmon populations in NB where the majority of land is publicly owned and leased to forestry-based companies. A summary of lease holder and major landowners in DU 16 watersheds is provided in tables 7 and 8 and figures 8 and 9. NB crown forest leases are managed by the NBDNR. Under the provincial forest management framework, NBDNR regularly audits the compliance of licensee's forest operations. Regulations, audit criteria, and performance reports are all available to the public via the NBDNR website[6]. Although it is not possible to determine many of the effects past forest activities have had on OBoF salmon populations, current implementation and regular auditing of operational standards is presumed to result in less aquatic impact per unit of operation than past practices.

Similar to agriculture, the main threats forestry poses to salmon populations are: altered stream flow and structure from landscape manipulation, increased sediment or chemical loading (herbicides), and altered temperature regimes (Moore and Wondzell 2005; Waters 1995). Most of these threats stem from the removal of vegetation, road infrastructure, and application of chemicals (Gilvear et al. 2002).

The average clear-cut size on NB crown lands is currently 35 ha and maximum allowable size is generally 100 ha (Martin 2003). In 2010, approximately 1.8% (54,000 ha) of NB crown land was clearcut (Maureen Toner, NBDNR-Fish and Wildlife, pers. comm., 2013). Glyphosate

[6] For more information, please visit the Government of NB website at http://www2.gnb.ca/content/gnb/en/departments/natural_resources/ForestsCrownLands.html.

herbicides, used to control competition of undesirable vegetation in areas planted with trees, were applied to approximately 12,000 ha annually from 2009-2011 (NBDNR 2012).

In a study on the Nashwaak River using test and control tributary basins, a 59% increase in summer peak flow was measured a year after 90% of the test basin was clear-cut (Dickison et al. 1981). Research in the Miramichi River drainage (non-OBoF) in New Brunswick did show decreased salmon egg survival following forest harvesting in the watershed although natural variability in juvenile survival was high (Cunjak et al. 2004). Although large portions of the SJR valley are now developed or used for agriculture, it has and continues to have a significant presence of forestry operations, and any effects of forestry will remain an important threat to salmon in this DU.

Forestry and agriculture practices are no less common on the American side of the SJR basin. The north Maine Woods, a 1.4 million hectare section of northwestern Maine, contains much of the American portion of the SJR watershed. This forested region is largely managed as industrial forest land. The effects of this land use could impact salmon downstream including in the Canadian jurisdiction of the SJR in DU 16. The fact that effects on the OBoF population could originate outside of Canadian jurisdiction poses a threat in itself and highlights the importance for international cooperation and collaboration in threat identification and recovery action planning.

Mining

In 2011-2012, the Fraser Institute recognized New Brunswick as the most attractive jurisdiction in the world for mining exploration and development (McMahon and Cervantes 2012). Within DU 16, exploration and mining opportunities are numerous and include such mineral commodities as: base metals (copper, lead, and zinc), gold and antimony, Tungsten, Tin, Molybdenum and Indium, Nickel and Copper, Manganese, Potash and Salt, Oil and Gas, and Rare Earths.

Fish affected by metals and metal mining effluents have shown; changes in behaviour, such as avoidance of effluent during migration runs, immunomodulation (modification of immune system), increased occurrence of larval deformities, increased tissue metal burdens, decreased survival, growth, reproductive potential, and fecundity, as well as alterations in histopathological, endocrine, and physiological parameters (Dubé et al. 2005).

The Sisson Brook Tungsten-Molybdenum project (Northcliff Resources/Geodex Minerals) is located in the Nashwaak Watershed and was set to complete Environmental Impact Assessment and permitting process by the end of 2012. No new information has been posted on the Northcliff Sisson Brook Project website by January 2013. The exploration project started in 2004 with the goal of the Sisson Brook Project being one of the largest tungsten mines in the world. Mine construction should commence in 2013 and be operational in 2014.

There are two potash mine operations on the Kennebecasis River watershed near Sussex, NB (Kidd et al. 2011). Before closing, a potash mine near Cassidy Lake, NB (on Hammond River watershed), encountered brine (fresh groundwater mixed with mine salts) entering the mining area. To evacuate the brine, a pipeline was constructed, mostly within the Hammond River basin from the Cassidy Lake Mine to the Bay of Fundy near St. Martins, NB, in the early 1980's. When similar brine problems were encountered in the Sussex mine, the brine pipeline was extended (much through parts of the Kennebecasis basin) and completed in late 2009. The current pipeline discharges up to 900 gallons per minute of salt-saturated brine into the Bay of Fundy (Figure 10). Little has been published on the effects of this brine on marine life, although Hutcheson (1983) reported brine concentrations could be lethal for certain Fundy marine life near the discharge source but predicted the brine is likely diluted quickly and near the outflow.

A brine line breakage in early 1980's affected over 1.5 km of the North Branch of Hammond River and salmon mortality was observed throughout (Peterson et al. 1988). The same study also found that Atlantic Salmon egg stages were least sensitive and parr stages most sensitive to brine solutions. Other spills have been noted in 1994, 1995, and 2009 (Campbell and Prosser 2009).

The Mount Pleasant Mine (Adex Mining Inc.) found in the Magaguadavic Watershed, sits on the only polymetallic deposit in the world. Metals found in the deposit include; indium, molybdenum, tin, tungsten and zinc. In 1980, the refurbishment of the Mount Pleasant tin mine to a tungsten mine, as well as the construction of an ore milling facility near St. George triggered concern for the potential effects of mine effluent on aquatic life within the Magaguadavic River (Martin 1984).

Hydraulic fracturing ("hydrofracking") is a modern drilling and extraction method used to access shale gas reserves previously considered inaccessible or unprofitable (Entrekin et al. 2011). High-pressure fracturing fluid creates fractures, which are propped open by the addition of sand and other granular materials to the fracturing fluid. Fracturing fluids can also contain: gels which are added to increase fluid viscosity and reduce fluid loss from the fracture, acids to remove drilling mud, biocides to reduce methane gas production from microbes, scale inhibitors to control precipitation of carbonates, and sulphates and surfactants to increase recovery of the fluid (Kargbo et al. 2010). The fluid is expected to breakdown quickly and be easily removed but Kargbo et al. (2010) reported that up to 80% of the injected fluid may not be recovered before the natural gas well is in production. Other fracturing agents are used to access natural gas reserves such as liquefied petroleum gas (LPG) and liquefied carbon dioxide (Dry Frac) (Al et al. 2012; Kargbo et al. 2010).

Environmental issues related to fracking include: sediment runoff and deforestation near streams and rivers from construction of pipelines and natural gas wells, reduced streamflow, and contamination of ground and surface water (Al et al. 2012; Kargbo et al. 2010; Entrekin et al. 2011).

Gas-bearing shale may be found in a large portion of New Brunswick (Figure 11, brown shaded portion). A number of companies are exploring in New Brunswick and Corridor Resources is producing gas from the McCully Gas Field near Sussex in the Kennebecasis watershed (Al et al. 2012). Corridor Resources uses the LPG method to stimulate gas release from shale by fracturing. LPG methods, which are mainly propane in gel form, reduce water consumption and generate no wastewater since all the fluid is recaptured (Kargbo et al. 2010).

Directed Fisheries - Freshwater (Recreational, Aboriginal, Commercial, Illegal)

Annual harvests of more than 550,000 lbs (250,000 kg) of salmon from the SJR and its tributaries were reported as late as 1860, while that number dropped to no more than 200,000 lbs (90,000 kgs) by 1890 (Kidd et al. 2011). Historical descriptions of reduced salmon stocks within the SJR date back to the early 1890's where the Nashwaak stocks were severely affected by dams and mills and the Canaan and Kennebecasis River salmon stocks were described as virtually extinct due to insufficient protection from overfishing (Kidd et al. 2011). Marshall et al. (1999) tabled estimated removals from 1970 until 1998. Aboriginal harvests ranged from 27-713 1SW salmon and 25-2,575 MSW salmon. Every year from 1974 until 1992, 1SW harvests were greater than 1,000 fish with the highest catch of 3,580 in 1976. Before hook and release of MSW salmon was mandatory in 1984, MSW salmon harvests ranged from 333-3,125 fish. From 1981 to 1983, the commercial fishery re-opened and harvested on average, 1,518 1SW and 3,095 MSW salmon per year (Marshall et al. 2000).

All directed salmon fishing has been closed to Aboriginal and recreational fishing in the OBoF region since the late 1990's and early 1980's for domestic commercial fishing (DFO and MRNF 2009; Jones et al. 2010). There are still four inactive commercial licenses remaining in the SJR area, although all commercial salmon fishing has been closed since 1984 (Jones et al. 2010). The Aboriginal food and recreational fisheries for the Saint John, Magaguadavic and St. Croix rivers have been closed since 1998, as salmon populations persistently failed to meet conservation requirements (Marshall et al. 2000; Jones et al. 2010).

All populations in the OBoF DU have a high exposure to illegal fishing (poaching). Any removal of adult salmon from OBoF rivers constitutes a severe threat to the population and a direct loss of spawners as they have survived all sources of mortality to that stage. As a mitigation measure, additional enforcement patrols, especially below the Tobique Dam and adult release sites (DFO and MRNF 2009) have been carried out in the recent years. Based on net and jig/hook markings recorded at Mactaquac and Tobique facilities, poaching activities has and continues to occur on the SJR system (Figure 12).

In 2008, conservation officers did report illegal fishing downriver from Mactaquac Dam although the removal of salmon was not observed (Jones et al. 2010). The CBC News reported on increased poaching activity in August of 2010 where conservation officers reported increased poaching activity and a few seizures within the season. DFO (2011b) estimated that 58 MSW salmon (or 12.6% of the total MSW returns) were lost to illegal poaching (mostly gillnet) activities in 2010.

Incidences of poaching are inherently difficult to quantify but those that have been reported include:

- In 1988, the Tobique First Nation conducted an illegal ‘fish-in’ in late July to early August and reportedly netted 25% of the MSW fish distributed above Mactaquac (Marshall 1989) and again in 1989 where a reported 800 salmon were taken (Marshall 1990).
- A man was convicted for illegal fishing after DNR officers confiscated an Atlantic Salmon illegally caught on the Nashwaak River in July, 2010.
- The Atlantic Salmon Federation published an account of an illegal salmon catch on the Kennebecasis River in 2011 where prosecution was asking for the highest fines.
- In the early 1980’s, illegal fishing (poaching) was reported at the St. George fishway where dead salmon were found with gaff or pitch fork wounds (Martin 1984).

Intentional illegal hook and release (or retention) angling for Atlantic Salmon under authority of licensed trout angling has been reported in areas of the Saint John watershed, in particular near adult release sites upriver of Mactaquac Dam and in lower tributaries with an early run component (Darin Manderville, DFO-Conservation and Protection, pers. comm., 2012). The number of adult salmon lost to this activity within the DU is unknown and mortality rates for hook and release salmon angling have been estimated to be variable (Dempson et al. 2002; Thorstad et al. 2003) and positively related to water temperature (DFO 2011b). Any illegal removal could pose a significant threat considering the low population numbers (Jones et al. 2014) and that trout angling is widespread in NB. In 2012, a number of holding pools below Beechwood Dam and a section of the Tobique River near salmon distribution sites were closed to angling to reduce the opportunity for illegal hook and release angling to take place (DFO variation order 2012-068).

By-catch - Freshwater (Recreational, Aboriginal, Commercial)

Several fisheries in the Gulf of St. Lawrence have been ranked according to concern for intercepting salmon as by-catch and include Gaspereau (Alewife and Blueback Herring) and American Eel as high concern for potential by-catch (American Shad was not assessed) (Chiasson et al. 2002). Currently there are 55 Shad, 67 Gaspereau and 23 eel commercial licenses issued within the OBoF DU (Sarah Cheney, DFO-Licensing, pers. comm.). Within the SJR, Shad and Gaspereau fisheries occur predominantly in the mainstem, Oromocto River and Grand Lake/Jemseg River complex. By-catch of salmon smolts in Gaspereau trap-net fisheries occurs in the SJR system but numbers of smolts lost in this fishery are unknown because of the unreliability of by-catch logbook recording.

There are active recreational gill net licenses for Shad (24) and Gaspereau (40) on the SJR, however, by-catch is not consistently reported (Tara Jenkins, DFO-Conservation and Protection, pers. comm.).

For population estimate purposes, the by-catch of returning adult salmon in the Shad and Gaspereau nets in the lower SJR and harbour is estimated to be 1% 1SW and 2.5% MSW of returns (Jones et al. 2010).

An Aboriginal Striped Bass fishery was established downriver of the Mactaquac Dam, which would result in small by-catches of Atlantic Salmon (DFO and MRNF 2009).

FRESHWATER THREATS SUMMARY

Based on available information, the habitat obstruction complex composes the most important threat to the OBoF salmon population's persistence in freshwater. Direct additive smolt mortality has been documented at up to 45% when migrating through three dams on the SJR. Head pond reservoirs compromise habitat in over 140 km of river on the SJR and alter temperature, flow regimes, and non-native predatory fish abundance. The Mactaquac Dam is a complete barrier to upstream migration and requires the handling of each migrating adult salmon through trapping and trucking facilities to pass fish upstream to spawn naturally in their natal stream.

To neutralize the negative effects of the Mactaquac Dam, over 40 years of DFO efforts have likely compromised the ability of OBoF populations to persist to some degree. Various stocking efforts prior to the Mactaquac Dam, although less documented, may also have contributed to the populations current status. Despite the potential that stocking efforts have threatened recovery potential for OBoF salmon, they are likely the only reason OBoF salmon currently occur above the Mactaquac Dam.

Any illegal removal of salmon at current population levels will continue to have increasingly severe effects on population persistence as populations decline. Because management can, to varying degrees, affect the amount of illegal removal, efforts should be maintained or improved to prohibit such actions.

Historic commercial harvests of salmon have been reported at more than 227,000 kg (500,000 lbs) annually in the SJR system alone. Therefore, past removals, along with other threats known to occur before the onset of major dam construction in the 1950's and 1960's, such as forestry and road building cannot be ignored when discussing the threats to this population's ability to persist.

After the St. Lawrence, the SJR is the longest river in northeastern North America. The SJR has an extensive history of settlement and industrialization (Saint John is the oldest incorporated city in Canada) and has been subject to impacts of habitat alterations, sedimentation and contamination. Many direct impacts (such as the degree to which sedimentation has reduced egg-smolt survival) to OBoF populations over time are difficult to link to specific causes and vary in dimensions of space, time and magnitude.

MARINE THREATS

Salmon Aquaculture

Human impact on marine fish and ocean resources has fuelled the growth of the aquaculture industry in the past 20 years with Atlantic Salmon making up over 90% of the finfish livestock worldwide (Naylor et al. 2005). The Royal Society of Canada Expert Panel on Sustaining

Canada's Marine Biodiversity presented the following among key findings on the effects of aquaculture:

> "Exchange of pathogens between farmed and wild species can seriously threaten wild species. Interbreeding between wild fish and escapees of the same species threatens the reproductive capability and recovery potential of wild populations of conservation concern."

Aquaculture siting in New Brunswick currently forbids the use of viable non-indigenous species to the North American Commission Area and encourages the use of broodstock based on local or nearby stocks to the site (Porter 1992). The protocols strongly endorse cages or facilities that minimize the risk of escaped fish from entering watercourses where wild fish spawn[7].

Here, aquaculture threats are considered from four perspectives concerning OBoF salmon:

- Effects of commercial salmonid production in freshwater hatcheries.
- Effects of domestic salmon escaping marine pens and interacting with wild fish.
- Effects of wild salmon interacting with marine farms and surrounding environments.
- Effects of the aquaculture of livestock other than salmonids.

Recent studies correlated proximity and density of aquaculture sites with negative effects on wild salmon populations (Ford and Myers 2008; Morris et al. 2008; Lund et al. 1991). Based on this work, the OBoF population is geographically positioned to be affected by aquaculture operations as all populations must pass within 100 km of the intensive aquaculture activities of the Passamaquoddy (Quoddy) region, in southwestern NB, during migration to and from freshwater (Figure 13).

In 2004, there were 97 licensed sites for finfish aquaculture in NB; all were located in the Quoddy region on the southwestern coast (Chang at al. 2005). Currently, there are 95 sites (Figure 13).

From 2000-2003, NB's total annual production of farmed salmon ranged from 29-38 thousand tonnes (GNB 2005). New Brunswick harvest of aquaculture salmon totalled approximately 20 thousand tonnes annually in 2011 and 2010 with each harvest representing approximately 4.5 million fish (Edward Olale, NB Department of Agriculture, Aquaculture and Fisheries (NBDAAF), pers. comm., 2013). For context, the entire North American Atlantic Salmon population is estimated not to have exceeded three million adult salmon over the last century (Friedland et al. 2003) and OBoF salmon returns were estimated to be less than 1000 adults in 2012 (Jones et al. 2014; DFO 2010).

Magaguadavic, St. Croix and some other Outer Fundy Complex rivers drain directly to Passamaquoddy Bay and surrounding region where all NB salmon farm operations occur (Figure 13). Based on current knowledge of marine migration routes (Marshall et al. 2014), OBoF salmon could also be affected by aquaculture operations on the Nova Scotian Atlantic coast as described by Bowlby et al. (2014).

Effects of commercial juvenile salmonid production in freshwater

Freshwater hatcheries have the potential to threaten freshwater quality through contaminated outflows from facility to watersheds but the hazard depends on facility capacity, species cultured, effluent treatment, and containment. Hatcheries can threaten natural system dynamics through the escape of cultured individuals or transmission of disease (Bowlby et al. 2014).

[7] Text adapted from DFO and MRNF (2009).

The Magaguadavic River salmon population is affected by both freshwater aquaculture (Chang 1998; Science and Reporting Branch 2007e) and marine aquaculture. On the Magaguadavic lie three commercial salmon hatcheries that produce smolts for the salmon farming industry and the river drains directly to the Passamaquoddy Bay (Carr and Whoriskey 2006). In some years, smolts escaping from freshwater hatcheries located on the river have comprised 50% of the river's total smolt run (Chang 1998). Lacroix et al. (2004b) showed that 9% of adult returns to the Magaguadavic, from the 1996 smolt cohort, were from smolts that escaped domestic commercial hatcheries upstream as juveniles. The same study showed that the cultured juveniles had only 20% the survival rate of wild smolts of the same cohort during the same marine migration. These findings demonstrate the potential for domestic salmon to 'pull-down' fitness of the wild population when interbreeding occurs.

In addition to the commercial hatcheries in operation on the Magaguadavic, Figure 14 shows other hatcheries in operation in the OBoF DU except one on Grand Manan Island (courtesy of NB Department of Environment and Local Government).

In the spring of 1998, a counting fence was installed and operated on the Tay River as part of a project to assess the wild smolt production on the Nashwaak River. Surprisingly, 134 (22%) of the total smolt captures were fish determined to have escaped from a private hatchery located upstream of the counting fence (Marshall et al. 1999).

Wild population interaction with farmed salmon escaped from marine cages

Escape of cultured salmon occurs through low-level 'leakage' and isolated events such as storms, which can cause containment pen breaches (Naylor et al. 2005). The number of escapes from aquaculture facilities into the North Atlantic has been suggested to be 2 million fish per year (Schiermeier 2003). The level of concern warranted by the threat of escaped farm salmon depends on the total farm population size, escape rate, and frequency. It was found that aquaculture escapes are prevalent enough in eastern North America to pose possible serious risk to wild salmon populations especially in those rivers located near aquaculture facilities (Morris et al. 2008).

The impacts of aquaculture escapes on wild populations of Atlantic Salmon include: interbreeding with wild salmon, which can lead to reductions in fitness and/or loss of local adaptation (Bourret et al. 2011; Fraser et al. 2008, 2010; Wappel 2003; Ford and Myers 2008), disease transmission (Wappel 2003; Ford and Myers 2008; Leggatt et al. 2010; Tlutsy et al. 2008; Thorstad et al. 2008), competitive displacement of wild salmon (Houde et al. 2010; Wappel 2003), disturbing/destroying wild salmon spawning redds, breeding in the wild, and increase uncertainties in wild stock assessment (Morris et al. 2008).

In Canada, policy for reporting escapes from aquaculture facilities varies by region or province (DFO 2012a). DFO and the NBDAAF produced a framework to manage escapes from NB aquaculture operations in 2009 (DFO and NBDAAF 2009). In 2010, section 14.1 of the *New Brunswick Aquaculture Act* was revised to require the industry to report incidents where more than 100 salmon are suspected to have escaped and to attempt to re-capture lost livestock within 24 hours of escape. Report of number and location of containment pen breeches is housed by the NBDAA and not distributed publicly (Lori O'Brien, NBDAAF, pers. comm., 2013). The most probable source of aquaculture origin salmon identified at counting facilities on OBoF rivers are from juvenile and adult escapes from Passamaquoddy Bay, Fundy-Isle or Cobscook Bay (USA) aquaculture areas (Jones et al. 2010).

Historic OBoF adult returns would have numbered as many as approximately 47,000 (ICES 2006) within the last four to five decades and were less than 1,000 in 2012 (Jones et al. 2014). Using recent annual harvest levels for example, farmed salmon in the Quoddy region in the past decade outnumber wild adult OBoF Atlantic Salmon returns on average about 1000:1 but with the record low returns in 2012 it may have been at least 4000:1. As such, even proportionally, very small escape rates could result in appreciable numbers of potential interactions with wild fish. Using the above farmed:wild adult salmon example, escape rates from NB farm sites as low as 0.1% would quadruple the current wild salmon population. This matter of scale underscores the importance for continual improvements in any measures or policies to ensure farmed fish containment and nutrient loading around aquaculture sites.

Farmed salmon have indeed escaped freshwater hatcheries and marine net pen sites (sea cages) in the Bay of Fundy and remained in or ascended many rivers in the OBoF DU (Carr and Whoriskey 2006; Morris et al. 2008; Jones et al. 2010; Lacroix and Fleming 1998). Suspected aquaculture escapes have been identified by considerable erosion and partial regeneration of fin rays on all fins including the upper and/or lower lobes of the caudal fin, the presence of an adipose fin, and the interpretation of scale samples (Jones et al. 2010). During the late 1980's and early 1990's, farmed escapees were identified by "broom" tails and gross fin erosion (Marshall and Cameron 1995). An international scientific working group reported that the identification of farmed escapes based on external appearance is becoming increasingly difficult as a result of improved rearing practices within the industry (ICES 2011a). External characteristics are not prominent when a fish escapes as a juvenile.

The rivers most impacted by farmed salmon escapes that are monitored in Atlantic Canada are within the OBoF DU, the Magaguadavic (Carr and Whoriskey 2006) and St. Croix (Morris et al. 2008; Jones et al. 2010). On the Magaguadavic, escaped farmed salmon have been identified every year from 1992 to 2012 (Figure 15) and aquaculture escapees have comprised over 90% of the total adult run in some years (Jones et al. 2014; Carr and Whoriskey 2004).

Suspected aquaculture escapes have been monitored on the SJR at the Mactaquac Dam since 1990 (Jones et al. 2010) although possibly misidentified as wild before 1990. Since then, suspected escapees were detected in all but six years at Mactaquac with counts as high as 229 (1990), while most years had less than 20 (Figure 16). In the past decade, very few escapes have been caught at Mactaquac facilities with the exception of 27 caught in 2010 (Jones et al. 2014). More than 57% of the productive habitat in the OBoF DU occurs downstream of Mactaquac Dam and closer to the farm operations in Passamaquoddy Bay. Except for the counting facility on the Nashwaak River, escapes are not monitored below Mactaquac (150 km from the river mouth), thus counts from the Mactaquac Dam are a minimum for the entire SJR system.

Suspected aquaculture escapes have also been reported on the Bocabec River (Carr and Whoriskey 2004). The St. Croix River drains directly to the Passamaquoddy Bay and has reported presence of aquaculture escapees every year from 1994 to 2006 (last year of adult salmon returns monitored at the fishway). Aquaculture escapees comprised between 13% and 85% (39% median) of the annual total run of salmon to the St. Croix River (Jones et al. 2010; Carr and Whoriskey 2004).

Researchers documented a change in the genetic make-up of the Magaguadavic River salmon population, which has been potentially impacted by farmed salmon for nearly 20 years (Bourret et al. 2011). This research showed that aquaculture escapees had introgressed with wild salmon resulting in significant changes to the genetic integrity of the wild population. These changes could render the wild fish less adaptive to the natural environment (Bourret et al. 2011). The suspected aquaculture origin salmon collected at the fishway on the Magaguadavic River are sacrificed for sampling of pathogens (Jones et al. 2010).

Interactions of wild salmon entering vicinity of farm areas

On the effects of marine aquaculture on the surrounding environment, The Royal Society of Canada Expert Panel on Sustaining Canada's Marine Biodiversity included nutrient loading and chemical inputs as concerns for sustaining natural biodiversity. Further, reductions in benthic diversity and water pollution have been recorded near some farm sites because of the use of antibiotics or chemicals in marine fish culture operations (Bostick et al. 2005). In Cobscook Bay, Maine (off of Passamoquoddy Bay), Brooks et al. (1999) reported average ‘flushing’ times for surficial particles of two days before dilution in the open Bay of Fundy suggesting that introduced substances could linger in some areas of the Passamaquoddy region for varying lengths of time. Using a relatively long-term data set (established in 1987), Martin et al. (2009) found no strong evidence that there have been changes or increases in nutrients in the Passamaquoddy Bay associated with harmful algal blooms.

Recent research in Atlantic Canada showed a higher frequency and density of aggregations of wild fish in bays containing aquaculture operations than in adjacent vacant bays, which were scheduled for future aquaculture operations (Goodbrand et al. 2013). Although the authors did not identify wild aggregation species composition, the work demonstrates potential for predator-prey dynamics to be altered from ambient levels in bays containing aquaculture operations.

Lacroix (2008) tracked smolts of various river origins migrating through the Bay of Fundy and found no OBoF-origin (SJR above Mactaquac; Nashwaak River) smolts entered the Passamaquoddy Bay region. The same study reported 10 IBoF smolts entering the Passamaquoddy Bay area and all but two were detected exiting. Lacroix (2008) noted lower survival of smolts in areas where predators were prevalent including: Grey Seals (*Halichoerus grypus*), Harbour Seals (*Phoca vitulina*), Spiny Dogfish (*Squalus acanthias*), and piscivorous birds.

When tracking smolts of both hatchery and wild origin from two rivers draining to the Passamaquoddy Bay region, Lacroix et al. (2004) recorded that 90%-97% successfully left estuaries and 71%-88% exited the Passamaquoddy Bay region into the Bay of Fundy.

There is a growing body of evidence correlating salmon aquaculture operation establishment, proximity, and growth with various measures of decline in wild salmon populations (Ford and Myers 2008; Dill et al. 2009; Morris et al. 2008). However, aside from documented accounts of escaped fish (some carrying disease) in several OBoF rivers and evidence that escaped fish have interbred with wild fish, documented effects of aquaculture operations on Atlantic Canadian populations are sparse compared to European and western Canadian populations of salmon. Marine animal attraction to aquaculture sites has not been documented in the OBoF DU or directly linked to increased mortality in other wild populations although these links have been made in other regions (Dempster et al. 2002). Currently there is little evidence to show that effects of altered parasite, predator and pathogen dynamics, which are documented for other salmon populations near aquaculture operations, are not occurring on OBoF populations. Thus, continued research and collaboration with the aquaculture industry is encouraged to define the state of the industry’s effects on wild salmon populations of the OBoF.

Non-salmonid aquaculture

The NBDAAF currently leases 95 sites in the Passamaquoddy region of southwestern NB for aquaculture (Figure 13). Only one of these sites is licensed for shellfish and no commercial production of finfish, other than salmon, currently occurs in this region[8]. Non-salmonid aquaculture is considered to have negligible impact on the persistence of wild OBoF salmon.

Shifts in Marine Environment

Oceanic conditions

DFO and MRNF (2009) describe the effects of changes in the ocean on wild Atlantic salmon populations:

[8] For more information, visit NBDAAF website at http://www.gnb.ca/0027/Aqu/.

> "Changes in temperatures, salinities, currents, and species composition and distribution (including predators and prey of salmon) are all anticipated as a result of climate change. In combination, these factors will impact on Atlantic Salmon production and survival in fresh water and at sea. The population trajectories associated with these changes are difficult to model as the anticipated conditions are outside the range of values observed in the relatively short time frame during which salmon have been studied. Marine and estuarine conditions are believed to exert important influences on Atlantic Salmon, their ecology and survival. Climate induced changes, for example in sea surface temperature and salinity, may be some of the key factors affecting natural salmon mortality through changes in the distribution of plankton assemblages and associated dependent prey species, as well as predators (Cairns 2001). Regardless, projecting stock-specific effects of climate change on Atlantic Salmon will be problematic owing to differences in stock characteristics and local geography. To date, three approaches have been used to draw inferences: physiological approaches, empirical approaches using local weather and climate data related to salmon population dynamics, and distributional approaches linking projected climate change effects to presumed changes in fish species distributions."

Moore et al. (1995) found that smolts apparently require no period of acclimation when moving to saltwater. However, SJR smolts released from Mactaquac Dam and Nashwaak River had freshwater/estuarine migrations averaging three to five days in duration (Lacroix 2008) and may benefit from pre-oceanic growth resulting in reduced predation once at sea. Amiro et al. (2003) quantified North Atlantic sea surface temperatures (SSTs) according to estimated suitability for Atlantic Salmon marine migration. Their work showed that SSTs could be at or near unfavourable highs for OBoF salmon returning to their rivers in mid-late summer (Marshall et al. 2014). Marine habitat requirements for OBoF Atlantic Salmon are less well known than fresh water requirements (Marshall et al. 2014). The lack of information is due, in part, to the difficulty in collecting data and tracking salmon at sea. There is a tag and tracking data set (Ritter 1989; Ruggles and Ritter 1980; ICES 1990, 2008; Lacroix 2008, 2013; Lacroix and Knox 2005; Penney 1983; Whoriskey et al. 2006) that demonstrates placement of OBoF salmon in the Bay of Fundy, Scotian Shelf, Grand Banks, Newfoundland and Labrador coasts and the Labrador Sea where other investigators have described 'preferred' habitats and prey of Atlantic Salmon. The extent of current understanding of marine habitat requirements is discussed in the companion document, 'Habitat Considerations' for OBoF Atlantic Salmon (Marshall et al. 2014).

Predator-prey

Recent studies have documented marine predators to Atlantic Salmon to include seals, dogfish, sharks and tuna (Lacroix and Knox 2005; Lacroix et al. 2012).

Over the last 25 years, Grey Seal abundance has been shown to have increased significantly where populations are monitored by DFO in the Gulf of St. Lawrence, Sable Island, and coastal Nova Scotia (NS) (DFO 2012b). Bowen (2011) reported that Grey Seal populations in the northwest Atlantic are the highest in a century. Harbour Seal populations along southwestern NB, including near aquaculture operations have not been experiencing significant growth in abundance (Jacobs and Terhune 2000).

Lacroix and Knox (2005) noted that post-smolts collected during trawl surveys were often found with or near Spiny Dogfish suggesting dogfish as a possible predator of post-smolt. Smolts have also been identified as prey sources for Dogfish in the Bay of Fundy region by McRuer and Hurlbut (1996). Dogfish populations in the northwest Atlantic showed increases from 1980 to 1990 and have since declined to approximately 300,000 tons (Campana et al. 2007). Dogfish predation on post-smolts, even at low levels, could have a significant effect on populations due to the relative high abundance of Dogfish (Campana et al. 2007).

Shark species likely to predate juvenile or adult salmon in the northwest Atlantic include: Blue (*Prionace glauca*), Short-fin Mako (*Isurus oxyrinchus*) and Porbeagle (*Lamna nasus*) sharks (Dr. Steven Campana, DFO Science, pers. comm.). Present abundance of Porbeagle in the northwest Atlantic is approximately 25% of 1961 levels but is 95-103% of 2001 abundance, indicating recent stabilization and possibly upward trending (Campana et al. 2010). Blue Sharks are currently abundant in the northwest Atlantic, with North Atlantic by-catch alone estimated around 84,000 mt. Blue Shark abundance has declined by approximately five to six percent per year since 1995 (Campana et al. 2006). Short-fin Mako Shark abundance has declined since the 1970's but has been relatively stable since the late 1980's in the North Atlantic (Campana et al. 2006).

Atlantic Bluefin Tuna (*Thunnus thynnus*) abundance in the Atlantic Canadian region (including the BoF) is estimated to have had a sharp (approximately 70%) decline from 1970 to mid-1980, but has since been relatively stable (Maguire and Lester 2012).

Atlantic Herring (*Clupea harengus*) have been documented as an important (Dixon et al. 2012) and preferred prey species for wild Atlantic Salmon (Rikardsen and Dempson 2011). Renkawitz and Sheehan (2011) found that wild smolts from New England rivers consumed predominantly fish species when entering the marine environment while smolts, from captive origin that were released to the river before migrating to sea, consumed more crustaceans. Herring abundance has been positively related to marine survival of cohorts of Atlantic Salmon post-smolts (Rikardsen and Dempson 2011).

Herring abundance has been assessed by DFO (2011a) throughout much of the marine habitat thought to be important for OBoF post-smolts. There has been an overall 32% decline in stock biomass in the last decade and little evidence of rebuilding despite reductions in harvest levels. The Scotian Shelf area Herring stock status was variable between 1965 and 1995 although showed a general decline between 1975-1985 (DFO 1996a) preceding the recent decline in returning OBoF salmon. Worldwide harvest of Atlantic Herring declined sharply for over a decade beginning in the 1970's due to over-harvest in the previous decade (Figure 17[9]). Herring harvest from the northwestern Atlantic, which is presumed to be important feeding grounds for OBoF salmon (Marshall et al. 2014), composes 20-30% of the worldwide herring harvest[9].

Sand Lance (*Ammodytes dubius*) has also been documented as an important source of prey fish for Atlantic Salmon (Rikardsen and Dempson 2011; Lacroix and Knox 2005). Sand Lance stock abundance along the Scotian Shelf, a feeding corridor for migrating OBoF salmon, was variable between 1970-1996, although did show lower relative abundance through the 1980's (DFO 1996b).

Lacroix and Knox (2005) reported that the majority of prey items consumed by a sample of migrating smolts (including those from OBoF rivers) were species of the Hyperiidae family of amphipods and Euphausiacea (krill sp.). The same study suggested prey availability was not limiting survival based on the samples collected.

Krill abundance estimates for the Scotian Shelf including the Fundian Channel was estimated by Harding (1996) and DFO (2000) partly in response to requests to open a krill fishery. These studies generally concluded that current krill abundance was capable of sustaining a modest fishery of 1000 mt and that abundance may be increasing.

Relatively low numbers of Herring and Sand Lance, through the mid-1970's and 1980's, preceded the beginning of recent severe declines in returning salmon stocks (COSEWIC 2010) by five to 15 years or approximately one to three salmon generations. Herring and Sand Lance

---

[9] From the Food and Agriculture Organization of the United Nations- Fisheries and Aquaculture Department-Atlantic Herring Factsheet.

are a relatively high-energy prey source for salmon (Renkawitz and Sheehan 2011) and could be important for attaining required growth rate to complete the marine migration. Herring abundance, at time of smolt migration, has been positively associated with marine phase survival (Rikardsen and Dempson 2011). Sand Lance is known to be a significant source of prey for Grey Seals (Iverson et al. 2004). Grey Seal populations have experienced rapid growth in recent decades and are currently at record highs in the northwest Atlantic (Bowen 2011). Declines in some prey items, and growth of some populations of predators, preceded or coincide with the recent collapse of salmon populations. However, it is difficult to establish predictive relationships between predator and prey abundances due, in part, to the complexity of food webs particularly for non-specialist predators. Currently, shifts in abundance of preferred prey and predators for OBoF salmon cannot be ruled out as contributing to the observed decline in marine survival. Based on observations by DFO staff at the Mactaquac Biodiversity Facility, suspected predator wounds have potentially increased recently on returning OBoF salmon (Figure 3).

Parasite and Disease

Ectoparasitic copepods (specifically, *Lepeophtheirus salmonis*), commonly referred to as 'sea lice', are the most pathogenic parasite in salmon farming (Costello 2009). The parasites, both at the larval and mobile adult stages, infest salmon through transfer from other fish (wild or cultured) and feed on salmon skin, flesh, and mucus. As most parasites, they can proliferate in high host density areas and then be released into the surrounding environment where they can infest other available hosts (Costello 2009). With depressed populations of wild salmon, any additional mortality caused by sea lice is a concern (Carr and Whoriskey 2004). Although sea lice are a natural parasite of salmonids, they likely occur in higher than ambient densities around farm sites because of the increased density of hosts (Carr and Whoriskey 2004). Basic theory of epidemiology (Anderson 1993) suggests that; any parasite or disease found to affect farmed salmon could pose a significant threat to wild OBoF salmon due to both farmed escapees interacting with wild individuals and wild salmon passing near farm regions, which contain constant high host densities. Current research on salmon lice transmission dynamics to wild hosts is predominately from Europe and western Canada. Less has been documented for North American Atlantic Salmon. Heuch et al. (2005) reported that several sources have demonstrated that lice loads greater than 11, on migrating European Atlantic Salmon smolts, were lethal and that negative sub-lethal effects were greater for smaller fish.

The 'reservoir' effect (Frazer 2007) describes that temporal and spatial occurrence of sea lice is held abnormally high by the high host density of salmon farm sites. This can result in juvenile wild salmon hosts being exposed to densities of lice in coastal areas that did not naturally exist for the salmon at that life stage. Naturally, few juvenile salmon would be exposed to lice during seaward migration in spring from coastal regions (Dill et al. 2009). Only those latest migrants, when they could encounter earliest returning adults would have significant exposure. Research from western Canada has demonstrated that salmon smolts experienced significantly greater lice loading by moving through areas with salmon farms (Krkošek et al. 2005). Similar research in Europe supported findings of higher lice loading on fish in the vicinity of salmon farming operations but longer term monitoring has shown large variation in lice load numbers on wild fish (Heuch et al. 2005).

The Magaguadavic River program, headed by the Atlantic Salmon Federation, has been monitoring sea lice on returning salmon since 1992. Between 1992 and 2002, 21% of the wild and 17% of the farmed salmon caught were found to carry sea lice (Carr and Whoriskey 2004). From 2003 to 2012, annual returns to the Magaguadavic ranged from one to 27 and averaged nine adult salmon. Proportion of annual wild returns carrying sea lice ranged from 0%-33%, averaging 17% lice load (Atlantic Salmon Federation, unpublished data).

Presence of ectoparasite on returning adult salmon is observed at the Mactaquac sorting facility and the Tobique Dam. These observations suggest parasites have been present on more returning salmon over the last decade (Figure 18), however, parasite species identification has not been carried out regularly. Considering literature documenting survival of the *L. salmonis* in freshwater varies from only hours to weeks (Whelan 2010; Finstad et al. 1995), it would be expected that their presence on returning salmon would decline during migration to higher tributaries on the SJR. The observations, of parasite presence at the Tobique Dam facility not consistently being lower than those at Mactaquac, suggest the possibility that parasites include freshwater species. Multiple species of parasites on salmon have been observed on the Penobscot River, Maine and included both fresh (*Argulus stizostethii*) and salt water *(Lepeophtheirus salmonis)* species (Powell et al. 1999). *S*ampling to properly identify the range of parasites found on migrating salmon on the SJR would address this knowledge gap.

Diseases occur in wild as well as cultured fish (Olivier and MacKinnon 1998). Disease outbreaks can be instigated by nutritional or genetic factors of the host, as well as environmental factors (Olivier and MacKinnon 1998). The risk of infection in fish is generally increased with fish density but is also affected by temperature, dissolved oxygen, current velocity, and accumulation of metabolic waste products (Saunders 1991). If sub-optimal, these conditions increase stress in fish and when exposed to pathogens, outbreaks can occur. OBoF salmon pass near or through high host density areas (salmon farms) along their migration routes, which increases exposure to several potential pathogens.

Five major diseases and parasites affecting the maritime aquaculture industry are; *Renibacterium salmoninarum* - bacterial kidney disease (BKD), *Aeromonas salmonicid* - furunculosis, *Vibrio anguillarum* - vibriosis, sea lice, and infectious salmon anemia (ISA) while major diseases affecting wild salmon are; furunculosis and BKD (Olivier and MacKinnon 1998; Lawler et al. 2009).

BKD was detected in the Magaguadavic River (1998), although, this sample was labelled an aquaculture escape (MacKinnon et al. 1998). Table 9 summarizes the results of health testing carried out on 35 wild and 564 aquaculture escape salmon samples from the Magaguadavic River from 1992 to 2005.

Vibriosis is a bacterial disease that affects Winter Flounder (*Pseudopleuronectes americanus*) and Pollock (*Pollachius virens*) adjacent to aquaculture areas in Atlantic Canada. As a result, the culture sites and adjacent wild hosts could act as a reservoir for vibriosis (Saunders 1991). Saunders (1991) reported that, although the disease had yet to be detected in wild salmon in Canada, it had been detected in a sea-cage in NB. Data from the Atlantic Salmon Federation indicates vibriosis has been detected once in a wild fish returning to the Magaguadavic River in 1992 (Table 9; Jon Carr, Atlantic Salmon Federation, pers. comm.).

ISA was first detected in aquaculture cages in NB (Bay of Fundy) in 1996 although, initially, the disease was diagnosed as hemorrhagic kidney syndrome (HKS) (Bouchard et al. 1999; Kibenge et al. 2000). ISA spread to 21 farm sites by 1997 and 35 by 1998. Although a widespread culling was undertaken, 17 of the sites remained contaminated and in 1999, wild and cultured Atlantic Salmon entering NB rivers in the Bay of Fundy region were found to have the disease (Cipriano 2009; Bostick et al. 2005). More specifically, four of 58 escaped farmed Salmon captured and 14 of the 20 wild fish collected for broodstock in the Magaguadavic River, in 1999, tested positive for ISA (Table 9; ICES 2000). Cipriano (2009) mentions the virus was found in a population of wild Atlantic Salmon kept in a land-based facility although the location was not disclosed. Although transmission from net-pen salmon to wild stocks has been shown (Bostick et al. 2005), Lacroix and Knox (2005) did not find evidence of aquaculture sites infecting post-smolts during migration through the aquaculture corridors following disease testing and observations of post-smolt collections in the Outer Bay.

Aeromonas salmonicida, is a causative agent for furunculosis and is ubiquitous to the SJR (Marshall et al. 2000). This disease agent was detected in wild salmonid samples from the; Tobique River (1988-1989), SJR (1990, 1998), and Nashwaak River (1997) (MacKinnon et al. 1998).

Red Vent Syndrome (RVS) has been reported in wild Atlantic Salmon in Ireland, Norway, Canada and Iceland (Noguera et al. 2009). The identification and reporting of abnormal, hemorrhagic vents, on returning wild Atlantic Salmon has increased since 2005 and the high presence of *Anisakis*, a roundworm with pan-global distribution, has been identified as the cause (Noguera et al. 2009; Murphy et al. 2010). The increased occurrence of RVS is hypothesized to be associated with warming environments induced by climate change in the North Atlantic Ocean (Noguera et al. 2009). A peak in the frequency and severity of inflamed, swollen bleeding vents, on wild returning Atlantic Salmon was reported in the United Kingdom in 2006 and 2007 (Beck et al. 2008) coinciding with the first reports in Canadian rivers (Levsen and Berland 2012).

RVS has not been shown to induce wild mortalities and the extent of the infection varies with time spent in freshwater where fish that had been in freshwater for a longer period of time showed signs of recovery (Levsen and Berland 2012). To date, RVS is restricted to wild Atlantic Salmon and may negatively affect spawning ability, fecundity, migratory behaviour, growth rate, and ability of the fish to endure changing oceanic conditions (Murphy et al. 2010). Murphy et al. (2010) suggest a close surveillance of post-smolts to identify the location and food source of infection of *Anasakis* sp. in salmon during the marine phase. Occurrence of RVS is observed on SJR salmon sorted at the Mactaquac Biodiversity Facility, although concerted efforts to note presence/absence, as well as describe severity, did not start until 2009 (Figure 18). Recent trends in RVS occurrence in returning salmon at Mactaquac Dam do not appear to correlate with lower corresponding smolt runs, however, correlations with decreased marine survival of smolts is yet to be measured (Jones et al. 2014).

Infectious Pancreatic Necrosis (IPN) has been detected in both marine and freshwater environments in New Brunswick, although only a few epizootic outbreaks in trout fry in freshwater hatcheries were associated with this viral infection (MacKinnon et al. 1998). The disease agent (IPN) was detected in salmonid samples from: Muniac Stream (1995-1996), Baker Brook (1987), Grand Reed Brook (headwater reaches of SJR, 1995-1996), Passamaquoddy Bay (1989), SJR (1989, 1994), Oromocto lake (1990), and the Magaguadavic River (1998), although this sample was suspected to be an aquaculture escape (MacKinnon et al*.* 1998).

One case of *Edwardsiella tarda* (aka. ES, fish gangrene, Red disease) was found in a wild salmonid in Harvey Lake, NB, which is part of the Saint John watershed (MacKinnon et al. 1998).

Depressed Population Phenomena

Amiro et al. (2008) described aspects of depressed population phenomena for declining salmon populations in the IBoF:

> "There are presently many hypotheses for the decline in abundance of iBoF Atlantic Salmon and these are often treated in isolation. However, the potential effect of several threats acting together, either independently or synergistically, cannot be discounted. Additionally, the threats to survival may have changed over time and the possibility exists that whatever was responsible for the decline in abundance may be unrelated to the threats to recovery. Mechanisms that could restrict recovery due to reduced survival in either the marine or freshwater environments, and that are independent of those causing the original decline, include the consequences of very low abundance, such as inbreeding depression, behavioral shifts, inability to find mates, and ineffective size of

schools (DFO 2006[10]). These reactions are collectively known as low population phenomena and can be modeled by depensatory population models (Hilborn and Walters 1992). It is the nature of depensatory population models that when numbers are low, the population is hypersensitive to threats. Depending on the nature of the model, the probability of extirpation can increase exponentially with further population decreases (Begon et al. 1996). This feature seriously affects the ability to assess populations that follow depensatory models; they are either already extirpated, not at low enough levels to determine the nature of the population functionality, or rapidly extirpating. Hence, depensatory functionality remains a debatable point (e.g., Lierman and Hilborn 1997). If depensatory functionality is suspected and a population is low, then the only mitigation is to first increase population size, and as population increases, identify, and treat priority threats."

Lacroix and Knox (2005) noted that tagged and released smolt (including those from OBoF rivers) later caught as post-smolts were at densities too low to support natural schooling behaviour. Salmon smolts have a tendency to school, at least during daylight hours, as a defence to predation (Dutil and Coutu 1988; Skilbrei et al.1994). The absence of critical density of smolts to form schools, due to declining smolt production from OBoF rivers, could result in a further depressed ability to avoid predation.

Genetic bottlenecks have been demonstrated in the adjacent IBoF population, however, analyses of OBoF samples suggest genetic variation is less of a concern for populations of the OBoF (O'Reilly and Jones 2014). OBoF post-smolts have been sampled during trawl surveys and were suggested to be at densities too small to effectively defend against predation.

Shipping Traffic

Shipping traffic and noise has been suggested to cause avoidance-type behaviours in Atlantic Salmon (DFO and MRNF 2009). Shipping can directly impact fish when contaminant spills occur; the degree of impact depends on the containment, volume, location, and timing. Introduction of invasive species, from the exchange of ballast water, could also indirectly impact Atlantic Salmon, however, no examples were noted in the reviewed literature (DFO and MRNF 2009). DFO (2005) presented thematic maps of shipping traffic in Atlantic Canada showing concentrated traffic to the city of Saint John at the mouth of the SJR (Figure 19).

The Irving oil refinery is located outside the city of Saint John, NB, on the Fundy coast and is the largest oil refinery in North America. Constructed in 1960 on 3.2 km^2, this refinery produces more than 300,000 barrels per day. Refining facility input and output products are moved mainly by ship via the Irving Canaport facility (also located on the Bay of Fundy coast) where up to 6 million barrels of crude oil can be held before refining. In addition to ship traffic, the volume of oil products being moved regularly and directly in the migration route of OBoF salmon could have devastating effects on marine life in the Outer Bay of Fundy region in the event of a spill.

Directed Fisheries and By-catch - Marine/Estuarine

Interceptory drift-net fisheries ended in 1967 in Atlantic Canadian waters and moved toward river specific management (DFO and MRNF 2009). At its peak, the drift net fishery in the Bay of Fundy off Saint John, NB, involved 100 boats with an additional 50 smaller boats fishing closer to the harbour (Dunfield 1974). Salmon were also captured in gillnets and weirs set to catch

[10] From the November 2006 draft "Recovery strategy for the Atlantic Salmon (Salmo salar), Inner Bay of Fundy population" from the Species at Risk Act Recovery Strategy Series, which has since been published in 2010 as "DFO. 2010. Recovery Strategy for the Atlantic salmon (*Salmo salar*), Inner Bay of Fundy populations [Final]. *In* Species at Risk Act Recovery Strategy Series. DFO, Ottawa, Ontario. xiii + 58 pp + Appendices.

other species such as: American Shad, Striped Bass, Mackerel (*Scomber scombrus*), and Herring (*Culpea harengus*) (Dunfield 1974). An experimental fishery at the mouth of the SJR from 1970-1973 captured over 2000 MSW size salmon (Penney 1983).

Currently, there are 216 Herring weir licenses issued within the OBoF DU (Sarah Cheney, DFO-Licensing, pers. comm.). Herring fisheries occur near the mouth of the SJR and along the NB coast including within Passamaquoddy Bay. Herring weirs, also used for the Mackerel fishery, and an extensive pelagic fishery are present in the coastal Passamaquoddy region and in the outer portion of the Bay of Fundy where Atlantic Salmon migrate, thus increasing the threat of by-catch. Both adult and post-smolt salmon have been reported to get incidentally caught in weirs during their migration (Kerswill 1960; Lacroix et al. 2004; Lacroix 2008).

The fishery at West Greenland has reported catches of nine to 43 tons in the past 10 years (ICES 2011b). The estimated catch of North American origin salmon at West Greenland has varied between 2,300 and 10,000 fish, with 93% to 98% of the catch being 1SW non-maturing salmon, i.e., fish destined to have been 2SW or 3SW maiden salmon had they not been captured. The monthly mortality rate of salmon from the time of the West Greenland fishery (August-December) to the return to homewaters (July of the following year) has been estimated to be 0.03 per month, equal to a survival rate of 0.74 over the 10-month period.

From the run reconstruction conducted by the ICES Working Group on North Atlantic Salmon (ICES 2011b), we can estimate the number of SFA 23 origin (or OBoF DU) 2SW salmon likely to have been harvested at West Greenland at the 1SW non-maturing stage using the following input data:

A) Total catch of salmon (in numbers) at West Greenland in year (t).

B) Catch of North American fish = Proportion of the catch which is North America origin * (A).

C) Fish captured at West Greenland must be discounted for the proportion that would have died before returning to Canada. A mortality rate (instantaneous) of 0.03 per month is used. The fishery at West Greenland runs from mid-August to November, so time between fishery at West Greenland and returns to OBoF would be (for example, September fishery in 2009 to returns to OBoF in July 2010) 10 months, therefore mortality (proportion) = (1-exp(-0.03*10)) = 0.25.

D) Using estimates of returns of 2SW salmon in North America in year t+1, one can estimate proportion of the catch of North American fish by Salmon Fishing Area, if it is assumed that the stocks from all regions of eastern North America are exploited at the same rate at West Greenland.

The estimated catch at West Greenland, of SFA 23 origin 2SW salmon, is equivalent to the SFA 23 returns 2SW (t) / North America returns of 2SW salmon (t) multiplied by the 2SW catch of North American origin 2SW salmon in West Greenland (t-1). The SFA 23 equivalents (potential returns to OBoF rivers) is determined by applying the monthly natural mortality rate (C) to the estimated catch of SFA 23 origin 2SW salmon caught in West Greenland.

Estimated catch of 2SW equivalents of SFA 23 origin salmon at West Greenland, in the past 10 years (2001 to 2010 fishery years), has varied from 49 to 184 fish per year (median estimate ranges; (Table 10), representing losses of 4.2% to 15.0% of the potential 2SW returns to SFA 23 for those years. The estimated harvest of OBoF salmon, for 20 years prior to 1992, is often 30-50% of the returning run, which cannot yet be ruled out as a contributor to current depleted status. Historical tag return information, from non-maturing 1SW salmon captured during the insular Newfoundland and southern/northern Labrador commercial salmon fisheries (Marshall et al. 2014), indicate that these fisheries were also capturing 2SW salmon equivalents of OBoF salmon origin before the moratoria in 1992 and 1998, respectively and therefore reducing 2SW returns to OBoF rivers.

Since closure of the Canadian commercial salmon fisheries in 1998, most of the high seas losses, would occur at West Greenland, although some of the losses may also occur in the Labrador resident food fisheries and in the fishery at St. Pierre and Miquelon. The landings of large salmon, from the Aboriginal fishery in Labrador, have varied between six and 17 tons during 2001 to 2010 with 2SW salmon catches estimated to be in the range of 700 to 2,000 fish per year, the majority expected to be destined for rivers in Labrador (DFO and MRNF 2009). The fishery at St. Pierre and Miquelon has captured between two and 3.6 tons in the past 10 years, about three quarters were small salmon, the remainder large salmon with estimated 2SW catches of just over 200 to just under 400 fish annually.

Information provided to ICES (2004) suggested that there were still some commercial marine fisheries with the potential for salmon by-catch but no significant amount was reported by any of the fisheries surveyed. It is difficult to quantify the effect many threatening activities would have on adult salmon numbers if populations were nearer pre-decline levels.

MARINE THREATS SUMMARY

Marine threats are less understood than those occurring in freshwater, which increases uncertainty around their estimated impact on populations. As with other maritime Atlantic Salmon populations, there has been a recent decline in return rates from the marine environment for OBoF populations (Gibson et al., unpublished report[11]; Jones et al. 2014). This trend is often described as a decline in marine survival; however, Bowlby et al. (2014) describe the potential for this assertion to be misleading:

> “Smolt-to-adult return rates are used as a proxy for at-sea survival, and are based on smolt abundance estimates and adult escapement estimates in the following years (after accounting for age distributions and variations in spawning history). As such, at-sea or marine mortality is a misnomer because it also includes sources of mortality for smolts or adults while in fresh water. For example, threats like chemical contaminants or low pH in fresh water that interfere with the successful transition to the marine environment (e.g., those that reduce osmoregulatory capabilities, influence homing ability, or lower individual growth or condition factor) would lead to higher mortality rates in the marine environment and thus would become a component of at-sea mortality. These specific threats may be exerting influence in fresh water, but their population-level impact on mortality rates occurs after smolts enter the marine environment. A second example would be adult removals in freshwater or estuarine environments that take place before fish are enumerated (e.g., mortality from by-catch or poaching). It is not known how large the freshwater components of at-sea mortality may be relative to threats taking place exclusively in the marine environment.”

There is evidence of interbreeding of domesticated fish with wild OBoF populations, which resulted in a decline in some measures of fitness. There are published accounts, from other salmon populations, to support the hypothesis that aquaculture operations can alter natural predator, parasite and disease dynamics by altering the density, availability and distribution of hosts (farmed salmon). Documentation of specific threats arising from aquaculture operations in the Bay of Fundy is not extensive. However, little evidence was found to suggest the effects of aquaculture operations on salmon populations in western Canada and Europe would not be possible or currently occurring to some degree in Atlantic Canada. Based mostly on evidence

[11] Unpublished supporting document by A.J.F. Gibson, R.A. Jones, and G.J. MacAskill, on the “Recovery Potential Assessment for Outer Bay of Fundy Atlantic Salmon: Population Dynamics and Viability” (2014).

from Europe and western Canada, and until directed research suggests otherwise, OBoF salmon interactions with aquaculture operations should be considered as an important threat to OBoF population persistence at least because of the large farm population relative to wild salmon.

Changes in abundance of marine predator and prey species for OBoF salmon, possibly in response to climate driven shifts of oceanic conditions, offer potential correlations in salmon population declines but are not definitive. Also, evidence of competition for commonly used prey (such as Sand Lance by currently hyper-abundant Grey Seal populations) presents further complications in establishing casual relationships between predator/prey abundance and salmon population status. The relative lack of understanding of salmon habitat use during the marine migration continues to be an obstacle for determining causes of population decline. The current depressed state of the population makes it inherently difficult to detect effects of any marine threat but also increases the relative severity of any threat impacting the population. Despite knowledge gaps on marine habitat use for salmon, evidence from other research suggests ocean condition shifts have occurred which could significantly affect salmon populations. Therefore, unfavourable marine conditions, linked with depressed population phenomena, remain a vague but important threat to OBoF population persistence.

THREATS APPLICABLE TO FRESHWATER, ESTUARINE, AND MARINE ENVIRONMENTS

Scientific Research

DFO and MRNF (2009) described the potential threat of scientific operations on Atlantic Salmon populations:

> "Mortality associated with scientific research (capturing, collecting, handling or holding) of Atlantic Salmon is not deemed to be detrimental to robust salmon populations. However, loss of potential adult salmon in small populations, especially those 'listed' under SARA could be harmful to population recovery. Under the *Fisheries Act*, a scientific permit is required to fish for, capture, or kill any Atlantic Salmon for scientific purposes. Section 73 of the SARA requires a permit to fish for, capture directly, incidentally kill, or harass any listed species (an iBoF salmon). If the mortality is incidental to a licensed activity and will not affect the recovery of the species, then a permit may be issued for the licensed activity. In the case of iBoF salmon, no permits for incidental mortality have been issued because, to date, there is no indication that there are any fish available for incidental mortality. A scientific permit can be issued to directly fish for, capture, kill, harass, or disturb the residence or habitat of a listed species if the research benefits the recovery of the species. In both cases, the Regional Director of Science acting on behalf of the Minister provides a recommendation to management on the risk of the activity to a salmon population and its ecosystem, and assesses the benefits for recovery associated with the research. Scientific research permits provide the only mechanism to allow research that is likely to cause harm to a fish but benefits the potential for recovery.
>
> The largest portion of research is focused on population assessments and today entails the enumeration of juveniles by electrofishing, pre-smolt and smolt in rotary screw traps, and the live capture of adults in nets and traps installed within counting fences and fish ways. The deleterious effects of electrofishing on individual fish are well established (Snyder 2003) but, as argued by Fay et al. (2006), impacts only a very small portion of the population and in all likelihood can be regarded as compensatory, that is, contributes to enhanced survival of those remaining. Traps for smolts and adults have been designed for relatively 'passive' capture and holding free of entanglement. All operations minimize handling as much as possible, avoid chemical anaesthetics as much as

possible, and cease operation and handling at, depending on life stage, physiological stressful water temperatures. Research that requires direct mortality is generally conducted on fish obtained from the LGB or their progeny and is incidental to the persistence of the LGB and hence to population persistence. Therefore, the threat posed by research is generally mitigated by recovery actions that research activities seek to improve."

PROPOSED CUMULATIVE THREAT IMPACT ASSESSMENT

Following DFO science advice in 2010, which suggested that threat interpretation could be improved if assessed cumulatively, a cumulative threats impact table has been proposed (Table 11). This table ranks the concern of certain threats in Table 1 for each OBoF river (Figure 1; Table 2) based on the information reviewed in this document. Threats that cannot be quantitatively or even qualitatively assessed for each river in the OBoF DU are omitted from this exercise. Because this approach produces a relative impact (rather than an independent absolute value of impact) for each river, threats lacking information specific to each river are omitted (such as most marine threats) as they would produce no useful differences in impacts between rivers.

Table 1 contains rankings on the overall Level of Concern (High, Medium, or Low) for each identified threat to the entire OBoF DU. Based on information presented in this document, a three level ranking of impact for each threat was made for each river (considering the impact of any threat is not the same on all rivers) approximately following threats table definitions for the levels of severity (High, Medium, or Low) in Appendix 2.

Assigning a number to levels of impact and level of concern (H=3, M=2, L=1) for each particular threat on each river (multiplying threat impact on each river by overall threat concern) produces a score, which indicates the assessed impact of the threat on each river. Summing the scores for each threat yields a cumulative threat impact assessment for each river (Table 11). No score (blank) for a threat indicates no known impact on the particular river. Thus, higher scores reflect an assessed higher impact from considered threats.

Some rivers are more studied or reported than others. Information on some threats was not available for all rivers. In an attempt to avoid less studied rivers unduly appearing less impacted by threats, impact scores were divided by the number of threats assessed (averaged). This approach effectively lowers the impact scores on rivers that are better studied as impacts are divided by a larger number of 'known' threats.

Table 11 assesses the cumulative impact of threats on each river with sensitivity to the level of concern for each threat to the overall DU. It provides summation of threat impacts throughout the DU which is important for prioritizing habitat allocations (Marshall et al. 2014) and distribution targets (Jones et al. 2014).

Measures of accessible habitat (Table 2), productive capacity (Figure 20) and wild salmon density (Jones et al. 2014) are based on empirical measurement and thus provide a more robust platform for these prioritization considerations. The proposed cumulative threat impact rankings are based only on the information reviewed in this document and should only be considered after the more robust measures are included in prioritization considerations. For example, only after rivers are identified as adequately accessible, sized, and populated, should their assessed threat impact be considered as a guide to finalize prioritizations for recovery planning.

ACKNOWLEDGEMENTS

The authors thank: J. Carr of the Atlantic Salmon Federation, St. Andrews, NB, L. Marshall, T. Goff, and G. Lacroix, DFO Science [retired], Dr. Steven Campana, L. Anderson and S. Dolan, DFO Science, D. Manderville and T. Jenkins, DFO Conservation and Protection, A. Smith and S. Heartz, DFO-CFB Gagetown Unit, S. Cheney, DFO- Licensing, M. Sabine, K. DeBouver, M. Toner and K. Collet, NB Department of Natural Resources, T. Lyons, NB Department of Environment and Local Government, E. Olale and L. O'Brien, NB Department of Agriculture, Aquaculture and Fisheries, for their contribution to the contents of the document. Reviewers of various drafts included: G. Chaput, DFO Science, R. Cunjak, UNB (Fredericton)/Canadian Rivers Institute, M. Robertson, L. Harris, R. Claytor, DFO Science, and J. Carr, Atlantic Salmon Federation during the Recovery Potential Meeting that took place in February 2013 and A. Plummer for final editing.

LITERATURE CITED

Al, T., K. Butler, R. Cunjak, and K. MacQuarrie. 2012. Opinion: Potential impacts of shale gas exploitation on water resources. University of New Brunswick, Fredericton, NB: 7 p. (Last accessed 14 April 2014).

Allen, K.R. 1941. Studies on the biology of the early stages of the salmon (*Salmo salar*). III. Growth in the Thurso River system, Caithness. J. Ani. Ecol. 10: 273-295.

Amiro, P.G. 1993. Habitat measurements and population estimation of juvenile Atlantic Salmon (*Salmo salar*). Can. Spec. Pub. Fish. Aquat. Sci. 118: 81-97.

Amiro, P.G. 2006. A synthesis of fresh water habitat requirements for Atlantic Salmon (*Salmo salar*). DFO Can. Sci. Advis. Sec. Res. Doc. 2006/017.

Amiro, P.G., A.J.F. Gibson, and K. Drinkwater. 2003. Identification and exploration of some methods for designation of critical habitat for survival and recovery of Inner Bay of Fundy Atlantic Salmon (*Salmo salar*). DFO Can. Sci. Advis. Sec. Res. Doc. 2003/120.

Amiro, P.G., J.C. Brazner, and J.L. Giorno. 2008. Assessment of the Recovery Potential for the Atlantic Salmon Designatable Unit Inner Bay of Fundy: Threats. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/059.

Anderson, R.M. 1993. Epidemiology. *In* Modern Parasitology. Edited by F.E.G. Cox. Blackwell Scientific Publications, Oxford, London, UK. pp. 75-116.

Araki, H., B. Cooper, and M.S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biol. Lett. 5: 621-624.

Arciszewski, T.J., K.A. Kidd, and K.R. Munkittrick. 2011. Comparing responses in the performance of sentinel populations of stoneflies (Plecoptera) and Slimy Sculpin (*Cottus cognatus*) exposed to enriching effluents. Ecotox. Environm. Saf. Vol. 74(7): 1844-1854.

Armstrong, J.D., P.S. Kemp, G.J.A. Kennedy, M. Ladle, and N.J. Milner. 2003. Habitat requirements of Atlantic Salmon and Brown Trout in rivers and streams. Fish. Res. 62: 143-170.

Barr, L.M. 1962. A life history of the Chain Pickerel, *Esox niger* LeSueur, in Beddington Lake, Maine. Thesis (M.Sc.) University of Maine, Orono, ME: 88 p.

Baum, E.T. 1982. Saint John River Watershed V.2: An Atlantic Salmon river management report. State of Maine Atlantic Sea Run Salmon Commission, Bangor, ME.

Beck, M., R. Evans, S.W. Feist, P. Stebbing, M. Longshaw, and E. Harris. 2008. *Anisakis simplex sensu lato* associated with red vent syndrome in wild adult Atlantic Salmon *Salmo salar* in England and Wales. Dis. Aquat. Org. Vol. 82: 61-65.

Begon, M., J.L. Harper, and C.R. Townsend. 1996. Ecology: Individuals, Populations and Communities. Blackwell Sciences, 3rd Edition, Oxford, UK: 1068 p.

Bell, C.R., M.A. Holder-Franklin, and M. Franklin. 1980. Heterotrophic bacteria in two Canadian rivers- I. Seasonal variations in the predominant bacterial populations. Wat. Res. Vol. 14: 449-460.

Blackwell, B.F. and F. Juanes. 1998. Predation on Atlantic Salmon smolts by Striped Bass after dam passage. N. Amer. J. Fish. Manage. 18: 936-939.

Blanchet, S., J.J. Dodson, and S. Brosse. 2006. Influence of habitat structure and fish density on Atlantic Salmon *Salmo salar* L. territorial behaviour. J. Fish Biol. 68: 951-957.

Blanchet, S., G. Loot, L. Bernatchez, and J.J. Dodson. 2007. The disruption of dominance hierarchies by a non-native species: An individual-based analysis. Oecolog. 152: 569-581.

Booth, D.B., D. Hartley, and R. Jackson. 2002. Forest cover, impervious surface area, and the mitigation of stormwater impacts. J. Amer. Wat. Res. Assess. 38: 835-845.

Bostick, K., J. Clay, and A. McNevin. 2005. Farm-level issues in aquaculture certification: Salmon. World Wildlife Fund, Washington, DC: 26 p.

Bouchard, D., W. Keleher, H.M. Opitz, S. Blake, K.C. Edwards, and B.L. Nicholson. 1999. Isolation of infectious salmon anemia virus (ISAV) from Atlantic Salmon in New Brunswick, Canada. Dis. Aquat. Org. 35: 131-137.

Bourret, V., P.T. O'Reilly, J.W. Carr, P.R. Berg, and L. Bernatchez. 2011. Temporal change in genetic integrity suggests loss of local adaptation in a wild Atlantic Salmon (*Salmo salar*) population following introgression by farmed escapees. Heredity 106: 500-510.

Bowen, W.D. 2011. Historical Grey Seal abundance and changes in the abundance of Grey Seal predators in the Northwest Atlantic. DFO Can Sci. Advis. Sec. Res. Doc. 2011/026.

Bowlby, H.D., T. Horsman, S.C. Mitchell, and A.J.F. Gibson. 2014. Recovery Potential Assessment for Southern Upland Atlantic Salmon: Habitat requirements and availability, threats to populations, and feasibility of habitat restoration. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/006.

Brasfield, S.M. 2007. Investigating and interpreting reduced reproductive performance in fish inhabiting streams adjacent to agricultural operations. Thesis (Ph.D.) University of New Brunswick, Saint John, NB: 157 p.

Brawn, V.M. 1982. Behaviour of Atlantic Salmon (*Salmo salar*) during suspended migration in an estuary, Sheet Harbour, Nova Scotia, observed visually and by ultrasonic tracking. Can. J. Fish. Aquat. Sci. 39: 248-256.

Breau, C., R.A. Cunjak, and S.J. Peake. 2011. Behaviour during elevated water temperatures: Can physiology explain movement of juvenile Atlantic Salmon to cool water? J. Anim. Ecol. 80(4): 844-53.

Brooks, D.A., M.W. Baca, and Y.T. Lo. 1999. Tidal circulation and residence time in a macrotidal estuary: Cobscook Bay, Maine. Estuar., Coast., Shelf Sci. 49: 647-665.

Brown, T.G., B. Runciman, S. Pollard, and A.D.A. Grant. 2009. Biological synopsis of Largemouth Bass (*Micropterus salmoides)*. Can. Manuscr. Rep. Fish. Aquat. Sci. 2884: v + 27 p.

Bult, T.P., S.C. Riley, R.L. Haedrich, R.J. Gibson, and J. Heggenes. 1999. Density dependent habitat selection by juvenile Atlantic Salmon (*Salmo salar*) in experimental riverine habitats. Can. J. Fish. Aquat. Sci. 56: 1298-1306.

Bunn, S.E. and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ. Man. Vol. 30(4): 492-507.

Burnley, T., H. Stryhn, and K.L. Hammell. 2012. Post-handling mortality during controlled field trials with marine grow-out Atlantic Salmon, *Salmo salar* L. Aquacult. 368: 55-60.

Caissie, D. 2006. The thermal regime of rivers: A review. Fresh. Biol. 51: 1389-1406.

Caissie, D., C. Breau, J. Hayward, and P. Cameron. 2012. Water temperature characteristics within the Miramichi and Restigouche rivers. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/165.

Cairns, D.K. (ed.). 2001. An evaluation of possible causes of the decline in pre-fishery abundance of North American Atlantic Salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2358: 67 p.

Cairns, D.K. (ed.). 2002. Effects of land use practices on fish, shellfish, and their habitats on Prince Edward Island. Can. Tech. Rep. Fish. Aquat. Sci. 2408: 157 p.

Carr, J. 2001. A review of downstream movements of juvenile Atlantic Salmon (*Salmo salar*) in the dam-impacted Saint John River drainage. Can. Manuscr. Rep. Fish. Aquat. Sci. 2573: 76 p.

Carr, J. and K. Felice. 2006. Status of Rainbow Trout in New Brunswick watercourses. Project Report for NB Environmental Trust Fund and NB Wildlife Trust Fund: 47 p.

Carr, J. and F. Whoriskey. 2002. Assessment of Atlantic Salmon in southwestern New Brunswick, Outer Bay of Fundy rivers, with emphasis on the Magaguadavic River, 1992-2001 project report. Project Report for NB Environmental Trust Fund and NB Wildlife Trust Fund: 46 p.

Carr, J. and F. Whoriskey. 2004. Sea lice infestation rates on wild and escaped farmed Atlantic Salmon (*Salmo salar* L.) entering the Magaguadavic River, New Brunswick. Aquacult. Res. 38: 723-729.

Carr, J.W. and F.G. Whoriskey. 2006. The escape of juvenile farmed Atlantic Salmon from hatcheries into freshwater streams in New Brunswick, Canada. ICES J. Mar. Sci. 63: 1263-1268.

Carr, J.W. and F.G. Whoriskey. 2009. Atlantic Salmon (*Salmo salar*) and Smallmouth Bass (*Micropterus dolomieu*) interactions in the Magaguadavic River, New Brunswick. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/074.

Campana, S.E., L. Marks, W. Joyce, and N.E. Kohler. 2006. Effects of recreational and commercial fishing on Blue Sharks (*Prionace glauca*) in Atlantic Canada with inferences on the North Atlantic population. Can. J. Fish. Aquat. Sci. 63: 670-682. doi: 10.1139/F05-251.

Campana, S.E., A.J.F. Gibson, L. Marks, W. Joyce, R. Rulifson, and M. Dadswell. 2007. Stock structure, life history, fishery and abundance indices for Spiny Dogfish (*Squalus acanthias*) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/089.

Campana, S.E., A.J.F. Gibson, M. Fowler, A. Dorey, and W. Joyce. 2010. Population dynamics of Porbeagle in the Northwest Atlantic, with an assessment of status to 2009 and projections for recovery. SCRS/2009/095. Collect. Vol. Sci. Pap. Internat. Comm. Conserv. Atl. Tunas (ICCAT), 65(6): 2019-2182 (2010).

Campbell, S. and S. Prosser. 2009. Hammond River watershed management plan. Report by Hammond River Association: 231 p. (Last accessed 14 April 2014).

Cedarholm, C.J., L.M. Reid, and E.O. Salo. 1981. Cumulative effects of logging road sediment on salmonids populations of the Clearwater River, Jefferson County, Washington. *In* Proceedings of conference on salmon spawning gravel: A renewable resource in the Pacific Northwest? Rep. 19. Washington State University, Water Research Center, Pullman, Washington, DC. pp. 38-74.

Chang, B.D. 1998. The salmon aquaculture industry in the Maritime Provinces. DFO Can. Stock Assess. Sec. Res. Doc. 1998/151.

Chang, B.D., F.H. Page, and B.W.H. Hill. 2005. Preliminary analysis of coastal marine resource use and the development of open ocean aquaculture in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2585: iv + 36 p.

Chaput, G. 2012. Overview of the status of Atlantic Salmon (*Salmo salar*) in the North Atlantic and trends in marine mortality. ICES J. Mar. Sci. 69: 1538-1548.

Chaput, G. and D. Caissie. 2010. Risk assessment of Smallmouth Bass (*Micropterus dolomieu*) introductions to rivers of Gulf Region with special consideration to the Miramichi River (N.B.). DFO Can. Sci. Advis. Sec. Res. Doc. 2010/065.

Chaput, G.J. and R.A. Jones. 2004. Catches of downstream migrating fish in fast-flowing rivers using rotary screw traps. Can. Manuscr. Rep. Fish. Aquat. Sci. 2688: v + 14 p.

Chiasson, G., P.A. Gallant, and P. Mallet. 2002. Traditional and local knowledge: Estuarine fisheries by-catch in the southern Gulf of St. Lawrence; Ecosystem based fisheries management considerations. Can. Manuscr. Rep. Fish. Aquat. Sci. 2613: vi + 45 p.

Chow, L., Z. Xing, G. Benoy, H.W. Rees, F. Meng, Y. Jiang, and J.L. Daigle. 2011. Hydrology and water quality across gradients of agricultural intensity in the Little River watershed area, New Brunswick, Canada. J. Soil Wat. Cons. Vol. 66(1): 71-84.

Cipriano, R.C. 2009. Antibody against infectious salmon anaemia virus among feral Atlantic Salmon (*Salmo salar*). ICES J. Mar. Sci. 66: 865-870.

Clowater, D. and M. Phillips. 2008. Fish habitat compensation on the TransCanada highway project in New Brunswick. Paper prepared for presentation at the “Fish Habitat Compensation – A requirement for some transportation projects” session of the 2008 Annual Conference of the Transportation Association of Canada. Toronto, Ontario: 21 p. (Last accessed 14 April 2014).

Cocci, A.A., M.P. McKim, R.C. Landine, and T. Viraraghavan. 1980. Evaluation of secondary treatment systems for treating potato-processing wastewater. Agri. Wast. 2: 273-277.

Connor, K.J. and S. Gabor. 2006. Breeding waterbird wetland habitat availability and response to water-level management in Saint John River floodplain wetlands, New Brunswick. Hydrobiol. 567: 169-181.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada: xlvii + 136 p.

Costello, M.J. 2009. How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. Proc. R. Soc. B. 276: 3385-3394. doi:10.1098/rspb.2009.0771.

Crown Lands Network. 2004. Unlocking the economic potential of New Brunswick crown lands. 22 p. (Last accessed 14 April 2014).

Culp, J.M., E. Luiker, L. Noel, E. Foster, R.A. Curry, and D. Hryn. 2006. Status and effects of nutrient loading on Saint John River: Final report. Report prepared for The New Brunswick Environmental Trust Fund. New Brunswick Cooperative Fish and Wildlife Research Unit. Report #06-03.

Culp, J.M., L. Noel, E. Luiker, and R.A. Curry. 2008. Cumulative effects assessment of hydroelectric discharge and nutrient loading on Saint John River ecosystem health. *Report prepared for* The New Brunswick Environmental Trust Fund. New Brunswick Cooperative Fish and Wildlife Research Unit. Report #01-08.

Cunjak, R.A. 1988. Behavior and microhabitat of young Atlantic Salmon (*Salmo salar*) during winter. Can. J. Fish. Aquat. Sci. 45: 2156-2160.

Cunjak, R.A. and R.W. Newbury. 2005. Atlantic coast rivers of Canada. *In* Rivers of North America. Edited by A.C. Benke and C.E. Cushing. Elsevier Inc. (Academic Press), San Diego, CA. pp. 939-980.

Cunjak, R.A. and J. Therrien. 1998. Inter-stage survival of wild juvenile Atlantic Salmon, *Salmo salar* L. Fish. Manage. Ecol. 5: 209-223.

Cunjak, R.A., D.L. Guignion, R.B. Angus, and R.A. MacFarlane. 2002. Survival of eggs and alevins of Atlantic Salmon and Brook Trout in relation to fine sediment deposition. *In* Effects of land use practices on fish, shellfish, and their habitats on Prince Edward Island. Edited by D.K. Cairns. Can. Tech. Rep. Fish. Aquat. Sci. 2408. pp 82-91.

Cunjak, R.A., R.A. Curry, D.A. Scruton, and K.D. Clarke. 2004. Fish-forestry interactions in freshwaters of Atlantic Canada. *In* Fishes and Forestry: Worldwide watershed interactions and management. Edited by T.G. Northcote and G.F. Hartman. Blackwell Publishing Ltd., Oxford, UK. pp. 439-462.

Curry, R.A. and K.R. Munkittrick. 2005. Fish assemblage structure in relation to multiple stressors along the Saint John River, New Brunswick, Canada. Amer. Fish. Soc. Symp. 45: 505-521.

Curry, R.A., C.A. Doherty, T.D. Jardine, and S.L. Currie. 2007. Using movements and diet analyses to assess effects of introduced Muskellunge (*Esox masquinongy*) on Atlantic Salmon (*Salmo salar*) in the Saint John River, New Brunswick. Environ. Biol. Fish. 79: 49-60.

Dalziel, J.A. 1956. Pocologan River salmon survey. Canad. Dep. Fish. Forestry, Fish. Serv., Resourc. Developm. Br., MS Rpt., 56-7: 6 p.

Dempson, J.B., G. Furey, and M. Bloom. 2002. Effects of catch and release angling on Atlantic Salmon, *Salmo salar* L., of the Conne River, Newfoundland. Fish. Manage. Ecol. 9 (3): 139-147.

Dempster, T., P. Sanchez-Jerez, J.T. Bayle-Sempre, F. Gimenez-Casalduero, and C. Valle. 2002. Attraction of wild fish to sea cage fish farms in the southwestern Mediterranean Sea: Spatial and short term temporal variability. Mar. Ecol. Prog. Series 242: 237-252.

Dennis, I.F, T.A. Clair, and K. Kidd. 2012. The distribution of dissolved aluminum in Atlantic Salmon (*Salmo salar*) rivers of Atlantic Canada and its potential effect on aquatic populations. Can. J. Fish. Aquat. Sci. 69: 1174-1183. doi:10.1139/F2012-053.

DFO. 1996a. 4VWX Herring. DFO Atl. Fish. Stock Stat. Rep. 96/18E.

DFO. 1996b. Scotian Shelf Sand Lance. DFO Atl. Fish. Stock Stat. Rep. 96/77E.

DFO. 2000. State of phytoplankton, zooplankton and krill on the Scotian shelf in 1998. DFO Sci. Stock Stat. Rep. G3-02 (2000).

DFO. 2001. Gaspereau Maritime Provinces Overview. DFO Sci. Stock Stat. Rep. D3-17 (2001)

DFO. 2005. Scotian Shelf: An atlas of human activities. Oceans and Coastal Management Division, Oceans and Habitat Branch, DFO (Maritimes Region). (Last accessed 14 April 2014.)

DFO. 2010. Recovery Strategy for the Atlantic salmon (*Salmo salar*), Inner Bay of Fundy populations [Final]. *In* Species at Risk Act Recovery Strategy Series. DFO, Ottawa, Ontario. xiii + 58 pp + Appendices.

DFO. 2010. Guidelines for terms and concepts used in the Species at Risk program. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/065.

DFO. 2011a. 2011 Assessment of 4VWX Herring. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/046.

DFO. 2011b. Status of Atlantic Salmon in Salmon Fishing Areas (SFAs) 19-21 and 23. DFO Can. Sci. Advis. Sec. Sci. Resp. 2011/005.

DFO. 2012a. Aquaculture in Canada 2012. A report on sustainability. National Aquaculture Strategic Action Plan Initiative, Canadian Council of Fisheries and Aquaculture Ministers. Fisheries and Oceans Canada, Ottawa, ON: 37 p. (Last accessed 14 April 2014).

DFO. 2012b. 2011-2015 integrated fisheries management plan for Atlantic seals. Fisheries and Oceans Canada, Ottawa, Ontario. (Last accessed 14 April 2014).

DFO. 2014. Recovery Potential Assessment for Outer Bay of Fundy Atlantic Salmon. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/021

DFO and MRNF. 2008. Conservation status report, Atlantic Salmon in Atlantic Canada and Québec: PART I – Species Information. Can. Manuscr. Rep. Fish. Aquat. Sci. 2861: 208 p.

DFO and MRNF. 2009. Conservation status report, Atlantic Salmon in Atlantic Canada and Québec: PART II – Anthropogenic Considerations. Can. Manuscr. Rep. Fish. Aquat. Sci. 2870: 175 p.

DFO and NBDAAF. 2009. The New Brunswick breach of containment governance framework for marine salmon farm operations. (May 2009). Aquaculture Management Office, DFO, Dartmouth, NS, and NBDAAF Regional Office, St. George, NB: 18 p.

Dickison, R.B.B., D.A. Daugharty, and D.R. Randall. 1981. Some preliminary results of the hydrological effects of clear-cutting a small watershed in central New Brunswick. *In* Fifth Canadian hydrotech conference proceedings. Can. Soc. Civil Eng. pp. 59-75.

Dill, L.M., C.J.C. Losos, B.M. Connors, and P. Mages. 2009. Comment on Beamish et al. (2005) “A proposed life history strategy for the salmon louse, *Lepeophtheirus salmonis* in the subarctic Pacific”. Aquacult. 286: 154-155.

Dixon, H.J., M. Power, J.B. Dempson, T.F. Sheehan, and G. Chaput. 2012. Characterizing the trophic position shift in Atlantic Salmon (*Salmo salar*) from freshwater to marine life-cycle phases using stable isotopes. ICES J. Mar. Sci. 69: 1646-1655.

DNR Staff Review. 2004. Staff review of the Jaakko Pöyry Report. New Brunswick crown forests: Assessment of stewardship and management. (January 2004). Department of Natural Resources, Fredericton, NB: 68 p. (Last accessed 14 April 2014).

Dominy, C.L. 1973. Recent changes in Atlantic Salmon (*Salmo salar*) runs in the light of environmental changes in the Saint John River, New Brunswick, Canada. Biol. Conserv. 5(2): 105-113.

Dubé, M.G. and D.L. MacLatchy. 2001. Identification and treatment of waste stream at a bleached kraft pulp mill that depresses a sex steroid in the Mummichog (*Fundulus heteroclitus*). Environ. Toxicol. Chem. 20: 985-995.

Dubé, M.G., D.L. MacLatchy, J.D. Kieffer, N.E. Glozier, J.M. Culp, and K.J. Cash. 2005. Effects of metal mining effluent on Atlantic Salmon (*Salmo salar*) and Slimy Sculpin (*Cottus cognatus*): Using artificial streams to assess existing effects and predict future consequences. Sci. Tot. Environ. 343: 135-154.

Dudley, R.W., C.W. Schalk, N.W. Stasulis, and J.G. Trial. 2011. A digital terrain model of bathymetry and shallow-zone bottom-substrate classification for Spednic Lake and estimates of lake-level-dependent habitat to support Smallmouth Bass persistence modeling: U.S. Geol. Surv. Sci. Invest. Rep. 2010/5255: 18 p.

Dunfield, R.W. 1974. Types of commercial salmon fishing gear in the Maritime Provinces 1971. DOE, Fish Mar. Serv., Resource Develop. Branch, Halifax, NS. Info. Public MAR/N-74-1: 43 p.

Dutil, J.D. and J.M. Coutu. 1988. Early marine life of Atlantic Salmon, *Salmo salar,* postsmolts in the Northern Gulf of St. Lawrence. Fish. Bull. 86: 197-212.

Dutka, B.J., K. Jones, K.K. Kwan, H. Bailey, and R. McInnis. 1988. Use of microbial and toxicant screening tests for priority site selection of degraded areas in water bodies. Wat. Res. Vol. 22(4): 503-510.

Elson, P.F. 1975. Atlantic Salmon rivers, smolt production, and optimal spawnings: An overview of natural productions. *In* Proceeding of the New England Atlantic Salmon restoration conference, Boston, Mass. January 14-16, 1975. Edited by J.R. Bohhe and L Sochasky. Ser. 6, [Spec. Publ. Ser. Int. Atl. Salm. Found.]. Dec. 1975. pp. 96-119.

Entrekin, S., M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid expansion of natural gas development poses a threat to surface waters. Front Ecol. Environ. 9(9): 503-511.

Fairchild, W.L., S.B. Brown, and A. Moore. 2002. Effects of freshwater contaminants on marine survival in Atlantic Salmon. NPAFC Tech. Rep. No. 4: 30-32

Fay, C., M. Burton, S. Craig, A. Hecht, J. Pruden, R. Saunders, T. Sheehan, and J. Trial. 2006. Status review for anadromous Atlantic Salmon (*Salmo salar*) in the United States. Rep. Nat. Mar. Fish. Serv. U.S. Fish Wild. Serv.: 294 p.

FB Environmental Associates. 2010a. Total Maximum Daily Load (TMDL) report: Dudley Brook Aroostook County, Maine. Report prepared for the Maine Department Environ. Prot., Portland, ME: 74 p.

FB Environmental Associates. 2010b. Total Maximum Daily Load (TMDL) report: Presquile Stream (and Christina Reservoir) Aroostook County, Maine. Report prepared for the Maine Dept. Environ. Prot., Portland, ME: 36 p.

Finstad, B., P.A. Bjørn, and S.T. Nilsen. 1995. Survival of salmon lice, *Lepeophtheirus salmonis* Krøyer, on Arctic Charr, *Salvelinus alpinus* (L.), in fresh water. Aquacult. Res. 26: 791-795.

Flanagan, J.J. 2003. The impacts of fine sediments and variable flow regimes on the habitat and survival of Atlantic Salmon (*Salmo salar*) eggs. Thesis (M.Sc.) University of New Brunswick, Fredericton, NB: 141 p.

Flanagan, J.J., R.A. Jones, and P. O'Reilly. 2006. A summary and evaluation of Atlantic Salmon (*Salmo salar*) smolt monitoring and rotary screw fish trap activities in the Big Salmon River, 2001-2005. Can. Tech. Rep. Fish. Aquat. Sci. 2646: vii + 31 p.

Fleming, I.A., A. Lamberg, and B. Jonsson. 1996. Effects of early experience on the reproductive performance of Atlantic Salmon. Behav. Ecol. 8(5): 470-480.

Fletcher, J.S. and A.L. Meister. 1982. The St. Croix River: An Atlantic Salmon river management report by the Atlantic Sea-Run Salmon Commission, Bangor, ME: 42 p.

Ford, J.S and R.A. Myers. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. PLoS Biol. 6(2): e33. doi:10.1371/journal.pbio.0060033.

Francis, A.A. 1980. Densities of juvenile Atlantic Salmon and other species, and related data from electroseining studies in the Saint John River system, 1968-78. Can. Data Rep. Fish. Aquat. Sci. 178: 102 p.

Francis, A.A. 1984. Numbers of Atlantic Salmon ascending the Tobique Narrows fishway, Saint John River System, N.B., 1978-83. Can. Data Rep. Fish. Aquat. Sci. 475. vii + 15p.

Fraser, D.J. 2008. How well can captive breeding programs conserve biodiversity? A review of salmonids. Evol. Applic. 1(4): 535-586. doi:10.1111/j.1752-4571.2008.00036.x.

Fraser, D.J., A.M. Cook, J.D. Eddington, P. Bentzen, and J.A. Hutchings. 2008. Mixed evidence for reduced local adaptation in wild salmon resulting from interbreeding with escaped farmed salmon: Complexities in hybrid fitness. Evol. Appl. 1(3): 501-512. doi:10.1111/j.1752-4571.2008.00037.x.

Fraser, D.J., A.L.S. Houde, P.V. Debes, P. O'Reilly, J.D. Eddington, and J.A. Hutchings. 2010. Consequences of farmed–wild hybridization across divergent wild populations and multiple traits in salmon. Ecol. Appl. 20(4): 935-953.

Fraser, D.J., L.K. Weir, L. Bernatchez, M.M. Hansen, and E.B. Taylor. 2011. Extent and scale of local adaptation in salmonid fishes: Review and meta-analysis. Heredity. 106: 404-420.

Frazer, L.N. 2007. Comment on "Sea lice on adult Pacific Salmon in the coastal waters of British Columbia, Canada by R.J. Beamish et al." Fish. Res. 85(3): 328-331. doi:10.1016/j.fishres.2006.10.010.

Freedman, J.A., R.A. Curry, and K.R. Munkittrick. 2012. Stable isotope analysis reveals anthropogenic effects on fish assemblages in a temperate reservoir. River Res. Applic. 28(10): 1804-1819. doi:10.1002/rra.1576.

Friedland, K.D., D.G. Reddin, J.R. McMenemy, and K.F. Drinkwater, 2003. Multidecadal trends in North American Atlantic Salmon (*Salmo salar*) stocks and climate trends relevant to juvenile survival. Can. J. Fish. Aquat. Sci 60: 563-583.

Galloway, B.J., K.R. Munkittrick, S. Currie, M.A. Gray, R.A. Curry, and C.S. Wood. 2003. Examination of the responses of Slimy Sculpin (*Cottus cognatus*) and White Sucker (*Catostomus commersoni*) collected on the Saint John River (Canada) downstream of pulp mill, paper mill, and sewage discharges. Environ. Tox. Chem. 22(12): 2898-2907.

Gibson, R.J. 1973. Interactions of juvenile Atlantic Salmon (*Salmo salar* L.) and Brook Trout (*Salvelinus fontinalis* (Mitchill)). *In* Proceedings of the International Atlantic Salmon Symposium. Edited by M.W. Smith and W. M. Carter. Intern. Atl. Salm. Found. Spec. Public., Series 4: 181-202.

Gibson, A.J.F. and R.A. Myers. 2002. Effectiveness of a high-frequency-sound fish diversion system at the Annapolis Tidal Hydroelectric Generating Station, Nova Scotia. N. Amer. J. Fish. Manage. 22(3): 770-784.

Gibson, R.J., D.E. Stansbury, R.R Whalen, and K.G. Hillier. 1993. Relative habitat use, and inter-specific and intra-specific competition of Brook Trout (*Salvelinus fontinalis*) and juvenile Atlantic Salmon (*Salmo salar*) in some Newfoundland rivers. Can. Spec. Publ. Fish. Aquat. Sci.118: 53-69.

Gibson, A.J.F., R.A. Jones, and H.D. Bowlby. 2009. Equilibrium analyses of a population's response to recovery activities, a case study with Atlantic Salmon. N. Am. J. Fish. Man. 29: 958-974.

Gillis, C.-A. and M. Chalifour. 2010. Changes in the macrobenthic community structure following the introduction of the invasive algae *Didymosphenia geminata* in the Matapedia River (Quebec, Canada). Hydrobiol. 647: 63-70.

Gilvear, D.J., K.V. Heal, and A. Stephen. 2002. Hydrology and ecology quality of Scottish river ecosystems. Sci. Tot. Environ. 294: 131-159.

GNB. 2005. Report of the task force on fostering a sustainable salmon farming industry for Atlantic Canada. Atlantic Task Force on Samon Farming, Govt. NB, Fredericton, NB: 40 p. (Last accessed 14 April 2014).

Goodbrand, L., M.V. Abrahams, and G.A. Rose. 2013. Sea cage aquaculture affects distribution of wild fish at large spatial scales. Can. J. Fish. Aqu. Sci. 70:1289-1292. doi:10.1139/cjfas-2012-0317.

Gray, M.A. 2003. Assessing non-point source pollution in agricultural regions of the upper St. John River basin using the Slimy Sculpin (*Cottus cognatus*). Thesis (Ph.D.) University of New Brunswick, Fredericton, NB: 163 p.

Gucinski, H., M.J. Furniss, R.R. Ziemer, and M.H. Brookes. 2001. Forest roads: A synthesis of scientific information. General Technical Report. PNWGTR-509. US Dept. Agricul., For. Ser., Pac. Northw. Res. Stat., Portland, OR: 120 p. (Last accessed 14 April 2014).

Hall, C.J., A. Jordan, and M.G. Frisk. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecol. 26: 95-107.

Harding, G.C.H. 1996. Ecological factors to be considered in establishing a new krill fishery in the Maritimes Region. DFO Atl. Fish. Res. Doc. 96/99.

Harwood, A.J., J.D. Armstrong, S.W. Griffiths, and N.B. Metcalfe. 2002. Sympatric association influences within-species dominance relations among juvenile Atlantic Salmon and Brown Trout. Anim. Behav. 64: 85-95.

Henderson, N.J. and B.H. Letcher. 2003. Predation on stocked Atlantic Salmon (*Salmo salar*) fry. Can. J. Fish. Aquat. Sci. 60: 32-42.

Hermoso, V., M. Clavero, F. Blanco-Garrido, and J. Prenda. 2011. Invasive species and habitat degradation in Iberian streams: An analysis of their role in freshwater fish diversity loss. Ecol. Appl. 21(1): 175-188.

Heuch, P.A., P.A. Bjørn, B. Finstad, J.C. Holst, L. Asplin, and F. Nilsen. 2005. A review of the Norwegian "National action plan against salmon lice on salmonids: The effect on wild salmonids". Aquacult. 246: 79-92.

Hesthagen, T., B.M. Larsen, and P. Fiske. 2011. Liming restores Atlantic Salmon (*Salmo salar*) populations in acidified Norwegian rivers. Can. J. Fish. Aquat. Sci. 68: 224-231.

Higgins, H., A. St.-Hilaire, S.C. Courtenay, and K.A. Haralampides. 2011. Suspended sediment dynamics in a tributary of the Saint John River, New Brunswick. Can. J. Civ. Eng. 38: 212-232.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: Choices, dynamics and uncertainty. Chapman and Hall, New York, NY, USA. 570 p.

Houde, A.S., D.J. Fraser, and J.A. Hutchings. 2010. Fitness-related consequences of competitive interactions between farmed and wild Atlantic Salmon at different proportional representations of wild-farmed hybrids. ICES J. Mar. Sci. 67: 657-667.

Hoyle, J.A. and C. Lake. 2011. First occurrence of Chain Pickerel (*Esox niger*) in Ontario: Possible range expansion from New York waters of eastern Lake Ontario. Can. Field-Natur. 125(1): 16-21.

Hunt, C.W., J.E. Salisbury, and D. Vandemark. 2011. Contribution of non-carbonate anions to total alkalinity and overestimation of pCO_2 in New England and New Brunswick rivers. Biogeosci. 8: 3069-3076.

Huntsman, A.G. 1933a. St. John November salmon - the earliest run known. *In* Biol. Bd. Canada. Progr. Rep. Atl. Biol. Sta., St. Andrews, NB. No. 6, Note No. 25. January. pp. 7-10.

Huntsman, A.G. 1933b. Passamoquody sardine fishing makes Tobique salmon angling. *In* Biol. Bd. Canada. Progr. Rep. Atl. Biol. Sta., St. Andrews, NB. No. 8, Note No. 32. July. pp. 6-9.

Hutcheson, M. 1983. Toxicological effects of potash brine on Bay of Fundy marine organisms. Marine Environ. Res. Vol. 9(4): 237-255.

ICES. 1990. Report of the Study Group on the North American Salmon Fisheries, 26 Feb-2 Mar 1990 Halifax, Nova Scotia, Canada. ICES CM1990/M:3: 111 p.

ICES. 2000. Report of the Working Group on North Atlantic Salmon (WGNAS), 3-13 April 2000, Copenhagen, Denmark, ICES Document CM 2000/ACFM:13: 301 p.

ICES. 2004. Report of the Working Group on North Atlantic Salmon (WGNAS). ICES Advis. Comm. ICES CM 2004/ACFM:20: 286 p.

ICES. 2006. Report of the Working Group on North Atlantic Salmon (WGNAS), 4-13 April 2006, ICES Headquarters. ICES CM 2006/ACFM:23: 254 p.

ICES. 2008. Report of the workshop on salmon historical information- new investigation from old tagging data (WKSHINI). ICES CM 2008/DFC:02: 51 p.

ICES. 2011a. Report of the workshop on age determination of salmon (WKADS), 18-20 January 2011, Galoway, Ireland. ICES CM 2011/ACOM:44: 66 p.

ICES. 2011b. Report of the Working Group on North Atlantic Salmon. ICES Document CM 2011/ACOM:09: 286 p.

Ingram, J.H. 1980. Capture and distribution of the Atlantic Salmon and other species at Mactaquac dam and hatchery, Saint John River, N.B., 1972-76. Can. Data Rep. Fish. Aquat. Sci. 181: 74 p.

Ingram, J.H. 1985. Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system, 1977-82. Can. Data Rep. Fish. Aquat. Sci. 508: vii + 59 p.

Ingram, J.H. and B.V. Ensor. 1990. Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system, 1983-88. Can. Data Rep. Fish. Aquat. Sci. 791: 55 p.

International St. Croix River Watershed Board (ISCRWB). 2010. Annual report covering; the orders of approval with respect to the control of the discharge of the St. Croix River at Forest City, Vanceboro, and the water levels of East Grand Lake, Spednic Lake, Grand Falls Flowage and Milltown Dam Forebay and the water quality and aquatic ecosystem health of the St. Croix River boundary waters. *Submitted* to the International Joint Commission: 86 p.

Isaacman, L. and K. Lee. 2010. Current state of knowledge on the environmental impacts of tidal and wave energy technology in Canada . DFO Can. Sci. Advis. Sec. Res. Doc. 2009/077.

Iverson, S.J., C. Field, W.D. Bowen, and W. Blanchard. 2004. Quantitative fatty acid signature analysis: A new method of estimating predator diets. Ecol. Mono. 74(2): 211-235.

Jacobs, S.R. and J.M. Terhune. 2000. Harbour Seal (*Phoca vitulina*) numbers along the Bay of Fundy in autumn in relation to aquaculture. Northeast. Natural. 7(3): 289-296.

Jones, R.A., L. Anderson, and T. Goff. 2004. Assessments of Atlantic Salmon stocks in southwest New Brunswick, an update to 2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/019: ii + 70 p.

Jones, R.A, L. Anderson, J.J. Flanagan, and T. Goff. 2006. Assessments of Atlantic Salmon stocks in southern and western New Brunswick (SFA 23), an update to 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/025: ii + 82 p.

Jones, R.A., L. Anderson, A.J.F. Gibson, and T. Goff. 2010. Assessments of Atlantic Salmon stocks in south western New Brunswick (outer portion of SFA 23): An update to 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/118.

Jones, R.A., L. Anderson, and C.N. Clarke. 2014. Assessment of the recovery potential for the Outer Bay of Fundy population of Atlantic Salmon (*Salmo salar*): Status, trends, distribution, life history characteristics and recovery targets. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/008.

Jonsson, B. and N. Jonsson. 2011a. Farmed Atlantic Salmon in nature. *In* Ecology of Atlantic Salmon and Brown Trout. Edited by D.L.G. Noakes. Fish Fish. Ser. 33. Springer Publishing, Dordrecht Heidelberg London New York. pp. 517-566.

Jonsson, B. and N. Jonsson. 2011b. Ecology of Atlantic Salmon and Brown Trout: Habitat as a template for life histories. Fish Fish. Ser. 33. Springer Publishing, Dordrecht Heidelberg London New York: 708 p.

Julien, H.P. and N.E. Bergeron. 2006. Effect of fine sediment infiltration during the incubation period on Atlantic Salmon (*Salmo salar*) embryo survival. Hydrobiol. 563: 61-71.

Kargbo, D.M., R.G. Wilhelm, and D.J. Campbell. 2010. Natural gas plays in the Marcellus Shale: Challenges and potential opportunities. Environ. Sci. Technol. 44: 5679-5684.

Kemp, P., D. Sear, A. Collins, P. Naden, and I. Jones. 2011. The impacts of fine sediment on riverine fish. Hydrol. Process. 25: 1800-1821. doi:10.1002/hyp.7940.

Kerswill, C.J. 1960. Effects of proposed Passamaquoddy power project on anadromous fishes in Canadian waters. J. Fish. Res. Bd. Canada 17: 713-720.

Kibenge, F.S.B., S.K. Whyte, K.L. Hammell, D. Rainnie, M.T. Kibenge, and C.K. Martin. 2000. A dual infection of Infectious Salmon Anaemia (ISA) virus and a togavirus-like virus in ISA of Atlantic Salmon *Salmo salar* in New Brunswick, Canada. Dis. Aquat. Org. Vol. 42: 11-15.

Kidd, S.D., A. Curry, and K.R. Munkittrick [eds]. 2011. The Saint John River: A state of the environment report. Canadian Rivers Institute, University of New Brunswick. ISBN 978-1-55131-158-6. 175 p.

Kihslinger, R.L., S.C. Lema, and G.A. Nevitt. 2006. Environmental rearing conditions produce forebrain differences in wild Chinook Salmon *Oncorhynchus tshawytscha*. Comp. Biochem. Physiol.- Part A Molec. Integr. Physiol. 145(2): 145-151. doi:10.1016/j.cbpa.2006.06.041.

Kircheis, D. and T. Liebich. 2007. Habitat requirements and management considerations for Atlantic Salmon (*Salmo salar*) in the Gulf of Maine Distinct Population Segment (GOM DPS) – Draft – November 2007: 137 p. (Last accessed 14 April 2014).

Kraft, S.A. 2009. Naive prey versus nonnative predators: A role for behavior in endangered species conservation. Thesis (M.Sc.) Utah State University, Logan, UT: 77 p.

Krkošek, M., M.A. Lewis, and J.P. Volpe. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proc. Roy. Soc. B- Biol. Sci. 272: 689-696.

Lacoul, P., B. Freedman, and T. Clair. 2011. Effects of acidification on aquatic biota in Atlantic Canada. Environ. Rev. 19: 429-460.

Lacroix, G.L. 2008. Influence of origin on migration and survival of Atlantic Salmon (*Salmo salar*) in the Bay of Fundy, Canada. Can. J. Fish. Aquat. Sci. 65: 2063-2079. doi:10.1139/F08-119.

Lacroix, G.L. 2013. Population-specific ranges of oceanic migration for adult Atlantic Salmon (*Salmo salar*) documented using pop-up satellite archival tags, Canada. Can. J. Fish. Aquat. Sci. 70: 1-20.

Lacroix, G.L. and I.A. Fleming. 1998. Ecological and behavioural interactions between farmed and wild Atlantic Salmon: Consequences for wild salmon. DFO Can. Stock Assess. Sec. Res. Doc. 98/162.

Lacroix, G.L. and D. Knox. 2005. Distribution of Atlantic Salmon (*Salmo salar*) post-smolts of different origins in the Bay of Fundy and Gulf of Maine and evaluation of factors affecting migration, growth, and survival. Can. J. Fish. Aquat. Sci. 62: 1363-1376. doi:10.1139/F05-055.

Lacroix, G.L., P. McCurdy, and D. Knox. 2004. Migration of Atlantic Salmon postsmolts in relation to habitat use in a coastal system. Trans. Am. Fish. Soc. 133: 1455-1471. doi:10.1577/T03-032.1.

Lacroix, G.L., D. Knox, T.F. Sheehan, M.D. Renkawitz, and M.L. Bartron. 2012. Distribution of U.S. Atlantic Salmon postsmolts in the Gulf of Maine. Trans. Am. Fish. Soc. 141(4): 934-942.

Lalonde, B.A., W. Ernst, and F. Comeau. 2011. Trace metal concentrations in sediments and fish in the vicinity of ash lagoon discharges from coal-combustion plants in New Brunswick and Nova Scotia, Canada. Arch. Environ. Contam. Toxicol. 61: 472-481.

Lawlor, J.L., A. Dacanay, J.A. Hutchings, L.L. Brown, and S.A. Sperker. 2009. Differences in pathogen resistance within and among cultured, conservation-dependent, and endangered populations of Atlantic Salmon, *Salmo salar* L. Environ. Biol. Fish. 84: 69-78.

LeBlanc, K. 1995. Effects on the reproductive endocrine function of the Mummichog (*Fundulus heteroclitus*) and the Goldfish (*Cadassius auratus*) exposed to Saint John, New Brunswick, harbour waters. Thesis (M.Sc.) University of New Brunswick, Saint John, NB: 118 p.

Leggatt, R.A., P.T. O'Reilly, P.J. Blanchfield, C.W. McKindsey, and R.H. Devlin. 2010. Pathway of effects of escaped aquaculture organisms or their reproductive material on natural ecosystems in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/019.

Leim, A.H. 1924. The life-history of the Shad (*Alosa sapidissima* (Wilson)) with special reference to the factors limiting its abundance. Contrib. Can. Biol., New Series 2: 161-284.

Levsen, A. and B. Berland. 2012. Chapter 18: Anisakis Species. *In* Fish parasites: Pathobiology and protection. Edited by P.T.K. Woo and K. Buchmann. CAB International, Oxfordshite, UK. pp. 298-309.

Lierman, M. and R. Hilborn. 1997. Depensation in fish stocks: A hierarchic Bayesian meta-analysis. Can. J. Fish Aquat. Sci. 54: 1976-1984.

Linton, E.D., D.A. Scuton, and R.S. McKinley. 2005. Physiological effects of thermo mechanical newsprint mill effluent on Atlantic Salmon (*Salmo salar* L.). Ecotoxicol. Environ. Saf. 62(3): 317-333.

Lund, R.A., F. Okland, and L.P. Hansen. 1991. Farmed Atlantic Salmon (*Salmo salar*) in fisheries and rivers in Norway. Aquacult. 98: 143-150.

MacDonald, J.R. and R.A. Hyatt. 1973. Supersaturation of nitrogen in water during passage through hydroelectric turbines at Mactaquac Dam. J. Fish. Res. Bd. Can. 30: 1392-1394.

MacKinnon, A.-M., M. Campbell, and G. Olivier. 1998. Overview of fish disease agents in cultivated and wild salmonid populations in the Maritimes. DFO Can. Stock Assess. Sec. Res. Doc. 1998/160.

Maguire, J.-J. and B. Lester. 2012. Bluefin Tuna (*Thunnus thynnus*) in Atlantic Canadian waters: Biology, status, recovery potential, and measures for mitigation. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/002.

Marshall, T.L. 1989. Assessment of Atlantic Salmon of the Saint John River, N.B., 1988. CAFSAC Res. Doc. 89/77.

Marshall, T.L. 1990. Assessment of Atlantic Salmon of the Saint John River, N.B., above Mactaquac, 1989. CAFSAC Res. Doc. 90/79.

Marshall, T.L. and J.D. Cameron. 1995. Assessment of Atlantic Salmon stocks of Saint John River and southwest New Brunswick, 1994. DFO Atl. Fish. Res. Doc. 95/129.

Marshall, T.L. and G.H. Penney. 1983. Spawning and river escapement requirements for Atlantic Salmon of the Saint John River, New Brunswick. CAFSAC Res. Doc. 83/66.

Marshall, T.L., G.J. Farmer, and R.E. Cutting. 1995. Atlantic Salmon initiatives in Scotia-Fundy Region, Nova Scotia and New Brunswick. *In* A hard look at some tough issues. Edited by S. Calabi and A. Stout. Proc. New England Atlantic Salmon Manage. Conf., Danvers, MA. pp. 116-133.

Marshall, T.L., R. Jones, and T. Pettigrew. 1997. Status of Atlantic Salmon stocks of southwest New Brunswick, 1996. DFO Can. Stock Assess. Sec. Res. Doc. 97/27.

Marshall, T.L., G.J. Chaput, P.G. Amiro, D.K. Cairns, R.A. Jones, S.F. O'Neil, and J.A. Ritter. 1999. Assessments of Atlantic Salmon stocks of the Maritimes Region, 1998. DFO Can. Stock Assess. Sec. Res. Doc. 99/25.

Marshall, T.L., R.A. Jones, and L. Anderson. 1999. Follow-up assessments of Atlantic Salmon in the Saint John River drainage, N.B., 1998. DFO Can. Stock Assess. Sec. Res. Doc. 99/109.

Marshall, T.L., R.A. Jones, and L. Anderson. 2000. Assessment of Atlantic Salmon stocks in southwest New Brunswick, 1999. DFO Can. Stock Assess. Sec. Res. Doc. 2000/010.

Marshall, T.L., C.N. Clarke, R.A. Jones, and S.M. Ratelle. 2014. Assessment of the Recovery Potential for the Outer Bay of Fundy population of Atlantic Salmon (*Salmo salar*): Habitat considerations. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/007.

Martin, G. 2003. Management of New Brunswick's crown forest. DNR, Fredericton, NB: 24 p. (Last accessed 14 April 2014).

Martin, J.D. 1984. Atlantic Salmon and Alewife passage through a pool and weir fishway on the Magaguadavic River, New Brunswick, during 1983. Can. Manuscr. Rep. Fish Aquat. Sci. 1776: iii + 11 p.

Martin, J.L., A.R. Hanke, and M.M. LeGresley. 2009. Long term phytoplankton monitoring, including harmful algal blooms, in the Bay of Fundy, eastern Canada. J. Sea Res. 61: 76-83.

McMahon, F. and M. Cervantes. 2012. Survey of mining companies 2011/2012. The Fraser Institute Annual Report. Vancouver, BC: 131 p.

McRuer, J. and T. Hurlbut. 1996. The status of Spiny Dogfish (*Squalus acanthias*, Linnaeus) in the Bay of Fundy, Scotian Shelf and Southern Gulf of St. Lawrence (NAFO Divisions 4TVWX) in 1995. DFO Atl. Fish. Res. Doc. 96/75.

Melanson, P.L., A.G. Chiasson, and S.C. Courtenay. 2004. Pulp and paper mill effluents as a source of cytochrome P4501A1 inducers in fish of the Miramichi River, New Brunswick. Can. Manuscr. Rep. Fish. Aquat. Sci. 2709: xi + 42 p.

Minns, C.K., R.G. Randall, E.M.P. Chadwick, J.E. Moore, and R. Green. 1995. Potential impact of climate change on the habitat and population dynamics of juvenile Atlantic Salmon (*Salmo salar*) in eastern Canada. *In* Climate change and northern fish populations. Edited by R.J. Beamish. Can. Spec. Publ. Fish. Aquat. Sci. 121. pp. 699-708.

Monk, W.A. and R.A. Curry. 2009. Models of past, present and future stream temperatures for selected Atlantic Salmon rivers in northeastern North America. Amer. Fish. Soc. Symp. 69: 215-230.

Mookerji, N., Z. Weng, and A. Mazumder. 2004. Food partitioning between coexisting Atlantic Salmon and Brook Trout in the Sainte-Marguerite River ecosystem, Quebec. J. Fish Biol. 64: 680-694.

Moore, A. 2009. The impact of environmental levels of persistent aquatic contaminants on Atlantic Salmon. CEFAS, Lowestoft Laboratory, Suffolk, UK: 10 p. (Last accessed 14 April 2014).

Moore, A. and N. Lower. 2001. The impact of two pesticides on olfactory-mediated endocrine function in mature male Atlantic Salmon (*Salmo salar* L.) parr. Compara. Biochem. Physiol. Part B 129: 269-276.

Moore, A., E.C.E. Potter, N.J. Milner, and S. Bamber. 1995. The migratory behaviour of wild Atlantic Salmon (*Salmo salar*) smolts in the estuary of the River Conwy, North Wales. Can. J. Fish. Aquat. Sci. 52: 1923-1935.

Moore, A., A.P. Scott, N. Lower, I. Katsiadaki, and L. Greenwood. 2003. The effects of 4-nonylphenol and atrazine on Atlantic Salmon (*Salmo salar* L) smolts. Aquacult. 222: 253-263.

Moore, R.D. and S.M. Wondzell. 2005. Physical hydrology and the effect of forest harvesting in the Pacific Northwest: A review. J. Ame. Wat. Res. Assoc. 41: 763-784.

Morantz, D.L., R.K. Sweeney, C.S. Shirvell, and D.A. Longard. 1987. Selection of microhabitat in summer by juvenile Atlantic Salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 44: 120-129.

Morris, M.R.J., D.J. Fraser, A.J. Heggelin, F.G. Whoriskey, J.W. Carr, S.F. O'Neil, and J.A. Hutchings. 2008. Prevalence and recurrence of escaped farmed Atlantic Salmon (*Salmo salar*) in eastern North American rivers. Can. J. Fish. Aquat. Sci. 65: 2807-2826.

Murphy, T.M., M. Berzano, S.M. O'Keeffe, D.M. Cotter, S.E. McEvoy, K.A. Thomas, N.P.Ó. Maoiléidigh, and K.F. Whelan. 2010. Anisakid larvae in Atlantic Salmon (*Salmo salar* L.) grilse and post-smolts: Molecular identification and histopathology. J. Parasitol. 96(1): 77-82.

National Research Council. 2003. Atlantic Salmon in Maine. The Committee on Atlantic Salmon in Maine, Board on Environmental Studies and Toxicology, Ocean Studies Board, Division on Earth and Life Sciences. National Research Council of the National Academies. National Academy Press. Washington, DC: 260 p.

Naylor, R., K. Hindar, I.A. Fleming, R. Goldburg, S. Williams, J. Volpe, F. Whoriskey, J. Eagle, D. Kelso, and M. Mangel. 2005. Fugitive salmon: Assessing the risks of escaped fish from net-pen aquaculture. Biosci. Vol. 55(5): 427-437.

Nelson, R.P., K. Ellis, and J.N. Smith. 2001. Environmental monitoring report for the Point Lepreau N.B. nuclear generating station - 1991 to 1994. Can. Tech. Rep. Hydrogr. Ocean Sci. 0.211: v + 125.

Neff, B.D., S.R. Garner, and T.E. Pitcher. 2011. Conservation and the enhancement of wild fish populations: Preserving genetic quality versus genetic diversity. Can. J. Fish. Aquat. Sci. 68: 1139-1154.

New Brunswick Crown Land Task Force. 2011. A path for a sustainable economic forest in New Brunswick. Province of New Brunswick, Fredericton, NB. ISBN 978-1-555471-649-7: 34 p. (Last accessed 14 April 2014).

NBDNR (New Brunswick Department of Natural Resources). 2012. 2011-2012 Annual Report. NBDNR, Fredericton, NB. ISBN 978-1-55471-483-4: 98 p. (Last accessed 14 April 2014).

Nieves-Puigdoller, K., B.T. Björnsson, and S.D. McCormick. 2007. Effects of hexazinone and atrazine on the physiology and endocrinology of smolt development in Atlantic Salmon. Aquat. Toxicol. 84: 27-37.

Noguera, P., C. Collins, D. Bruno, C. Pert, A. Turnbull, A. McIntosh, K. Lester, I. Bricknell, S. Wallace, and P. Cook. 2009. Red vent syndrome in wild Atlantic Salmon *Salmo salar* in Scotland is associated with *Anisakis simplex* sensu stricto (Nematoda: Anisakidae). Dis. Aquat. Org. Vol. 87: 199-215.

O'Connor, W.C.K. and T.E. Andrew. 1998. The effects of siltation on Atlantic Salmon (*Salmo salar*), embryos in the River Bush. Fish. Manag. Ecol. 5: 393-401.

Olivier, G. and A.-M. MacKinnon. 1998. A review of potential impacts on wild salmon stocks from diseases attributed to farmed salmon operations. DFO Can. Stock Assess. Sec. Res. Doc. 98/159.

O'Reilly, P.T., R. Jones, and S. Rafferty. 2014. Within- and among-population genetic variation in Outer Bay of Fundy Atlantic Salmon (*Salmo salar* L.), with special emphasis on the Saint John River system in the context of recent human impacts. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/069.

Peabody, G. and S.J. Mitchell. 2005. Meduxnekeag River Association- Interim Progress Report-. March: 23 p.

Penney, G.H. 1983. Recaptures of Atlantic Salmon tagged and released in the Bay of Fundy near the Saint John River. New Brunswick, 1970-1973. Can. Manuscr. Rep. Fish. Aquat. Sci. 1737.

Perley, M.H. 1852. Reports of the sea and river fisheries of New Brunswick. Printer to the Queen, Fredericton, NB: 328 p.

Peterson, R.H. 1978. Physical characteristics of Atlantic Salmon spawning gravel in some New Brunswick streams. Fish Mar. Serv. Tech. Rep. 785: iv + 28 p.

Peterson, R.H., D.J. Martin-Robichaud, and J. Power.1988. Toxicity of potash brines to early developmental stages of Atlantic Salmon (*Salmo salar*). Bull. Environ. Contam. Toxicol. 41: 391-397.

Philips, M. and D. Clowater. 2008. Fish habitat compensation of the Trans Canada project. Paper presented at the Annual Conference of the Transportation Association of Canada, Toronto, Ontario: 21 p. (Last accessed 14 April 2014).

Poff, N.L. and A.D. Huryn. 1998. Multi-scale determinants of secondary production in Atlantic Salmon (*Salmo salar*) streams. Can. J. Fish. Aquat. Sci. 55 (Suppl. 1): 201-217.

Porter, T.R. (ed.). 1992. Protocols for the introduction and transfer of salmonids. North Atlantic Salmon Conservation Organization, NAC, Edinburgh, UK (92) 24: iii + 119 p.

Powell, K., J.G. Trial, N. Dubé, and M. Opitz. 1999. External parasite infestation of sea-run Atlantic Salmon (*Salmo salar*) during spawning migration in the Penobscot River, Maine. Northeast. Natural. 6(4): 363-370.

Powers, G.M. and J.F. Orsborn. 1985. Analysis of barriers to upstream fish migration: An investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls. U.S. Dept. Energy, Bonneville Power Administration, Project 82-14. Portland, Oregon: 127 p. (Last accessed 14 April 2014).

Prouse, N.J. and J.F. Uthe. 1994. Concentrations of pesticides and other industrial chemicals in some sport fish species from a few sites in New Brunswick and Nova Scotia. Can. Tech. Rep. Fish Aquat. Sci. 1981: v + 39 p.

Ramos-Scharron, C.E. and L.H. MacDonald. 2007. Runoff and suspended sediment yields from an unpaved road segment, St. John, US Virgin Islands. Hydrol. Process. 21: 35-50.

Renkawitz, M.D. and T.F. Sheehan. 2011. Feeding ecology of early marine phase Atlantic Salmon *Salmo salar* post-smolts. J. Fish Biol. 79: 356-373.

Rikardsen, A.H. and J.B. Dempson. 2011. Dietary life-support: The food and feeding of Atlantic Salmon at sea. *In* Atlantic Salmon Ecology. Edited by Ø. Aas, S. Einum, A. Klemetsen, and J. Skurdal. Wiley-Blackwell, Oxford, UK. pp. 115-143.

Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic Salmon (*Salmo salar* L.). Can. Manuscr. Rep. Fish. Aqua. Sci. 2041. 136 p.

Roberge, C., S. Blanchet, J.J. Dodson, H. Guderley, and L. Bernatchez. 2008. Disturbance of social hierarchy by an invasive species: A gene transcription study. PLoS ONE 3(6): e2408. doi:10.1371/journal.pone.0002408.

Rosenberg, D.M., F. Berkes, R.A. Bodaly, R.E. Hecky, C.A. Kelly, and J.W.M. Rudd. 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5: 27-54.

Ruggles, C.P. and J.A. Ritter. 1980. Review of North American smolt tagging to assess the Atlantic Salmon fishery of West Greenland. Rapp. P.-v. Réun. Cons. Int. Explor. Mer 176: 82-92.

Ruggles, C.P. and W.D. Watt. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Bd. Can. 32(1): 161-170.

Saunders, R.L. 1978. The stock concept, a major consideration in salmon restoration. Atl. Salm. J. October: 21-23.

Saunders, R.L. 1991. Potential interaction between cultured and wild Atlantic Salmon. Aquacult. 90: 51-60.

Schiermeier, Q. 2003. Fish farms' threat to salmon stocks exposed. Nature 425, 753: 1 p. doi:10.1038/425753a. (Last accessed 14 April 2014).

Schröder, V. and C. Garcia de Leaniz. 2011. Discrimination between farmed and free-living invasive salmonids in Chilean Patagonia using stable isotope analysis. Biol. Invas. 13: 203-213.

Sciences and Reporting Branch. 2007a. New Brunswick Watersheds- Canaan River. Department of Environment of New Brunswick [online] (accessed 15 April, 2014).

Sciences and Reporting Branch. 2007b. New Brunswick Watersheds- Digdeguash River. Department of Environment of New Brunswick [online] (accessed 15 April 2014).

Sciences and Reporting Branch. 2007c. New Brunswick Watersheds- Hammond River. Department of Environment of New Brunswick [online] (accessed 15 April 2014).

Sciences and Reporting Branch. 2007d. New Brunswick Watersheds- Kennebecasis River. Department of Environment of New Brunswick [online] (accessed 15 April 2014).

Sciences and Reporting Branch. 2007e. New Brunswick Watersheds- Magaguadavic River. Department of Environment of New Brunswick [online] (accessed 15 April 2014).

Sciences and Reporting Branch. 2007f. New Brunswick Watersheds- St. Croix River. Department of Environment of New Brunswick [online] (last accessed 15 April 2014).

Scott, W.B. and E.J. Crossman. 1998. Freshwater fishes of Canada. Galt House Publication Ltd., Oakville, Ontario: 996 p.

Semple, J.R. 1991. Atlantic Salmon habitat survey: Enhancement opportunities and problems in the Dunbar Stream, Nashwaak River, New Brunswick. Can. Manuscr. Rep. Fish. Aquat. Sci. 2076: 35 p.

Shearer, W.M. 1992. The Atlantic Salmon: Natural history, exploitation and future management. Fishing News Books, Blackwell Sci. Publ., Oxford, UK: 244 p.

Skilbrei, O.T., M. Holm, K.E. Jørstad, and S.O. Handeland. 1994. Migration motivation of cultured Atlantic Salmon, *Salmo salar* L. smolts in relation to size, time of release and acclimation period. Aquacult. Fish. Manage. 25: 65-77.

Smith, K.E.H. 1969. Compendium St. John River System, N.B. Can. Dept. Fish and Forest., Res. Devel. Br., Halifax, N.S. MS Rept. No. 69-6: 238 p.

Smith, K.E.H. 1979. Capture and distribution of all fish species at Saint John River power dams, New Brunswick, from construction years to 1971. Can. Data Rep. Fish. Aquat. Sci. 171: viii + 55 p.

Snyder, D.E. 2003. Electrofishing and its harmful effects on fish. Information and Technology Report USGS/BRD/ITR-2003-002. US Government Printing Office, Denver, Colorado: 149 p.

Soulsby, C., A.F. Yougson, H.J. Moir, and I.A. Malcolm. 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: A preliminary assessment. Sci. Tot. Environ. 265: 295-307.

Stanford, J.A., J.V. Ward, W.J. Liss, C.A Frissell, R.N. Williams, J.A. Lichatowich, and C.C. Coutant. 1996. A general protocol for restoration of regulated rivers. Reg. Riv., Res. Manage. 12: 391-413.

Stantec. 2011. Fisheries management plan St. George Power PL- Final Draft. *Report prepared for the* St. George Power Limited Partnership, St. George, New Brunswick: 102 p.

Stasko, A.B. 1975. Progress of migrating Atlantic Salmon (*Salmo salar*) along an estuary, observed by ultrasonic tracking. J. Fish Biol. 7: 329-338.

Stocek, R.F., P.J. Cronin, and P.D. Seymour. 1999. The Muskellunge, *Esox masquinongy*, distribution and biology of a recent addition to the ichthyofauna of New Brunswick. Can. Field Nat. 113: 230-234.

Tenzin, K. 2006. The design of a non-lethal fish monitoring program for rivers in Bhutan. Thesis (M.Sc.) University of New Brunswick, Fredericton, NB: 169 p.

Thibault, I., L. Bernatchez, and J.J. Dodson. 2009. The contribution of newly established populations to the dynamics of range expansion in a one-dimensional fluvial-estuarine system: Rainbow Trout (*Oncorhynchus mykiss*) in Eastern Quebec. Diversity Distrib. 15: 1060-1072.

Thomas, V.G., C. Vásárhelyi, and A.J. Niimi. 2009. Legislation and the capacity for rapid-response management of nonindigenous species of fish in contiguous waters of Canada and the USA. Aquat. Conserv: Mar. Freshw. Ecosyst. 19: 354-364.

Thompson, D.H. 2001. Settlements and landscapes of the Musquash Estuary: Past and present. A report in support of the Musquash Marine Protected Area Campaign. Conserv. Council NB, Marine Conservation Program, Fredericton, New Brunswick: 18 p.

Thorstad, E.B., T.F. Næsje, P. Fiske, and B. Finstad. 2003. Effects of hook and release on Atlantic Salmon in the River Alta, northern Norway. Fish. Res. 60: 293-307.

Thorstad, E.B., I.A. Fleming, P. McGinnity, D. Soto, V. Wennevik, and F. Whoriskey. 2008. Incidence and impacts of escaped farmed Atlantic Salmon *Salmo salar* in nature. NINA Spec. Rep. 36: 110 p.

Tlusty, M.F., J. Andrew, K. Baldwin, and T.M. Bradley. 2008. Acoustic conditioning for recall/ recapture of escaped Atlantic Salmon and Rainbow Trout. Aquacult. 274: 57-64.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14: 18-30.

Vallière, G. 1998. An effects-based assessment of the health of fish in a small estuarine stream receiving effluent from an oil refinery. Thesis (M.Sc.) University of Sherbrook, Sherbrook, Quebec: 175 p.

Valois, A., R.A. Curry, and S.M. Coghlan. 2009. Smallmouth Bass (*Micropterus dolomieu*) invasion of Gulf Region rivers: Evaluating the impact on Atlantic Salmon (*Salmo salar*) populations. DFO Can. Sci. Adv. Sec. Res. Doc. 2009/075.

USASAC (U.S. Atlantic Salmon Assessment Committee). 2011. Annual report of the U.S. Atlantic Salmon Assessment Committee. Report No. 24-2011 Activities. Turner Falls, MA. Prepared for U.S. section to NASCO. USASAC Annual Report 2011/24.

Wappel, T. (Chair). 2003. The federal role in aquaculture in Canada. Report of the Standing Committee on Fisheries and Oceans. House of Commons Canada Publication, Ottawa, Ontario: 128 p. (Last accessed 14 April 2014).

Ward, D.M., K.H. Nislow, and C.L. Folt. 2008. Do native species limit survival of reintroduced Atlantic Salmon in historic rearing streams? Biol. Conserv. 141: 146-152.

Warner, K. 1956. Aroostook River salmon restoration and fisheries management. Maine Dept. Inl. Fish. Game, Augusta, ME: 66 p.

Warner, K., R.P. AuClair, S.E. DeRoche, K.A. Havey, and C.F. Ritzi. 1968. Fish predation on newly stocked Landlocked Salmon. J. Wild. Manage. 32(4): 712-717.

Washburn and Gillis Associates Ltd. 1986. Identification of fish habitat improvement opportunities in New Brunswick. *Report submitted to* DFO, Gulf Region, Fish. Res. Br, Fish Hab. Div.: 205 p.

Washburn and Gillis Assoc. Ltd. 1996. Assessment of Atlantic Salmon smolt recruitment in the Saint John River: Final report. *Manuscript prepared for* SALEN Inc.: 129 p.

Waters, T.F. 1995. Sediments in streams: Sources, biological effects and control. Amer. Fish. Soc. Mono. 7: 249 p.

Welch, W.E, P.E.K. Symons, and D.W. Narver. 1977. Some effects of potato farming and forest clearcutting on small New Brunswick streams. Fish. Mar. Ser. Tech. Rep. 745: iv + 13 p.

Wells, P.G. 1999. Environmental impacts of barriers on rivers entering the Bay of Fundy: Report of an *ad-hoc* Environmental Canada Working Group. Tech. Rep. Ser. No. 334, Canadian Wildlife Service, Ottawa, Ontario: 43 p.

Whelan, K. 2010. A review of the impacts of the salmon louse, *Lepeophtheirus salmonis* (Krøyer 1837) on wild salmonids. Atl. Salm. Trust, Perth, Scotland: 27 p. (Last accessed 14 April 2014).

Whoriskey, F.G., P. Brooking, G. Doucette, S. Tucker, and J.W. Carr. 2006. Movements and survival of sonically tagged farmed Atlantic Salmon released in Cobscook Bay, Maine USA. ICES J. Mar. Sci. 63(7): 1218-1223.

Wildish, D.J., A.J. Wilson, and H.M. Akagi. 1980. Sublittoral macro-infauna of Digdeguash estuary, New Brunswick, Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 1568: iii + 8 p.

Willis, T.V. 2006. St. Croix River Alewife - Smallmouth Bass interaction study. *In* Two reports of Alewives in the St. Croix River. Marine Rivers, Hallowell, ME. pp. 1-41.

Wilson, G.A.C. 1956. Saint Croix River Canadian Fisheries Survey. Resource Development Branch, Fisheries Service Maritimes Region, Canada, MS Rpt. No. 56-10: 1-30.

Wrona, F.J., T.D. Prowse, and J.D. Reist. 2005. Freshwater ecosystems and fisheries. *In* Arctic Climate Impact Assessment. Edited by L. Arris. Cambridge University Press, New York, NY. pp. 353-452.

Yang, Q., Z. Zhao, T. Lien Chow, H.W. Rees, C.P.-A. Bourque, and F.-R. Meng. 2009. Using GIS and a digital elevation model to assess the effectiveness of variable grade flow diversion terraces in reducing soil erosion in north-western New Brunswick, Canada. Hydrol. Process. 23: 3271-3280.

Yang, Q., G. Benoy, Z. Zhao, T.L. Chow, C.P.-A. Bourque, and F.-R. Meng. 2011. Watershed-level analysis of exeedance frequencies for different management strategies. Wat. Qual. Res. J. Can. 46(1): 64-73.

Yule, W.N. and A.D. Tomlin. 1971. DDT in forest streams. Bull. Environ. Contam. Toxicol. Vol. 5, No. 6: 479-488.

TABLES

Table 1: Summary of threats to, and rating of effects on, recovery and/or persistence of OBoF Atlantic Salmon. Table heading definitions used in assessment and procedure to generate Level of Concern rating found in Appendix 2.

		Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
Threat	**Specific Threat**	**Overall DU**	**% of DU Population affected**	**Current, Historic, Anticipated**	**Population Impacts**	**Evidence in general on A. Salmon**	**Evidence on OBoF salmon**	**Context for DU**
Freshwater								
Physical obstructions	Hydro dams	High	High	C, H, A Continuous	Extreme	Very High	Very High	Direct mortality. Eight major hydro dams in DU. Some require handling all fish. Affects migration, cumulative mortality through dams on the SJR up to 45%, headponds and tailraces harbour predators.
Directed salmon fishing (current)	Illegal Fishing (poaching)	High	High	H, C and A Seasonal	High	High	High	Direct spawner loss; population-level impact dependent on level of illegal fishing and overall population size. Evidence of salmon hook-and-release (H-and-R) or retention angling in trout fishery.
Water quality and quantity	Silt and sediment (Also see Agriculture, forestry, mining)	Medium	High	C, H, A Seasonal /Continuous	Medium	High	Medium	Road crossings, industrial run-off. Affects juvenile survival & physiology. Reduces habitat. Extensive forestry and agriculture in DU.
Water quality and quantity	Contaminants (Chemical and waste water)	Medium	High	C, H, A Recurrent	Medium	High	Medium	Reduces survival (freshwater marine); causes physiological changes. Some inadequate waste handling facilities in DU, extensive agriculture, mills, plants etc. >50% of NB citizens live in OBoF Watersheds.
Changes to biological communities	Invasive species (Fish)	Medium	High	C, H, A Seasonal	Medium	High	Medium	Head ponds provide habitat for some invasive predators. Increasing non-native predator diversity and abundance in SJR. Potential for increased predation rates at low population level.

Threat	Specific Threat	Level of Concern Overall DU	Extent % of DU Population affected	Occurrence and Frequency Current, Historic, Anticipated	Severity Population Impacts	Causal Certainty Evidence in general on A. Salmon	 Evidence on OBoF salmon	Rationale Context for DU
Changes to biological communities	Historic Stocking (Adult collection, captive spawn, rear to smolt, release)	Medium	High	H, A	Medium	High	Low	Declines in fitness associated with captive matings and juvenile captive exposure, but little evidence of non-stocked rivers out-performing stocked.
Physical obstructions	Other dams and obstructions (see Hydro dams and obstructions)	Medium	High	C, H, A Recurrent	Medium	High	Medium	>200 known in SJR system. Form temporary or permanent reductions in passage or habitat quantity. Water storage dams on Tobique reduce egg - smolt survival.
Physical obstructions	Crossing Infrastructure (roads/culverts)	Medium	High	H, C, A Recurrent	Medium	High	Low	Can form full or partial barriers to migration. Crossings can be point sources of pollution, sediments, and invasives.
Habitat alteration	Urbanization	Medium	High	H, C, A Continuous	Medium	Medium	Low	Aggregate of many threats. Salmon population viability is lower in more populated areas.
Habitat alteration	Agriculture	Medium	High	H, C, A Recurrent	Medium	Medium	Low	Altered flow, increases in temperatures and siltation, chemical run-off, loss of cover, reduces habitat productivity, and can reduce growth and survival of juveniles.
Habitat alteration	Forestry	Medium	High	H, C, A Recurrent	Medium	Medium	Low	Altered flow, forestry is dominant land use of DU (>80%). Significant past clear cutting in Salmon (Vic Co.), Tobique and Nashwaak basins.
Changes to biological communities	Salmonid aquaculture commercial hatcheries (see aquaculture)	Medium	High	C, H, A Recurrent	Medium	Medium	Medium	Known escapes from commercial facilities; known reduction in fitness, potential competition, disease transfer and introgression.
Water quality and quantity	Extreme temperature events	Low	High	C, A Seasonal	Low	High	Medium	Some cool refuge lost to regulated flow. Western NB expected to be highly affected by climate warming.

Threat	Specific Threat	Level of Concern Overall DU	Extent % of DU Population affected	Occurrence and Frequency Current, Historic, Anticipated	Severity Population Impacts	Causal Certainty Evidence in general on A. Salmon	 Evidence on OBoF salmon	Rationale Context for DU
Water quality and quantity	Water extraction (See extreme temperature, mining)	Low	High	C Continuous	Low	Medium	Low	Reduces flow which impacts survival. >50% of NB citizens live in OBoF Watersheds.
Water quality and quantity	Non-hydro power generation (nuclear, thermal and tidal applies to estuarine threats)	Low	High	C, H, A Continuous	Low	Low	Low	Threats occur in SJR with potential to affect all SJR populations. Tidal generation being explored in Passamaquoddy Bay.
Changes to biological communities	Native salmonid stocking	Low	High	C, H, A Recurrent	Low	Medium	Low	Brook Trout and Landlocked Salmon stocking is prevalent in lakes. Potential for competition, pathogen transfer, and predation.
Changes to biological communities	Current stocking (smolt collection and adult release, limited captive spawning)	Low	Medium	C, A Recurrent	Low	Medium	Low	Natural mate-choice, juveniles wild-exposed for lifetime.
Habitat alteration	Mining	Low	Medium	C, A, H Recurrent	Low	Medium	Low	Sedimentation; contaminant source; water extraction. Potential for increased hazard on Nashwaak (Tungsten mine) and Kennebecasis (Shale gas)
Water quality and quantity	Acidification	Low	Low	C Continuous	Low	High	Medium	Hammond, St. Croix, Digdeguash and Magaguadavic have had a few acidic samples but overall not considered limiting.
Water quality and quantity	Military activities (also see silt and sediments)	Low	Low	H, C, and A Periodic	High	Low	Low	Two rivers in DU on CFB Gagetown training areas. One suspected to be severely affected by sedimentation. Population-level impacts are unpublished.

Threat	Specific Threat	Level of Concern Overall DU	Extent % of DU Population affected	Occurrence and Frequency Current, Historic, Anticipated	Severity Population Impacts	Causal Certainty Evidence in general on A. Salmon	 Evidence on OBoF salmon	Rationale Context for DU
Changes to biological communities	Invasive species (other)	Low	Medium	C, A Recurrent	Low	Medium	Low	e.g., Didymo; forms mats that alter the composition of aquatic insect communities. Confirmed to be present on Tobique and Shikatehawk.
Directed salmon fishing (current)	Recreational fishing	Low	High	H, C	Low	Very High	High	No permitted fishery at present. If reopened for H&R, low mortality rates associated with regulated gear types and seasons.
Directed salmon fishing (current)	Aboriginal or commercial fishing	Low	Low	H, C	Negligible	Very High	High	No permitted food, social, ceremonial or commercial harvest in OBoF rivers.
By-catch in other fisheries	Recreational, Aboriginal or Commercial	Low	High	H, C, A Seasonal	Low	Medium	Medium	Shad, Gaspereau, eel have by-catch but is suspected to be low.
Marine/ Estuarine Environment								
Biotic and abiotic shifts	Marine Ecosystem Changes (climate and predator-prey)	High	Very High	C, H, A Continuous	Unknown	Medium	Low	Lower marine survival thought to limit recovery. Climate change affecting SST; currents and ice cover. Correlation of some predators increasing during OBoF decline (Grey Seals). Some prey species have declined (Herring).
	Salmonid aquaculture	High	High	C, H, A Continuous	High	High	Medium	High host density presents potential altered dynamics for predators, prey, and pathogens. Documented occurrence of escapes and wild fitness loss with introgression.
	Diseases and parasites	High	High	C, H, A Continuous	High	Medium	Medium	Several naturally occurring diseases documented in OBoF in wild and/or cultured fish. Linked to aquaculture through high spatial and temporal density of hosts.

Threat	Specific Threat	Level of Concern Overall DU	Extent % of DU Population affected	Occurrence and Frequency Current, Historic, Anticipated	Severity Population Impacts	Causal Certainty Evidence in general on A. Salmon	 Evidence on OBoF salmon	Rationale Context for DU
	Depressed Population Phenomenon	High	Very High	C, A Current	Unknown	Medium	Low	Smolt may be at densities too low to support schooling. Genetic bottleneck concerns with current low abundance.
Directed salmon fisheries	High seas fisheries (Greenland Labrador, St. Pierre)	Medium	Very High	C, H Seasonal	Medium	High	High	Three relatively small fisheries would increase mortality in the 2SW component of populations including OBoF. Estimates of OBoF portion of harvest >5%, <30% of returns.
Biotic and abiotic shifts	Shipping, transport, spills	Low	High	C, H, A Continuous	Low	Low	Low	Extensive shipping traffic during near-shore migrations could disrupt migration and impact marine habitats and prey distributions. Largest North American oil refinery near mouth of SJR serviced by sea.
By-catch in other fisheries	Commercial fisheries	Low	High	C, H Seasonal	Low	Low	Low	Mortality is low from permitted gear types and seasons. Herring weirs (including Mackerel). Little by-catch from offshore fisheries.
Directed fisheries	Fisheries on prey species of salmon (see shifts in marine conditions)	Low	High	C, A, H Continuous	Low	Medium	Low	Prey availability or changes in prey distribution may be linked to increased marine mortality. Evidence suggests food not limiting survival.
Biotic and abiotic shifts	Other species aquaculture (see aquaculture)	Low	Low	C, H, A Recurring	Low	Low	Low	All NB commercial finfish sites are salmon and only one site leased for non-finfish.
Applicable to Freshwater, Estuarine and Marine Environments								
Scientific Research	Monitoring, assessments, collections,and other research	Low	High	C, A, H Continuous	Low	Medium	Low	Documented cases of negative impacts from certain sampling methods. Generally, activities compensate for harm by contributing to population persistence.

Table 2: Productive (Gradient >0.12%) freshwater habitat (100m2 units) estimates for rivers of DU 16. Note that cells with no data are indicated with a period (.).

River / Major Tributaries	DU 16 Productive	Proportion of DU 16	Inaccessible by Dam
Saint John River (above.Mactaquac)			
Salmon R.	12,754	3.2%	.
SJR-Aroostook to Grand Falls	5,400	1.3%	.
Aroostook R.	1,221	0.3%	.
Tobique R.	78,562	19.4%	.
Muniac Str.	3,907	1.0%	.
River de Chute	2,026	0.5%	.
Monquart Str	0	0.0%	5,110
Shikatehawk Str.	4,540	1.1%	.
Big Presquile Str.	1,887	0.5%	.
Little Presquile Str.	1,632	0.4%	.
SJR-Hartland to Beechwood	0	0.0%	.
Becaguimec Str.	10,700	2.6%	.
Meduxnekeag R.	2,169	0.5%	.
Eel R.	5,443	1.3%	.
Shogomoc R.	2,250	0.6%	.
Pokiok R.	2,124	0.5%	.
Nackawic R.	7,656	1.9%	5,104
Mactaquac R.	2,045	0.5%	.
TOTAL ABOVE MACTAQUAC	**144,316**	**35.7%**	**10,214**
Keswick R.	10,100	2.5%	.
Nashwaaksis R.	2,570	0.6%	.
Nashwaak R.	56,920	14.1%	.
Oromocto R.	27,148	6.7%	.
Jemseg complex			
Portobello Cr.	1,350	0.3%	.
Noonan Br.	2,688	0.7%	.
Burpee Mill Str.	2,190	0.5%	.
Little R.	10,160	2.5%	.
Newcastle Cr.	5,220	1.3%	.
Gaspereau R.	18,240	4.5%	.
Salmon R.	16,280	4.0%	.
Coal Cr.	3,720	0.9%	.
Cumberland Bay	1,150	0.3%	.
Youngs Cove	2,300	0.6%	.
Canaan R.	23,870	5.9%	.
Bellisle Cr.	3,900	1.0%	.
Nerepis R.	6,760	1.7%	.
Kennebecasis R.	20,690	5.1%	.
Hammond R.	16,620	4.1%	.
TOTAL BELOW MACTAQUAC	**231,875**	**57.3%**	.
Musquash R.	0	0.0%	2,750
New R.	604	0.1%	.
Pocologan R.	226	0.1%	.
Magaguadavic R.	5,630	1.4%	.
Digdeguash R.	4,220	1.0%	.
Bocabec R.	427	0.1%	.
Waweig R.	556	0.1%	.
Dennis Str.	537	0.1%	.
St. Croix R.	16,183	4.0%	.
TOTAL OUTER FUNDY COMPLEX	**28,383**	**7.0%**	**2,750**
TOTAL DU 16	**404,574**	**100.0%**	**12,964**

Table 3: A summary of the nuclear and thermal generation dams located in DU 16 watersheds.

Name	Tributary	Operating Agency	No. Units	Unit Type	Power Output (MW)	Comment
Point Lepreau[1]	Lepreau	NB Power (1983)	n/a	Nuclear	635	Reactivated in November 2012 after 4 year refurbishment.
Grand Lake Generating Station[1]	Grand Lake	NB Power (1952)	n/a	Coal	57	Decommissioned in 2010.
Coleson Cove Generating Station[1]	Colson Cove (BoF) - near Saint John	NB Power (1976)	3	Heavy fuel oil	978	.
Courtney Bay Generating Station[1]	Courtney Bay (SJR)	NB Power (1961)	4	Fuel oil and Natural Gas	253	Decommissioned in 2008.

[1] NB Power (2007/2008).

Table 4a: Counts of Smallmouth Bass (when identified) at DFO monitoring sites located within the Saint John watershed, 1953- 2011. Note that cells with no data are indicated with a period (.).

						RST - Juveniles		
	Adults - Fishways / Fence					Spring		Fall
Year	**Tobique**	**Beechwood**	**Meduxnekeag**	**Mactaquac**	**Nashwaak**	**Tobique**	**Nashwaak**	**Tobique**
1953	0	.	.	.	.	.	.	.
1954	0	.	.	.	.	.	.	.
1955	0	.	.	.	.	.	.	.
1956	0	.	.	.	.	.	.	.
1957	0	0	.	.	.	.	.	.
1958	0	0	.	.	.	.	.	.
1959	0	0	.	.	.	.	.	.
1960	0	0	.	.	.	.	.	.
1961	0	0	.	.	.	.	.	.
1962	0	0	.	.	.	.	.	.
1963	0	0	.	.	.	.	.	.
1964	0	0	.	.	.	.	.	.
1965	0	0	.	.	.	.	.	.
1966	0	0	.	.	.	.	.	.
1967	0	0	.	.	.	.	.	.
1968	0	0	.	6	.	.	.	.
1969	0	0	.	90	.	.	.	.
1970	0	0	.	40	.	.	.	.
1971	0	0	.	84	.	.	.	.
1972	.	0	.	49	.	.	.	.
1973	.	0	.	93	.	.	.	.
1974	.	0	.	21	.	.	.	.
1975	.	0	.	28	.	.	.	.
1976	.	0	.	7	.	.	.	.
1977	.	0	.	4	.	.	.	.
1978	.	0	.	9	.	.	.	.
1979	.	0	.	15	.	.	.	.
1980	.	0	.	14	.	.	.	.
1981	.	0	.	9	.	.	.	.
1982	.	0	.	8	.	.	.	.
1983	.	.	.	3	.	.	.	.
1984	.	.	.	7	.	.	.	.
1985	.	.	.	2	.	.	.	.
1986	.	.	.	4	.	.	.	.
1987	.	.	.	10	.	.	.	.
1988	.	.	.	11	.	.	.	.
1989	.	.	.	.	.	.	.	.
1990	.	.	.	.	.	.	.	.
1991	.	.	.	.	.	.	.	.
1992	.	.	.	.	.	.	.	.
1993	.	.	45	.	0	.	.	.
1994	4	0	35	41	4	.	.	.
1995	0	114	1	43	.	.	.	.
1996	0	10	1	57	7	.	.	.
1997	0	38	3	25	8	.	.	.
1998	3	11	.	23	1	.	5	.
1999	8	79	.	.	2	.	10	.
2000	5	7	.	.	6	4	14	0
2001	0	116	.	.	7	0	12	0
2002	8	75	.	149	27	5	36	0
2003	3	.	.	.	15	0	10	0
2004	3	102	.	.	30	0	20	1
2005	16	7	.	.	6	0	7	.
2006	7	22	.	.	2	1	9	.
2007	1	26	.	.	2	0	3	.
2008	2	60	.	.	9	0	37	2
2009	.	.	.	5	8	0	5	0
2010	.	.	.	36	5	0	0	49
2011	0	56	.	25	19	0	7	0

Table 4b: Catches of all non-salmon species during electrofishing surveys of OBoF rivers in 2009. Note that cells with no catch are indicated with a period (.).

Location	Tributary	American Eel	Brook Trout	Brown Bullhead	Brown Trout	Burbot	Chain Pickerel	Chubb	Cray Fish	Dace	Fall Fish	Lake Chubb	Pumpkinseed Sunfish	Rainbow Trout	Sea Lamprey	Shiner	Slimy Sculpin	Smallmouth Bass	Stickleback	Sucker	Yellow Perch
Above Mactaquac Dam	Becaguimec	.	86	.	.	9	.	3	.	912	.	.	.	29	.	.	475	.	.	.	.
	Big Presque Isle	.	5	.	.	.	.	1	.	360	.	.	.	.	.	.	2	26	5	6	.
	Bulls Creek	.	23	.	.	.	.	.	.	9	.	.	.	.	.	.	10	.	.	.	.
	Eel	.	5	1	.	.	1	42	.	220	.	.	.	.	.	.	.	5	.	4	.
	Gibson Creek	.	.	.	.	.	.	34	.	80	.	.	.	.	.	.	.	2	.	86	.
	Longs Creek	.	15	.	.	.	.	8	5	294	.	.	.	.	.	.	13	.	.	8	2
	Little Presque Isle	.	.	.	.	.	.	19	.	285	.	.	.	.	.	6	.	2	.	20	.
	Mactaquac Stream	1	7	.	.	.	.	10	3	9	.	.	.	.	.	.	.	.	.	2	.
	Meduxnekeag	.	26	.	15	.	.	.	.	175	.	45	.	.	.	24	283	13	.	12	.
	Mill Stream	.	5	.	.	.	.	.	.	59	.	.	.	.	.	.	.	.	.	1	.
	Monquart	.	2	.	.	.	.	1	.	.	.	.	.	1	.	2	40	1	.	1	.
	Muniac	.	91	.	.	.	.	.	.	3	.	.	.	13	.	.	296	.	.	2	.
	Nackawic	1	.	4	.	1	.	11	.	92	.	.	.	.	.	.	.	2	.	13	.
	Pokiok	1	1	.	.	.	.	10	3	89	.	.	.	.	.	.	.	2	1	1	.
	River de Chute	.	90	.	.	.	.	.	.	.	.	.	.	.	.	.	785	.	.	.	.
	Shogomoc	.	.	.	.	.	.	11	.	10	.	.	3	.	.	.	.	2	.	5	2
	Shikatehawk	.	129	.	.	.	.	.	.	375	.	.	.	23	.	.	720	.	.	2	.
	Salmon (Vic. Co)	.	110	.	.	.	.	.	.	125	.	.	.	.	.	.	530	.	.	.	.
	Stickney Brook	.	6	.	.	.	.	117	.	3	.	.	.	273	.	.	77	.	.	6	.
	Tobique	.	202	.	.	4	.	.	3	925	.	21	.	.	.	.	655	.	.	14	.
	Sub-Total	**3**	**803**	**5**	**15**	**14**	**1**	**267**	**14**	**4025**	**.**	**66**	**3**	**339**	**.**	**32**	**3886**	**55**	**6**	**183**	**4**
Below Mactaquac Dam	Bellisle Creek	24	6	2	.	2	.	8	1	121	.	.	.	.	.	.	.	.	.	2	.
	Burpee Mill	82	68	.	.	.	.	.	.	559	.	.	.	.	3	4	87	.	1	2	.
	Cumberland Bay	65	.	.	.	2	2	31	.	80	.	.	.	.	1	.	.	.	.	6	.
	Coal Creek	22	6	.	.	.	.	13	.	210	.	.	.	.	.	.	.	.	1	8	.
	Canaan	364	91	1	.	2	1	257	.	1136	2	.	.	.	143	261	68	.	7	114	.
	Kennebecasis	.	370	1	.	9	.	2	.	503	.	.	.	.	113	127	1496	.	4	76	.
	Keswick	36	10	.	.	9	.	.	.	184	.	.	.	.	1	.	9	.	.	.	.
	Little River (Sunbury Co.)	40	1	.	.	7	.	3	.	47	.	.	.	.	2	11	.	.	.	.	.
	Nashwaaksis	64	27	.	.	1	.	8	1	163	.	.	.	.	1	.	3	.	.	1	.
	Nerepis	18	.	.	.	1	.	1	.	124	.	.	.	.	.	.	.	.	.	2	.
	Nashwaak	186	62	.	.	3	.	1	2	663	.	.	.	.	.	.	49	.	.	4	.
	Noonan	5	7	.	.	.	.	.	7	63	.	.	.	.	.	.	.	.	.	.	.
	Newcastle Creek	19	28	.	.	.	.	8	.	37	.	.	.	.	.	.	.	.	.	.	.
	Oromocto	143	23	1	.	10	.	82	.	767	.	.	.	.	9	.	.	.	.	23	.
	Salmon River (Queens Co.)	60	7	2	.	.	.	8	.	238	.	.	.	.	4	1	8	.	.	5	.
	Youngs Creek	39	.	3	.	.	1	90	.	97	.	.	.	.	2	.	.	.	.	8	.
	Sub-Total	**1167**	**706**	**10**	**.**	**46**	**4**	**512**	**11**	**4992**	**2**	**.**	**.**	**.**	**279**	**404**	**1720**	**.**	**13**	**251**	**.**
Outer Fundy Complex	Digdeguash	4	.	.	.	.	.	3	.	82	.	.	.	.	.	20	.	.	.	10	.
	Dennis Stream	23	1	.	.	.	.	6	.	230	.	.	.	.	3	20	.	1	.	14	.
	New River	3	1	.	.	.	.	.	.	18	.	.	.	.	.	.	.	.	.	1	.
	Pocologan	3	6	.	.	.	.	1	.	5	.	.	.	.	.	.	.	.	.	.	.
	Waweig	36	9	.	.	.	.	12	.	188	.	.	.	.	.	.	.	.	.	38	.
	Sub-Total	**69**	**17**	**.**	**.**	**.**	**.**	**22**	**.**	**523**	**.**	**.**	**.**	**.**	**3**	**40**	**.**	**1**	**.**	**63**	**.**
	GRAND TOTAL	**1239**	**1526**	**15**	**15**	**60**	**5**	**801**	**25**	**9540**	**2**	**66**	**3**	**339**	**282**	**476**	**5606**	**56**	**19**	**497**	**4**

Table 5: Known attributes of major hydroelectric dams located in the CU 17 drainage. Note that cells with no data are indicated with a period (.).

Name	Tributary	Operating Agency	No. Units	Unit Type	RPM	Total Head (m)	Power Output (MW)	Total unit Capacity (m^3/sec)	Total discharge capacity (m^3/sec)	Storage Area (m^3)	Upstream drainage area (km^2)	Head-pond length (km)	Head-pond area (ha)
Second Falls[1]	Green	Edmunston, N.B.	1	Vertical	280.0	7.5	3.0	63.0	.	800,000	1,100	0.7	50
			2	Horizontal	.	.	.	.	.	.	.	.	.
Edmundston[1]	Madawaska	Fraser Ltd.	2	.	.	6.1	1.5	.	.	.	.	.	.
Grand Falls[1]	Saint John	NB Power (1928)	4	Francis	163.3	39.9	63.0	220.9	3,680	15,860,000	21,900	41.0	1,416
Beechwood[1]	Saint John	NB Power (1957)	3	Kaplan	112.5	16.7	115.0	850.0	9,910	32,602,000	33,500	35.0	1,146
Mactaquac[1]	Saint John	NB Power (1968)	6	Kaplan	112.5	36.6	672.0	2,378.0	21,240	250,028,000	39,900	100.0	8,825
Squapan[2]	Aroostook	Algonquin Power Co. (2010)	1	Propeller	200.0	9.1	1.4	21.2	.	.	.	.	2,042
Caribou[2]	Aroostook	Algonquin Power Co. (2010)	2	Propeller	164.0	3.7	0.9	23.8	.	.	.	.	.
Tinker[2]	Aroostook	Algonquin Power Co. (2010)	1	Kaplan	180.0	25.3	33.5	113.3	.	.	6,060	.	.
			4	Francis	300.0	.	.	.	.	.	.	.	.
Sisson[1]	Tobique	NB Power (1965)	1	Francis	225.0	41.0	10.0	127.5	170	124,560,000			
Tobique Narrows[1]	Tobique	NB Power (1953)	2	Kaplan	225.0	21.5	20.0	128.0	2,605	7,908,000	4,330	16.5	415
Hargrove[1]	Monquart	Hargrove's (1966)	1	.	.	21.0	.	.	.	.	.	.	.
Musquash Hydrogenerating Station[3]	Musquash, East Branch	NBDNR (1922/23)	3	.	.	.	5	.	.	.	.	.	.
SGPLP Hydroelectric Station[4]	Magaguadavic	St. George Power Ltd Partnership (1902)*	2	Kaplan	.	19	15	13-43	260	.	.	.	.
Grand Falls Dam[5]	St. Croix, Baileyville	Woodland Pulp LLC (1915)	.	Francis	<400	14.9	9	.	651	108,546,402	3,419	37.0	7,122
Woodland Dam[5]	St. Croix, Baileyville	Woodland Pulp LLC (1906)	.	Francis and Leffel Twin	270.0	14.6	8	n/a	651	15,418,523	3,496	9.7	486
Cotton Mill Dam[5]	St. Croix, Milltown	NB Power (1881)	7	.	.	7.5	4	n/a	.	.	.	.	.

* References: 1) Carr 2001; 2) USASAC 2011; 3) Thompson 2001; 4) Stantec 2011; 5) J.R. Beaudoin (Woodland Pulp LLC., pers. comm.).

Table 6: Road and crossing densities for OBoF river watersheds.

Basin	Unpaved Crossing Density (#/10km stream)	Paved Crossing Density (#/10km stream)	Total Crossing Density (#/10km stream)	Unpaved Road Density (km/km^2 Basin)	Paved Road Density (km/km^2 Basin)	Total Road Density (km/km^2 Basin)
SJR Tobique-Aroostook Comp	2.97	3.96	6.93	0.84	0.84	1.68
Big PresqueIsle Comp	3.92	2.93	6.85	0.85	0.81	1.66
Meduxnekeag	2.86	3.56	6.42	0.89	0.98	1.87
DeChute Comp	3.33	2.65	5.98	1.00	0.70	1.70
Pokiok	2.34	0.84	3.18	1.07	0.27	1.34
Monquart	3.10	1.51	4.60	1.11	0.32	1.43
Becaguimec	2.80	1.86	4.67	1.12	0.36	1.47
Eel River	2.57	1.09	3.66	1.13	0.33	1.46
SJR Hartland-Beechwood Comp	3.95	4.42	8.37	1.13	1.03	2.16
SJR Nackawic-Hartland Comp	2.79	2.81	5.60	1.14	0.60	1.74
Mactaquac	3.09	1.56	4.65	1.15	0.35	1.50
SJR Aroostook-Gr. Falls Comp	4.07	3.98	8.05	1.28	1.14	2.42
Aroostook	1.74	3.38	5.12	0.60	0.79	1.39
Little Presquile	2.79	3.44	6.23	0.70	0.83	1.53
Muniac Comp	2.40	4.68	7.08	0.73	1.17	1.90
Shogomoc	2.98	0.38	3.37	1.31	0.14	1.45
Nackawic	3.25	1.06	4.31	1.32	0.29	1.62
Shikatehawk	3.16	1.52	4.68	1.51	0.33	1.84
Salmon River (Vic. Co.)	4.77	0.89	5.66	1.75	0.20	1.95
Tobique	3.26	0.48	3.74	2.08	0.09	2.17
Average SJR above Mact.	**3.11**	**2.35**	**5.46**	**1.13**	**0.58**	**1.71**
Nashwaaksis	3.28	1.84	5.12	0.44	1.15	1.60
Hammond	2.31	2.64	4.95	0.73	0.85	1.58
Bellisle	2.57	3.87	6.44	0.82	0.75	1.58
Newcastle Creek	2.67	1.06	3.74	0.90	0.23	1.14
Jemseg Comp	2.85	1.79	4.64	0.96	0.43	1.39
Kennebecasis	2.72	2.91	5.63	0.96	0.76	1.73
Nerepis	3.51	0.58	4.10	1.01	0.17	1.18
Burpee Mill	3.47	0.58	4.05	1.04	0.13	1.17
Youngs Cove	2.83	2.83	5.66	1.05	0.71	1.75
Cumberland Bay	2.51	1.32	3.83	1.05	0.22	1.28
Gaspereau	1.99	0.36	2.35	1.07	0.06	1.13
Noonan Brook	3.46	1.35	4.82	1.09	1.04	2.14
Salmon River (Queens Co.)	2.56	0.72	3.27	1.15	0.13	1.28
Oromocto	2.85	1.25	4.10	1.16	0.31	1.48
Little River	2.87	0.44	3.31	1.21	0.08	1.29
Canaan	2.83	1.18	4.02	1.25	0.25	1.50
Keswick	3.58	1.25	4.84	1.25	0.27	1.51
Coal Creek	3.24	0.37	3.61	1.34	0.10	1.44
Portobello Creek	3.63	0.67	4.29	1.42	0.16	1.59
Nashwaak	3.72	0.89	4.61	1.65	0.20	1.85
Average SJR below Mact.	**2.97**	**1.40**	**4.37**	**1.08**	**0.40**	**1.48**
Digdeguash	2.42	1.07	3.48	0.37	0.89	1.25
Musquash	1.46	0.38	1.84	0.59	0.16	0.75
Pocologan	1.85	2.62	4.47	0.79	0.62	1.40
Waweig	2.86	2.81	5.67	0.81	0.82	1.62
DennisStr	2.83	3.73	6.57	0.88	0.83	1.71
Magaguadavic	2.14	0.67	2.81	1.03	0.18	1.21
Bocabec	3.65	2.70	6.35	1.04	0.72	1.76
New	3.00	0.12	3.13	1.06	0.53	1.59
St. Croix	1.99	0.51	2.50	1.10	0.20	1.29
Average Non-SJR	**2.47**	**1.62**	**4.09**	**0.85**	**0.55**	**1.40**

Table 7: Crown Land licensees in DU 16. Forestry companies hold 25-year renewable licenses in New Brunswick (Crown Lands Network 2004).

License Name	Licensee	% of NB Crown Lands Managed	Origin of Company
License 9 and 10-Carleton License[1]	Nexfor Fraser	17	Massachusetts, USA
License 8-York License	St. Anne Nackawic	5	New York, USA
License 7-Fundy License[1]	J.D. Irving[2]	32	Saint John, NB
License 6-Queen-Charlotte License	J.D. Irving[2]	.	Saint John, NB

[1] License extends beyond DU16 watersheds.
[2] J.D. Irving manages both the Fundy and Queen-Charlotte License which covers 32% of the NB Crown Land.

Table 8: Major landowners in DU 16 estimated percent from NB Aquatic Bioweb Major Landowners map - see figures 8 and 9. Note that cells with no second or third landowner present in the area are indicated with (n/a).

River Tributary	Major Landowners (50-90%)	Est %	2nd Major Landowner (20-50%)	Est %	3rd Major Landowner (1-20%)	Est %
SJR, Upriver of Mactaquac Dam						
Salmon R.	J.D. Irving Ltd	50-60	Carleton-Victoria FPMB	20-30	H.J. Crabbe	20-30
SJR Aroostook-Grand Falls	Carleton-Victoria FPMB	60-70	H.J. Crabbe	30-40	n/a	n/a
Aroostook R.	Carleton-Victoria FPMB	80-90	H.J. Crabbe	10-20	n/a	n/a
Tobique R.	Frasier Paper Ltd.	50-70	Carleton-Victoria FPMB	20-30	H.J. Crabbe/Native Reserve	5-10
Muniac Str.	Carleton-Victoria FPMB	80-90	H.J. Crabbe	10-20	n/a	1-5
River de Chute	Carleton-Victoria FPMB	80-90	H.J. Crabbe	10-20	n/a	1-5
Monquart Str.	Carleton-Victoria FPMB	60-70	Crown Land- Carleton	20-30	H.J. Crabbe	5-10
Shikatehawk Str.	Carleton-Victoria FPMB	20-30	Crown Land- Carleton	20-30	H.J. Crabbe	5-10
Big Presquile Str.	Carleton-Victoria FPMB	80-90	H.J. Crabbe	10-20	n/a	.
Little Presquile Str.	Carleton-Victoria FPMB	70-80	H.J. Crabbe	10-20	Crown Land- Carleton	5-10
SJR Hartland-Beechwood	Carleton-Victoria FPMB	80-90	H.J. Crabbe	10-20	n/a	1-5
Becaguimec Str.	Carleton-Victoria FPMB	70-80	H.J. Crabbe	10-20	Crown Land- Carleton	1-5
Meduxnekeag R.	Carleton-Victoria FPMB	90-100	n/a	n/a	n/a	n/a
Eel R.	St. Anne-Nackawic Pulp Co. Ltd.	30-40	Crown Land- York	30-40	H.J. Crabbe	5-10
Shogomoc R.	Crown Land- York	70-80	J.D. Irving Ltd	10-20	St. Anne-Nackawic Pulp Co. Ltd.	5-10
Pokiok R.	Crown Land- York	60-70	St. Anne-Nackawic Pulp Co. Ltd.	30-40	York-Sudbury-Charlotte FPMB	5-10
Nackawic R.	Crown Land- York	30-40	York-Sudbury-Charlotte FPMB	30-40	J.D. Irving Ltd	5-10
Mactaquac R.	York-Sudbury-Charlotte FPMB	50-60	Crown Land- York	30-40	H.J. Crabbe	10-20
SJR, Downriver of Mactaquac Dam						
Keswick R.	J.D. Irving Ltd	60-70	York-Sudbury-Charlotte FPMB	20-30	H.J. Crabbe	1-5
Nashwaaksis R.	York-Sudbury-Charlotte FPMB	60-70	Crown Land- York	20-30	H.J. Crabbe	1-5
Nashwaak R.	York-Sudbury-Charlotte FPMB	30-40	Crown Land- York	20-30	Crown Land- Fundy	10-20
Oromocto R.	York-Sudbury-Charlotte FPMB	30-40	Crown Land- York	20-30	J.D. Irving Ltd	10-20
Jemseg R.	Crown Land- Eastern Habitat Joint Venture Lands	50-60	Southern NB FPMB	40-50	n/a	n/a
Portobello Cr. Gr. Lk	York-Sudbury-Charlotte FPMB	40-50	DND- Military Base	20-30	Crown Land- Fundy	10-20
Noonan Br., Gr. Lk	York-Sudbury-Charlotte FPMB	30-40	H.J. Crabbe	20-30	J.D. Irving Ltd	5-10
Burpee Mill Str., Gr. Lk.	DND- Military Base	40-50	York-Sudbury-Charlotte FPMB	10-20	Crown Land- Fundy	10-20
Little R. Gr Lk	Crown Land- Fundy	50-60	York-Sudbury-Charlotte FPMB	30-40	J.D. Irving Ltd	1-5
Newcastle Cr., Gr. Lk	Crown Land- Fundy	50-60	York-Sudbury-Charlotte FPMB	30-40	n/a	n/a
Gaspereau R. Gr. Lk	Crown Land- Queen-Charlotte	70-80	Southern NB FPMB	20-30	J.D. Irving Ltd	5-10
Salmon R. Gr. Lk	Crown Land- Queen-Charlotte	70-80	Southern NB FPMB	20-30	J.D. Irving Ltd	1-5
Coal Cr., Gr. Lk.	Crown Land- Queen-Charlotte	40-50	Southern NB FPMB	40-50	J.D. Irving Ltd	1-5
Cumberland Bay Gr. Lk	Southern NB FPMB	50-60	Crown Land- Queen-Charlotte	40-50	J.D. Irving Ltd	1-5
Youngs Cove Gr. Lk.	Southern NB FPMB	60-70	Crown Land- Fundy	30-40	J.D. Irving Ltd	1-5
Canaan R.	Crown Land- Fundy	50-60	Southern NB FPMB	30-40	J.D. Irving Ltd	5-10
Bellisle Cr.	Southern NB FPMB	90-95	J.D. Irving Ltd	1-5	n/a	n/a
Nerepis R.	DND- Military Base	80-90	Southern NB FPMB	10-20	J.D. Irving Ltd	1-5
Kennebecasis R.	Southern NB FPMB	70-80	J.D. Irving Ltd	10-20	Crown Land- Fundy	1-5
Hammond R.	Southern NB FPMB	80-90	J.D. Irving Ltd	10-20	n/a	n/a
Rivers in Outer Fundy Complex (DU16)						
Musquash R.	Crown Land- Fundy	60-70	Southern NB FPMB	30-40	J.D. Irving Ltd	1-5
New R.	Crown Land- Queen-Charlotte	50-60	J.D. Irving Ltd	20-30	Crown Land- Provincial Park	10-20
Pocologan R.	Crown Land- Queen-Charlotte	40-50	J.D. Irving Ltd	30-40	York-Sudbury-Charlotte FPMB	10-20
Magaguadavic R.	Crown Land- Queen-Charlotte	50-60	York-Sudbury-Charlotte FPMB	20-30	J.D. Irving Ltd	10-20
Digdeguash R.	York-Sudbury-Charlotte FPMB	50-60	Crown Land- Queen-Charlotte	30-40	J.D. Irving Ltd	1-5
Bocabec R.	Crown Land- Queen-Charlotte	30-40	York-Sudbury-Charlotte FPMB	30-40	J.D. Irving Ltd	10-20
Waweig R.	York-Sudbury-Charlotte FPMB	50-60	Crown Land- Queen-Charlotte	30-40	J.D. Irving Ltd	10-20
Dennis Str.	York-Sudbury-Charlotte FPMB	80-90	Crown Land- Queen-Charlotte	10-20	n/a	n/a
St. Croix R.	York-Sudbury-Charlotte FPMB	50-60	Crown Land- Queen-Charlotte	30-40	St. Anne-Nackawic Pulp Co. Ltd.	1-5

Notes: FPMB = Forest Products Marketing Board.

Table 9: Summary of bacteriology and virology screening of wild and escaped cultured salmon collected in the Magaguadavic River fish ladder, 1992-2012 (provided by the Atlantic Salmon Federation). Note that cells with no data are indicated with a period (.).

Year	Origin	Bacteriology										Virology			
		# sample	**No. with Pathogens**	Aeromonas	Pseudeomonas	Vibrio	BKD	IPN	Edwardsella tarda	HKS*	*Flavobacter sp.*	**# sample**	**No. with Pathogens**	ISA	Cytopathic Effect (*Herpeviridae*)
1992	Wild	7	3	2	1	1	.	.	.	.	.	0	0	.	.
	Cultured	0	0	.	.	.	.	.	.	.	.	0	0	.	.
1993	Wild	2	0	1	1	.	.	.	.	.		0	0	.	.
	Cultured	2	1	1	.	.	.	.	.	.	.	0	0	.	.
1994	Wild	1	0	1	.	.	.	.	.	.	.	0	0	.	.
	Cultured	23	17	4	.	2	.	.	.	.	.	0	0	.	.
1995	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	99	74	13	11	.	.	.	1	.	.	61	61	.	.
1996	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	0	0	.	.	.	.	.	.	.	.	0	0	.	.
1997	Wild	3	3	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	15	4	10	.	1	.	.	.	.	.	0	0	.	.
	Cultured	34	29	.	.	.	.	.	.	5	.	0	0	.	.
	Cultured	0	0	.	.	.	.	.	.	.	.	19	19	.	.
1998	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	60	59	.	.	.	1	.	.	.	.	60	60	.	.
1999	Wild	20	6	.	.	.	.	.	.	.	.	20	6	14	.
	Cultured	58	56	.	.	.	1	1	.	.	.	58	54	4	.
2000	Wild	1	1	.	.	.	.	.	.	.	.	7	7	.	.
	Cultured	28	28	.	.	.	.	.	.	.	.	28	28	.	.
2001	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	132	132	.	.	.	.	.	.	.	.	132	132	.	.
2002	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	34	34	.	.	.	.	.	.	.	.	34	34	.	.
2003	Wild	1	1	.	.	.	.	.	.	.	.	1	0	.	.
	Cultured	12	11	.	.	.	.	1	.	.	.	12	11	1	.
2004	Cultured	17	15	.	.	.	1	.	.	.	.	17	16	1	.
2005	Cultured	50	50	.	.	.	.	.	.	.	.	50	50	.	.
2006	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	8	8	.	.	.	.	.	.	.	.	8	8	.	.
2007	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	5	5	.	.	.	.	.	.	.	.	5	5	.	.
2008	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	5	5	.	.	.	.	.	.	.	.	5	5	.	.
2009	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	16	16	.	.	.	.	.	.	.	.	16	16	.	.
2010	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	29	29	.	.	.	.	.	.	.	.	29	27	.	2
2011	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	17	17	.	.	.	.	.	.	.	.	17	16	.	1
2012	Wild	0	0	.	.	.	.	.	.	.	.	0	0	.	.
	Cultured	11	10	.	.	.	.	.	.	.	.	11	11	.	.
1992-2012 totals	Wild	35	14	4	2	1	0	0	0	0	0	28	14	14	0
	Cultured	564	509	28	11	3	3	2	1	5	0	469	468	6	3

*HKS= Hemorrhagic Kidney Syndrome, later termed Infectious Salmon anemia virus (ISA).

Table 10: Estimated losses and estimated proportion of 2SW returns to SFA 23 (or OBoF origin), which are captured in the West Greenland fishery. Note that cells with no data are indicated with a period (.).

Year	2SW Returns to North America	2SW Returns to SFA 23	Prop. SFA 23 in North America	2SW catch of North America at West Greenland (year of fishery)	SFA 23-at Greenland (in year of return)	SFA 23-equivalents (corrected for 10 months of M)	Loss of Potential 2SW Returns
1970	166,700	10,590	0.064	.	.	.	.
1971	110,500	8,843	0.080	274,800	.	.	.
1972	139,600	9,615	0.069	206,100	18,927	14,021	59.3%
1973	146,700	5,117	0.035	259,400	7,189	5,326	51.0%
1974	200,300	12,880	0.064	215,100	16,680	12,357	49.0%
1975	166,600	15,830	0.095	270,400	20,438	15,141	48.9%
1976	161,800	17,290	0.107	157,100	28,895	21,406	55.3%
1977	218,300	20,430	0.094	198,400	14,702	10,892	34.8%
1978	150,700	9,763	0.065	144,300	12,853	9,522	49.4%
1979	74,970	6,187	0.083	197,300	11,909	8,822	58.8%
1980	221,300	22,940	0.104	168,200	20,452	15,151	39.8%
1981	153,500	13,140	0.086	224,200	14,398	10,667	44.8%
1982	148,100	11,830	0.080	202,900	17,909	13,267	52.9%
1983	118,400	11,740	0.099	37,320	20,119	14,904	55.9%
1984	115,700	19,170	0.166	45,130	6,183	4,581	19.3%
1985	132,500	20,190	0.152	137,800	6,877	5,094	20.1%
1986	160,200	12,080	0.075	171,800	10,391	7,698	38.9%
1987	125,900	8,481	0.067	172,200	11,573	8,573	50.3%
1988	133,500	5,700	0.043	118,000	7,352	5,447	48.9%
1989	113,200	8,011	0.071	60,690	8,351	6,186	43.6%
1990	117,900	6,692	0.057	72,630	3,445	2,552	27.6%
1991	108,400	8,949	0.083	110,700	5,996	4,442	33.2%
1992	121,600	8,346	0.069	41,460	7,598	5,629	40.3%
1993	109,200	4,582	0.042	2,633	1,740	1,289	22.0%
1994	95,950	3,289	0.034	2,628	90	67	2.0%
1995	126,400	3,720	0.029	26,680	77	57	1.5%
1996	109,600	5,062	0.046	26,900	1,232	913	15.3%
1997	88,440	2,972	0.034	18,150	904	670	18.4%
1998	63,430	1,506	0.024	6,011	431	319	17.5%
1999	67,230	2,508	0.037	8,962	224	166	6.2%
2000	68,810	1,097	0.016	8,251	143	106	8.8%
2001	79,070	2,108	0.027	11,970	220	163	7.2%
2002	50,140	516	0.010	4,484	123	91	15.0%
2003	76,020	1,127	0.015	4,833	66	49	4.2%
2004	73,430	1,471	0.020	6,035	97	72	4.6%
2005	74,630	911	0.012	5,816	74	55	5.7%
2006	71,520	1,046	0.015	6,862	85	63	5.7%
2007	67,560	676	0.010	9,203	69	51	7.0%
2008	72,580	927	0.013	10,500	118	87	8.6%
2009	86,380	1,686	0.020	9,279	205	152	8.3%
2010	66,710	910	0.014	12,190	127	94	9.3%
2011	140,700	2,874	0.020	8,700	249	184	6.0%

Table 11: Assessed cumulative threat impact for each OBoF river (Highest concern threats = darkest shading). Note that a period (.) indicates threat not applicable to river.

River	Hydro dams	Fishing Illegal	Salmonid aquaculture	Diseases and parasites	Other dams	Silt and sediment	Contaminants	Invasive species (Fish)	Crossing Infrastructure	Forestry	Urbanization	Agriculture	Historical Stocking	aquaculture hatcheries	FW Fishery by-catch	Invasive Species (other)	Stocking Recent	Native Salmonid stocking	Military activities	Non-hydro power generation	Acidification	Mining	Research/sampling	Impact score
Big Presquile	HH	LH	MH	MH	MM	MM	MM	MM	HM	MM	MM	HM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**3.136**
Little Presquile	HH	LH	MH	MH	MM	MM	MM	MM	HM	MM	MM	HM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**3.136**
SJR Hartland to Beechwood	HH	LH	MH	MH	.	MM	HM	HM	HM	MM	HM	MM	MM	HM	.	U	LL	.	.	LL	LL	.	.	**3.318**
Becaguimec	HH	LH	MH	MH	.	MM	U	MM	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.619**
Meduxnekeag	HH	LH	MH	MH	MM	MM	MM	MM	HM	MM	MM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**3.045**
Eel	HH	LH	MH	MH	MM	MM	U	MM	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.810**
Shogomoc	HH	LH	MH	MH	LM	MM	U	MM	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.714**
Pokiok	HH	LH	MH	MH	.	MM	U	MM	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.619**
Nackawic	HH	LH	MH	MH	HM	MM	MM	U	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.905**
Mactaquac	HH	LH	MH	MH	LM	MM	U	U	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.650**
Salmon	HH	LH	MH	MH	LM	MM	U	U	HM	HM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.850**
SJR Aroostook to Grand Falls	HH	LH	MH	MH	.	MM	HM	MM	HM	MM	HM	HM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**3.136**
Aroostook	HH	LH	MH	MH	MM	MM	MM	U	HM	MM	MM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**3.000**
Tobique	HH	HH	MH	MH	HM	MM	U	LM	MM	HM	LM	MM	HM	LM	.	ML	LL	.	.	LL	LL	.	LL	**3.273**
Muniac Str.	HH	LH	MH	MH	.	MM	U	LM	HM	MM	HM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.810**
River de Chute	HH	LH	MH	MH	.	MM	U	U	HM	MM	MM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.750**
Monquart	HH	LH	MH	MH	HM	MM	U	LM	MM	MM	LM	MM	MM	LM	.	U	LL	.	.	LL	LL	.	.	**2.810**
Shikatehawk	HH	LH	MH	MH	LM	MM	U	MM	MM	HM	LM	MM	MM	LM	.	ML	LL	.	.	LL	LL	.	.	**2.773**
Keswick	.	LH	MH	MH	.	HM	U	U	MM	MM	LM	MM	LM	LM	LL	U	.	.	.	ML	LL	.	.	**2.150**
Nashwaaksis	.	LH	MH	MH	.	HM	U	U	HM	LM	HM	MM	LM	LM	LL	U	.	.	.	ML	LL	.	.	**2.350**
Nashwaak	.	HH	MH	MH	LM	HM	U	LM	MM	HM	LM	MM	MM	LM	LL	U	.	.	.	ML	LL	LL	LL	**2.810**
Oromocto	.	LH	MH	MH	MM	MM	U	U	MM	MM	LM	MM	LM	LM	ML	U	.	.	ML	ML	LL	.	.	**2.400**
Jemseg R.	.	LH	MH	MH	.	MM	HM	LM	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.318**
Youngs Cove Gr. Lk.	.	LH	MH	MH	.	MM	HM	LM	HM	MM	MM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.500**
Portobello Gr. Lk	.	LH	MH	MH	.	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.429**
Noonan Gr. Lk	.	LH	MH	MH	.	HM	HM	U	MM	MM	HM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.619**
Burpee Mill Gr. Lk.	.	LH	MH	MH	LM	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.524**
Little Gr Lk	.	LH	MH	MH	.	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.429**
Newcastle Gr. Lk	.	LH	MH	MH	.	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.429**
Gaspereau Gr. Lk	.	LH	MH	MH	.	HM	HM	U	LM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	ML	.	.	**2.381**
Salmon Gr. Lk	.	LH	MH	MH	.	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.429**
Coal Gr. Lk.	.	LH	MH	MH	.	HM	HM	U	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.429**
Cumberland Bay Gr. Lk	.	LH	MH	MH	.	MM	HM	LM	MM	MM	LM	MM	LM	LM	LL	U	.	ML	.	ML	LL	.	.	**2.318**
Canaan	.	LH	MH	MH	.	MM	MM	MM	MM	MM	LM	MM	LM	LM	.	U	.	.	.	ML	ML	.	.	**2.227**
Bellisle	.	LH	MH	MH	.	MM	U	U	HM	MM	MM	MM	LM	LM	.	U	.	.	.	ML	LL	.	.	**2.200**
Nerepis	.	LH	MH	MH	.	HM	MM	U	MM	MM	LM	MM	LM	LM	.	U	.	.	HL	ML	LL	.	.	**2.333**
Kennebecasis	.	HH	MH	MH	.	MM	MM	LM	HM	MM	MM	HM	LM	HM	.	U	.	.	.	ML	LL	LL	.	**2.864**
Hammond	.	LH	MH	MH	.	MM	MM	MM	MM	MM	MM	MM	LM	LM	.	U	.	.	.	ML	ML	ML	.	**2.409**

River	Hydro dams	Fishing Illegal	Salmonid aquaculture	Diseases and parasites	Other dams	Silt and sediment	Contaminants	Invasive species (Fish)	Crossing Infrastructure	Forestry	Urbanization	Agriculture	Historical Stocking	aquaculture hatcheries	FW Fishery by-catch	Invasive Species (other)	Stocking Recent	Native Salmonid stocking	Military activities	Non-hydro power generation	Acidification	Mining	Research/sampling	Impact score
Musquash	HH	LH	HH	HH	HM	LM	U	LM	LM	MM	LM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.842**
New	.	LH	HH	HH	.	MM	U	U	MM	MM	MM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.389**
Pocologan	.	LH	HH	HH	LM	LM	U	U	MM	MM	MM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.389**
Magaguadavic	HH	HH	HH	HH	HM	MM	HM	MM	LM	MM	LM	LM	HM	HM	LL	U	LL	.	.	LL	ML	ML	LL	**3.909**
Digdeguash	.	LH	HH	HH	.	LM	LM	LM	MM	LM	MM	LM	LM	LM	LL	U	.	.	.	LL	ML	.	.	**2.136**
Bocabec	.	LH	HH	HH	.	MM	U	LM	HM	MM	MM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.474**
Waweig	.	LH	HH	HH	.	MM	U	U	HM	MM	MM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.500**
Dennis	.	LH	HH	HH	.	MM	MM	MM	HM	MM	MM	U	LM	LM	LL	U	.	.	.	LL	U	.	.	**2.650**
St. Croix	HH	LH	HH	HH	HM	MM	MM	HM	LM	MM	LM	LM	HM	HM	LL	U	.	.	.	LL	ML	.	.	**3.455**

FIGURES

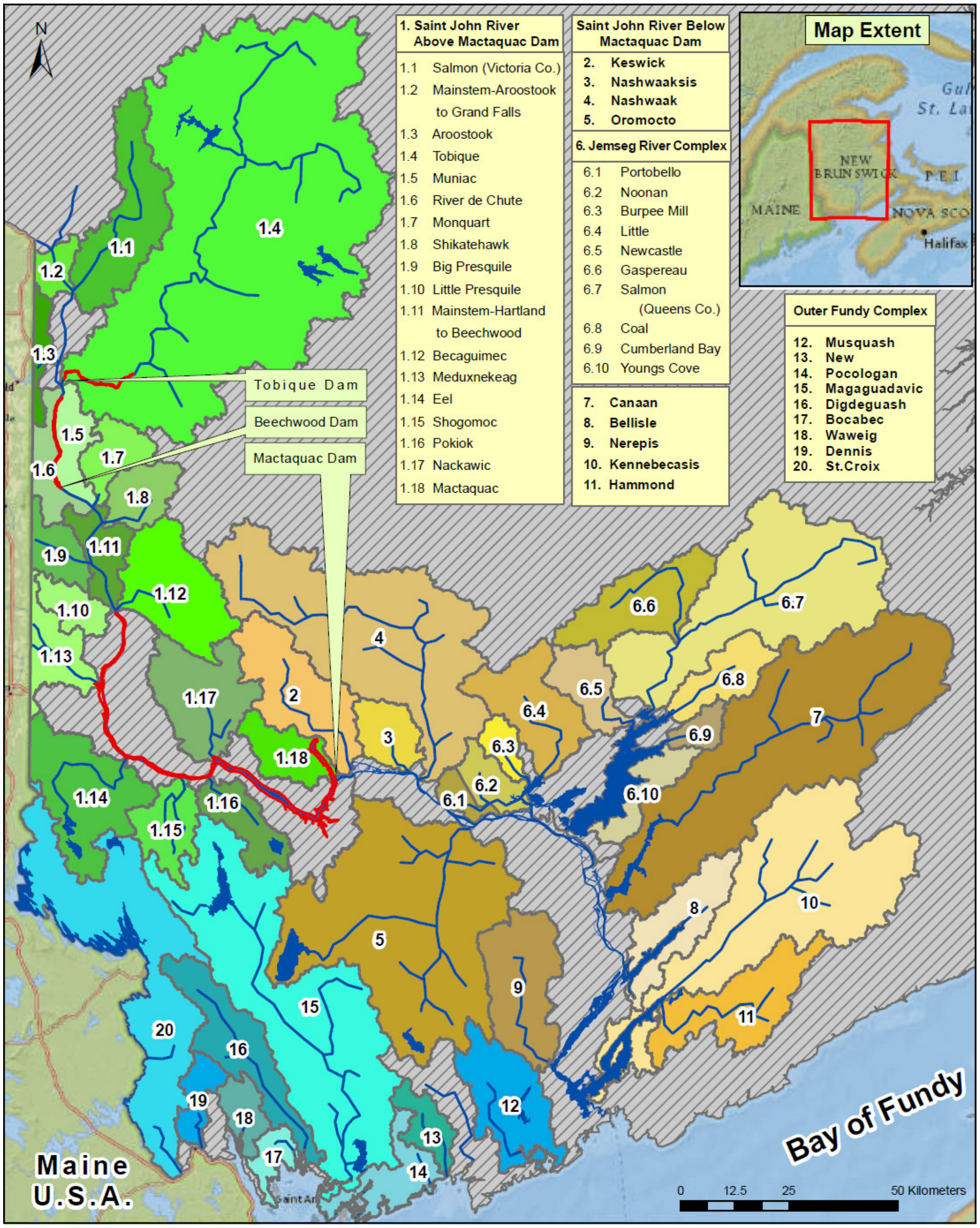


Figure 1: Twenty rivers considered in the OBoF DU including 16 tributary rivers and two mainstem sections of the SJR above Mactaquac Dam and ten tributaries of the Jemseg River complex. SJR tributary rivers above Mactaquac Dam are shaded green, rivers below Mactaquac Dam draining to the SJR are shaded brown and rivers of the Outer Fundy complex are shaded blue. Major headpond areas are outlined in red.

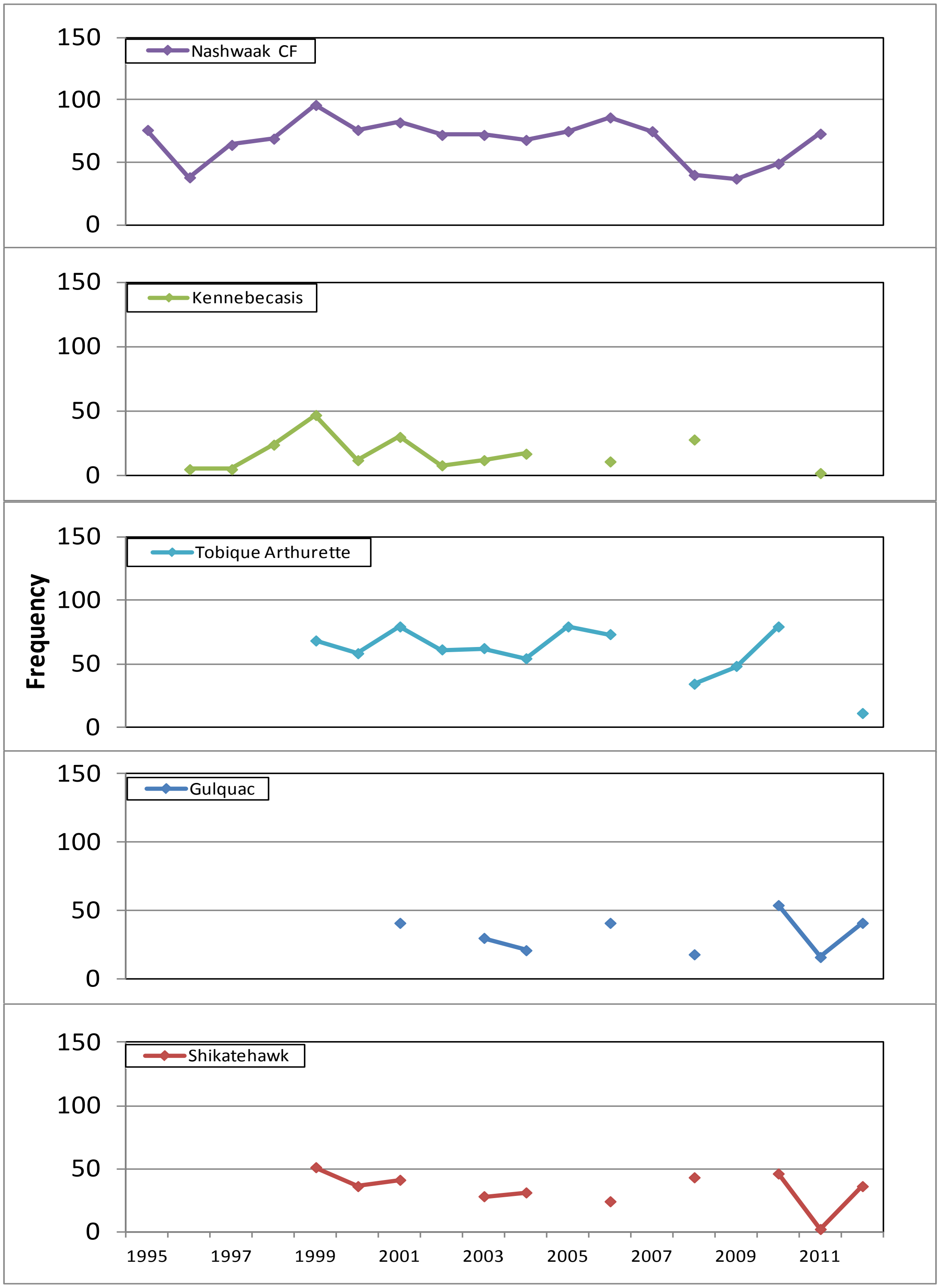
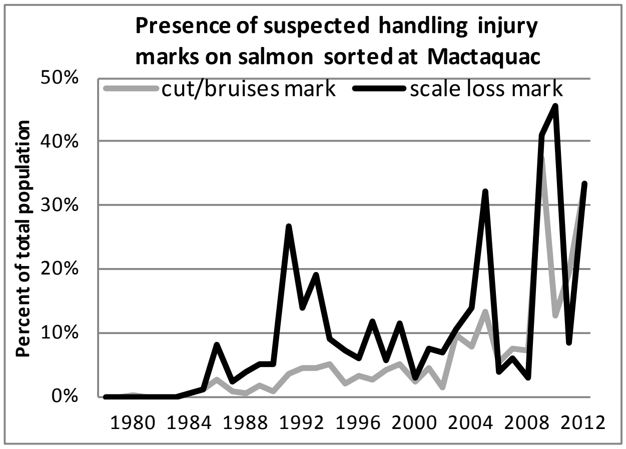


Figure 2: Frequency of days per year where minimum water temperature was 20°C or greater recorded at the Nashwaak, Kennebecasis, Tobique (at Arthurette), Gulquac (tributary of Tobique) and Shikatehawk rivers, between 1995 and 2012. (Gaps indicate unavailable data).



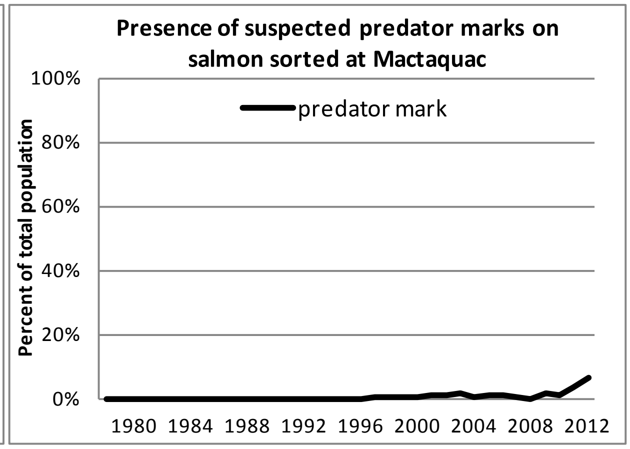


Figure 3: The percentage of the total population with a fish condition noted while sorting Atlantic Salmon at the Mactaquac Biodiversity Facility between 1978 and 2012. (Left) Suspected cuts/bruises and scale loss scars (both healed and new) were grouped to show possible trends in injuries likely sustained when encountering obstructions (e.g., collection facility at Mactaquac dam, difficult passage due to low water) or factors associated with the obstructions (e.g., salmon crowded with abundance of Gaspereau at collection facility) and (right) predator marks (both healed and new) encompass wounds suspected from large predatory fish (e.g., sharks), birds of prey (e.g., eagle), and marine mammals (e.g., seal).

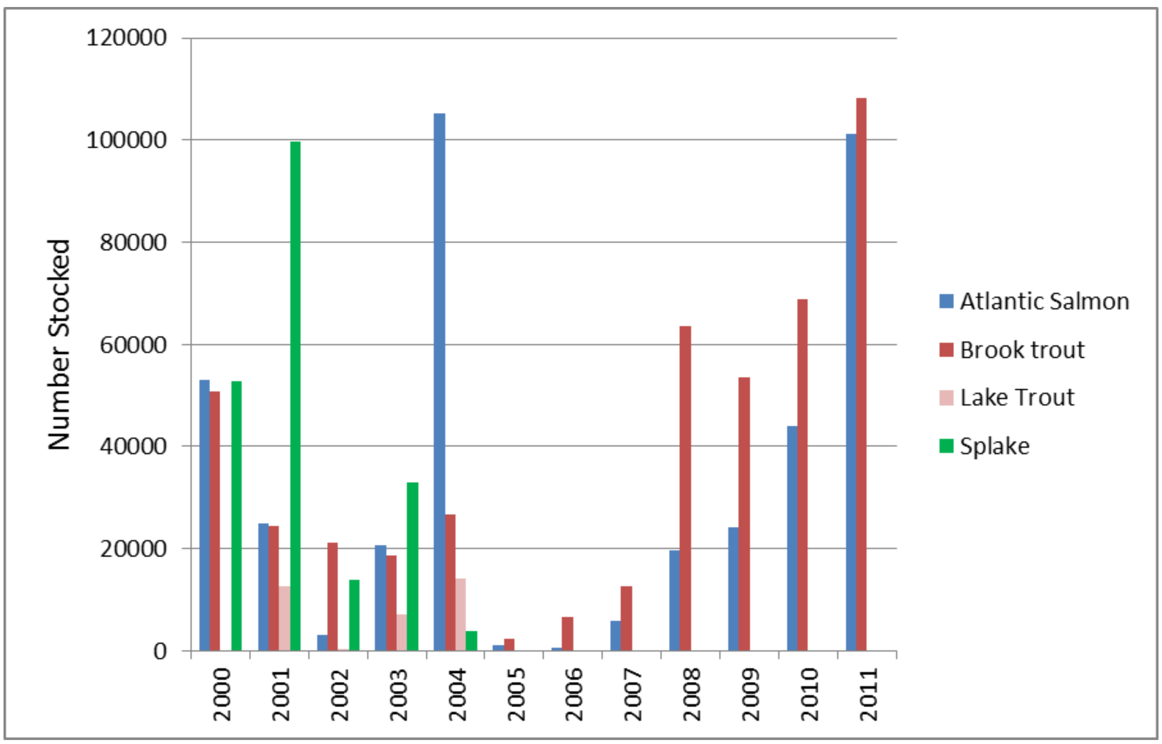


Figure 4: Summary of NBDNR Salmonid stockings to inland waters of counties containing OBoF watersheds (Madawaska, Victoria, Carleton, York, Sunbury, Kings, Queens, St. John, Charlotte) from 2000 to 2011. Data provided by NBDNR (2012).

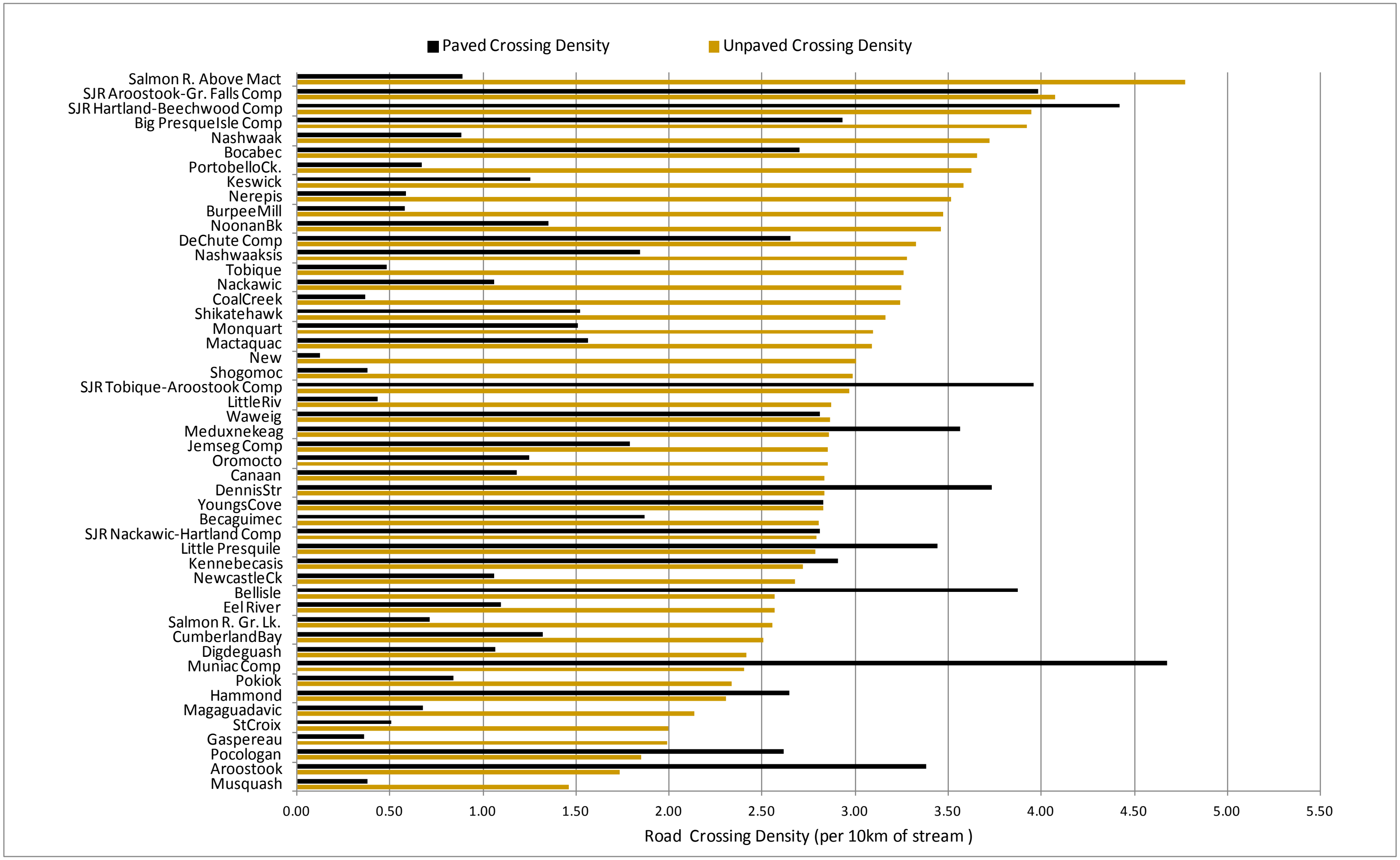


Figure 5: Road crossing density (#/10 km of stream) by road surface for OBoF watersheds including tributaries of the SJR above Mactaquac Dam. Ordered by unpaved crossing density. Produced from spatial data courtesy of NBDNR.

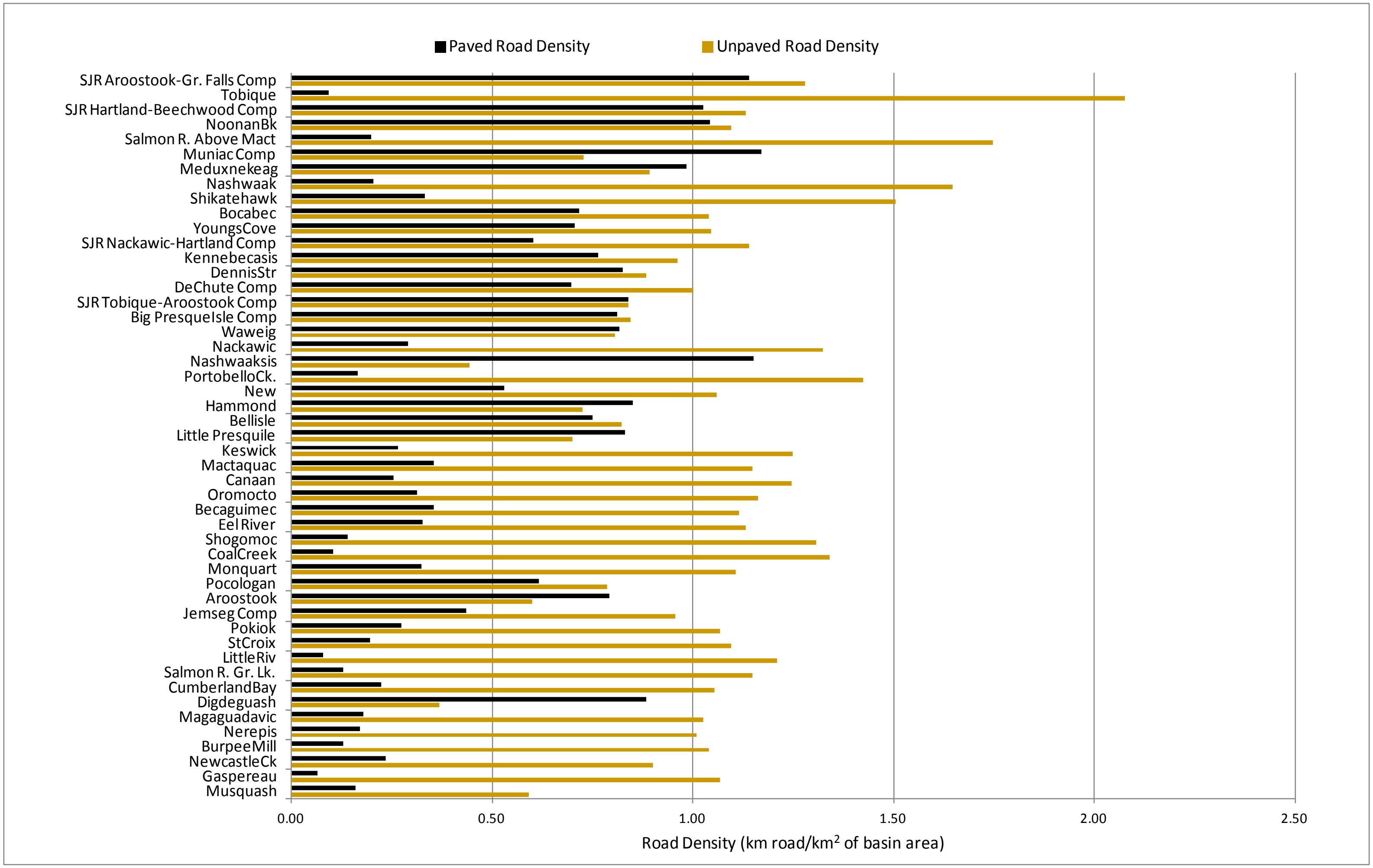


Figure 6: Road density (km per km^2 of basin area) by road surface for OBoF watersheds including tributaries of the SJR above Mactaquac Dam. Ordered by combined road density. Produced from spatial data courtesy of NBDNR.

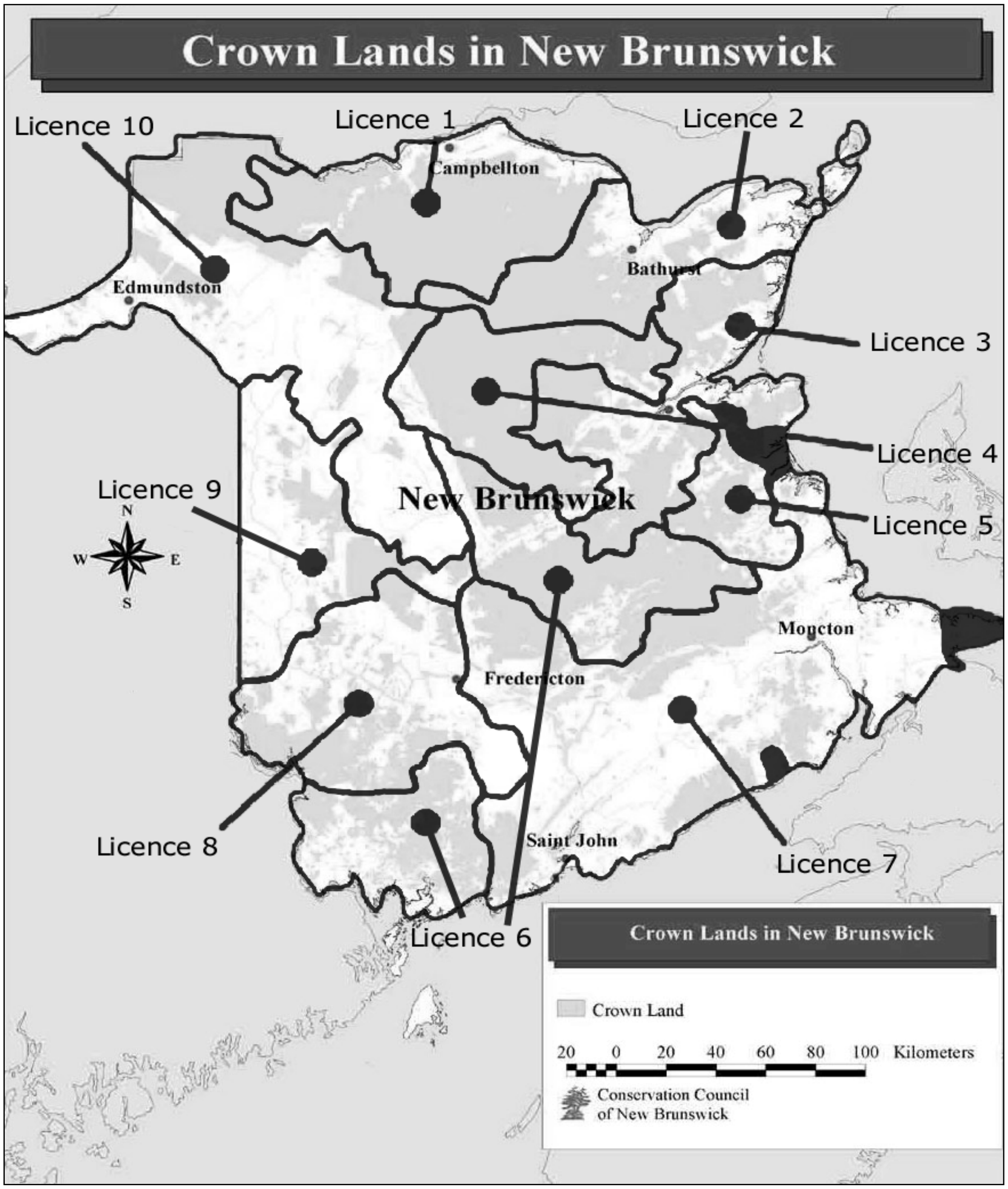


Figure 7: Map of crown land licenses in New Brunswick (Crown Land Network 2009/10).

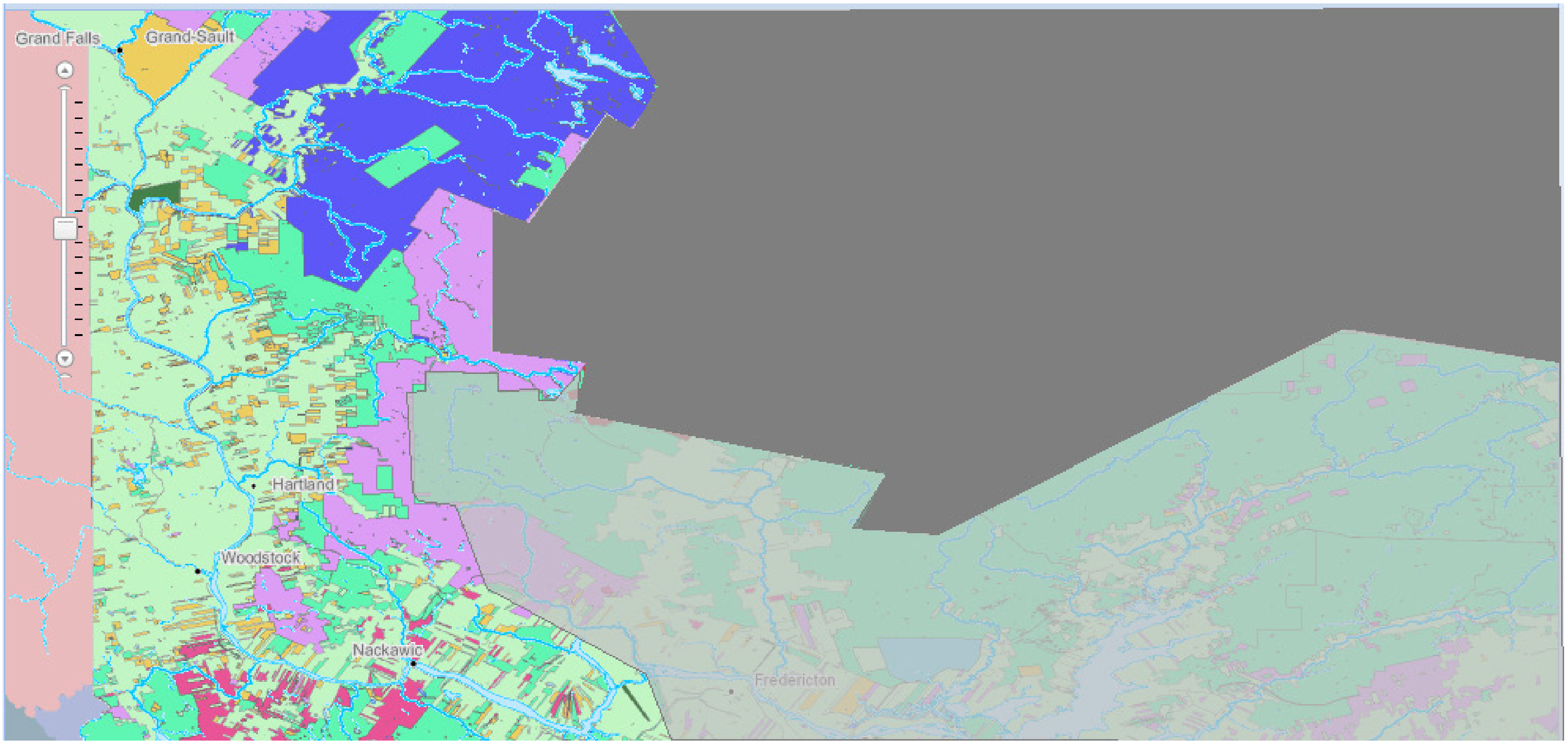


Figure 8: Maps depicting the landowner blocks in OBoF watersheds above Mactaquac Dam (NB Aquatic Bioweb). H.J. Crabbe, Fraser Paper Ltd., St. Anne-Nackawic Pulp Co., J.D. Irving Ltd., Crown Lands, Forest Products Marketing Boards, Dept. of National Defense.

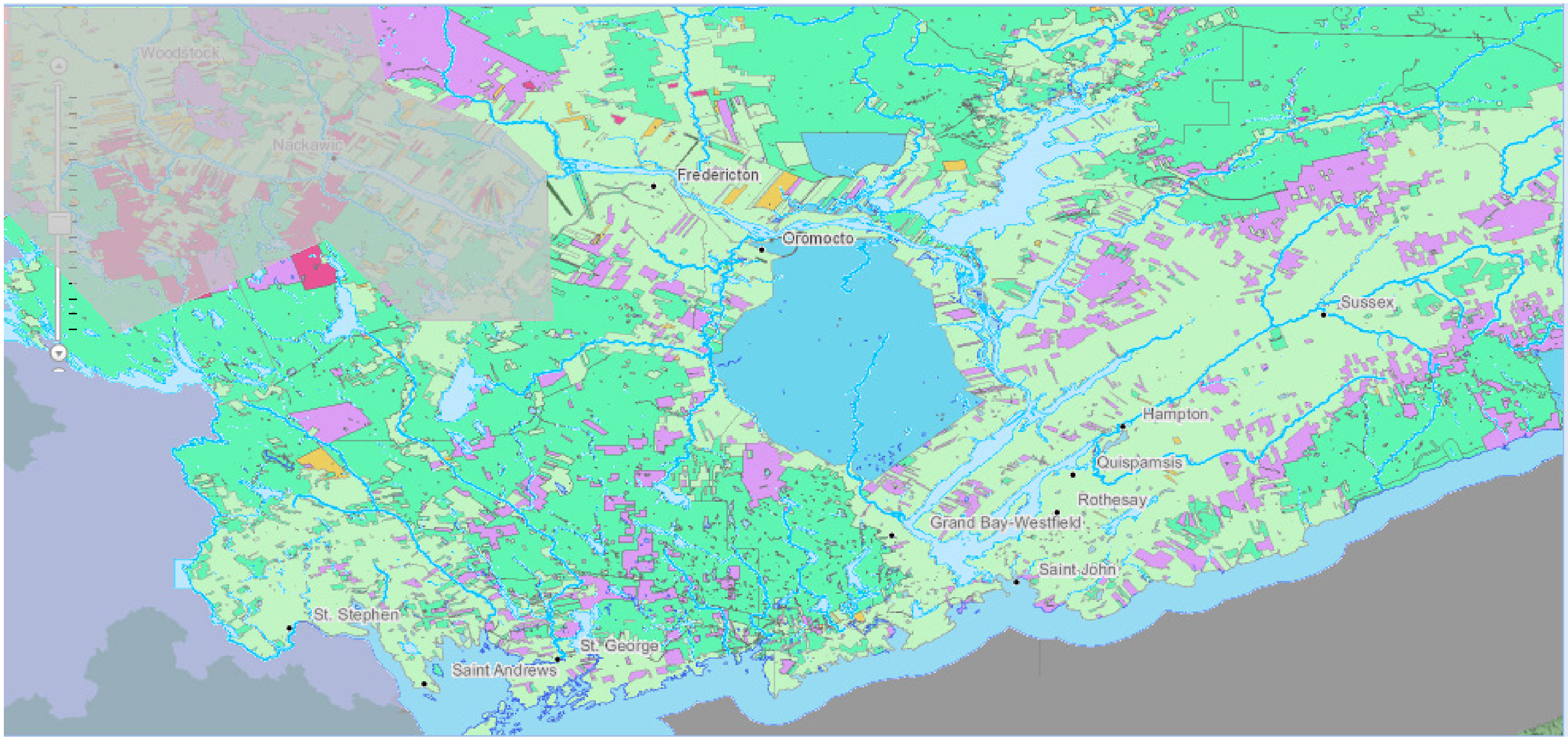


Figure 9: Maps depicting the landowner blocks in the section below Mactaquac Dam and for the Outer Fundy Complex rivers (NB Aquatic Bioweb). H.J. Crabbe, Fraser Paper Ltd., St. Anne-Nackawic Pulp Co., J.D. Irving Ltd., Crown Lands, Forest Products Marketing Boards, Dept. of National Defense.

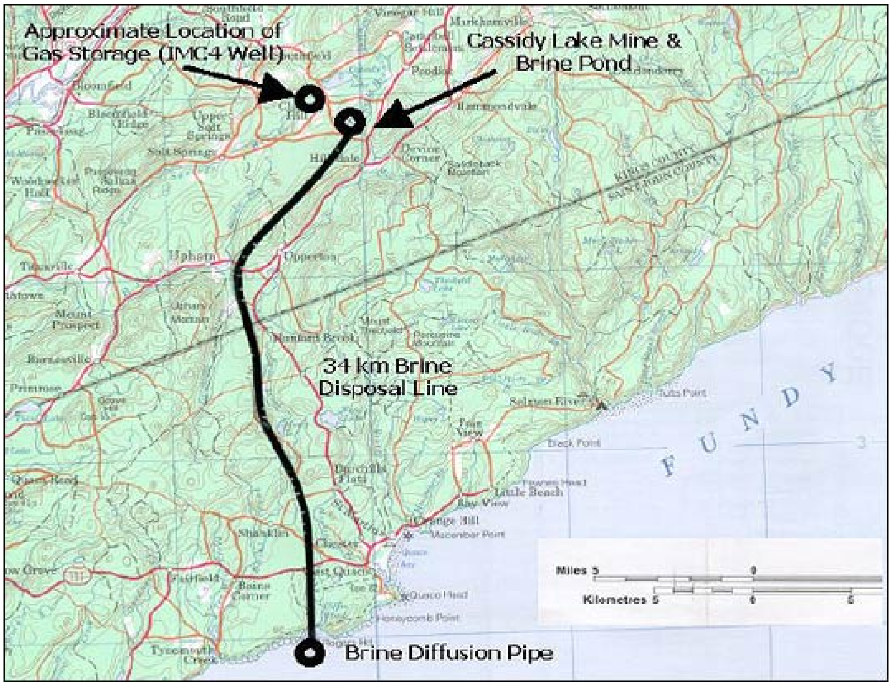


Figure 10: Sketch of southern NB and approximate location of potash brine disposal pipeline from Cassidy Lake, NB, to the Bay of Fundy

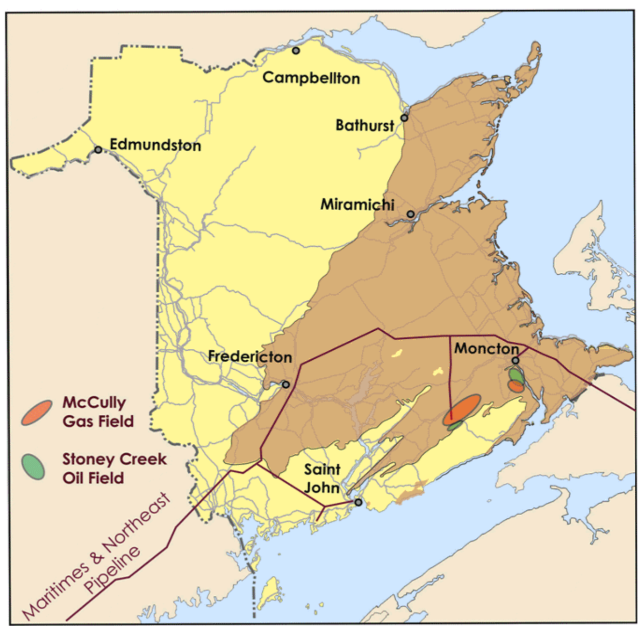
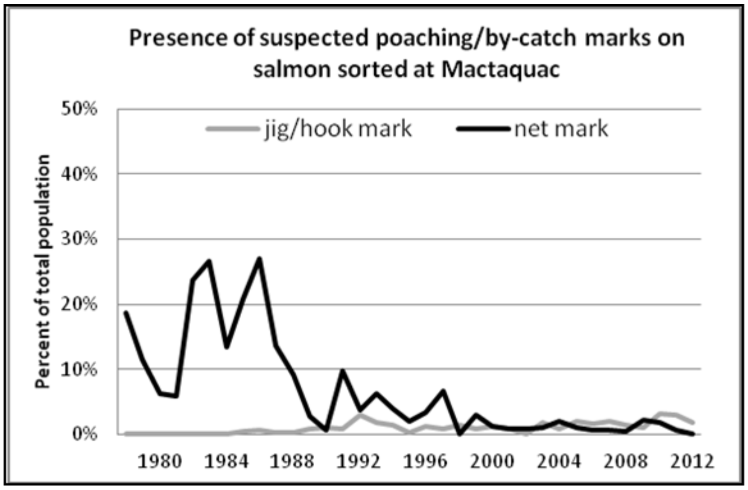
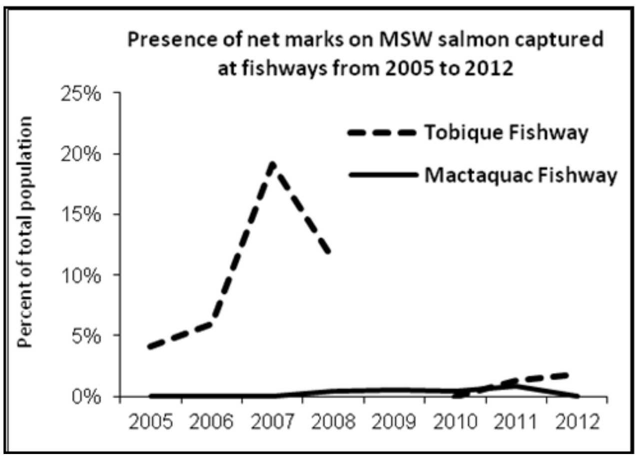


Figure 11: Distribution of the Maritimes Basin sedimentary rocks in New Brunswick (yellow). Gas-bearing shale units may be found at depth in these rocks. The McCully gas field is indicated by the orange and the Stoney Creek oil field by the green; these produced oil and gas from 1909 to 1991 and oil production again in 2007 (figure from New Brunswick Department of Energy and Mines: Oil and Natural Gas History).





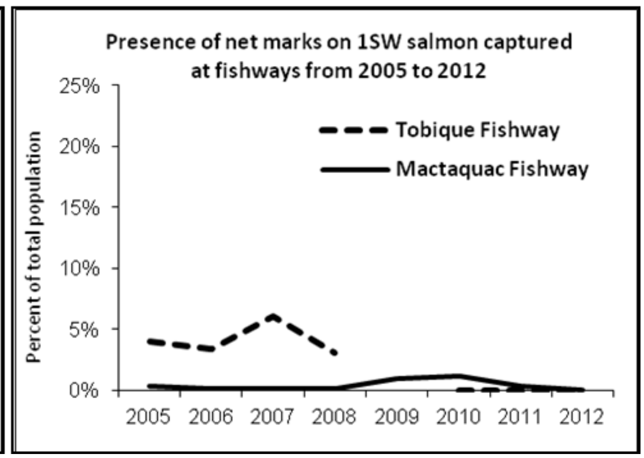


Figure 12: The percentage of the population with suspected jig/hook and net marks (both healed and new) observed while sorting Atlantic Salmon at the Mactaquac Biodiversity Facility during 1978-2012 and Tobique Narrows fishway during 2005-2012.

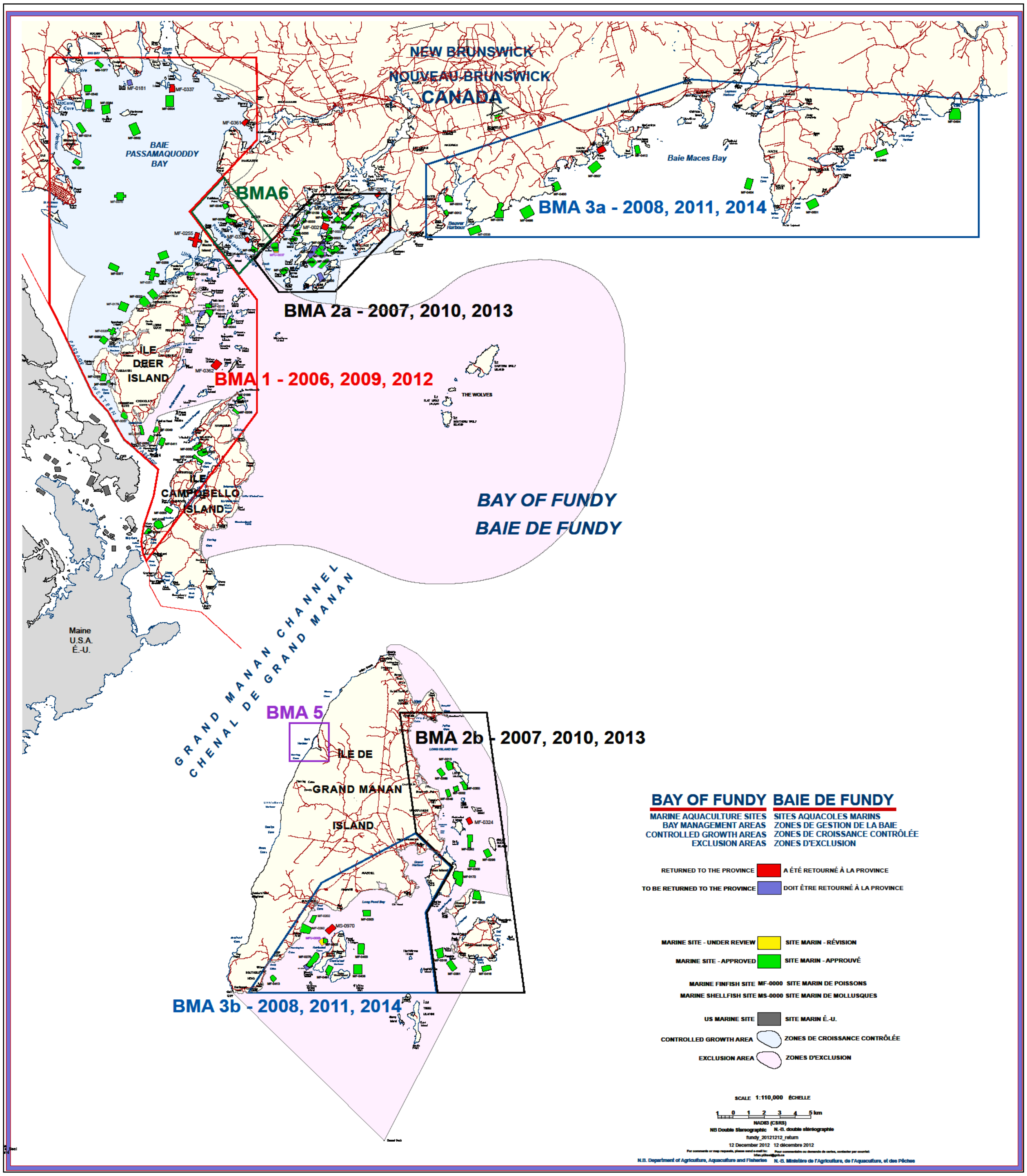


Figure 13: Locations of Bay Management Areas (BMA) and marine aquaculture sites in the Quoddy region of the Bay of Fundy (southwestern NB). Courtesy of the NBDAAF (2013).

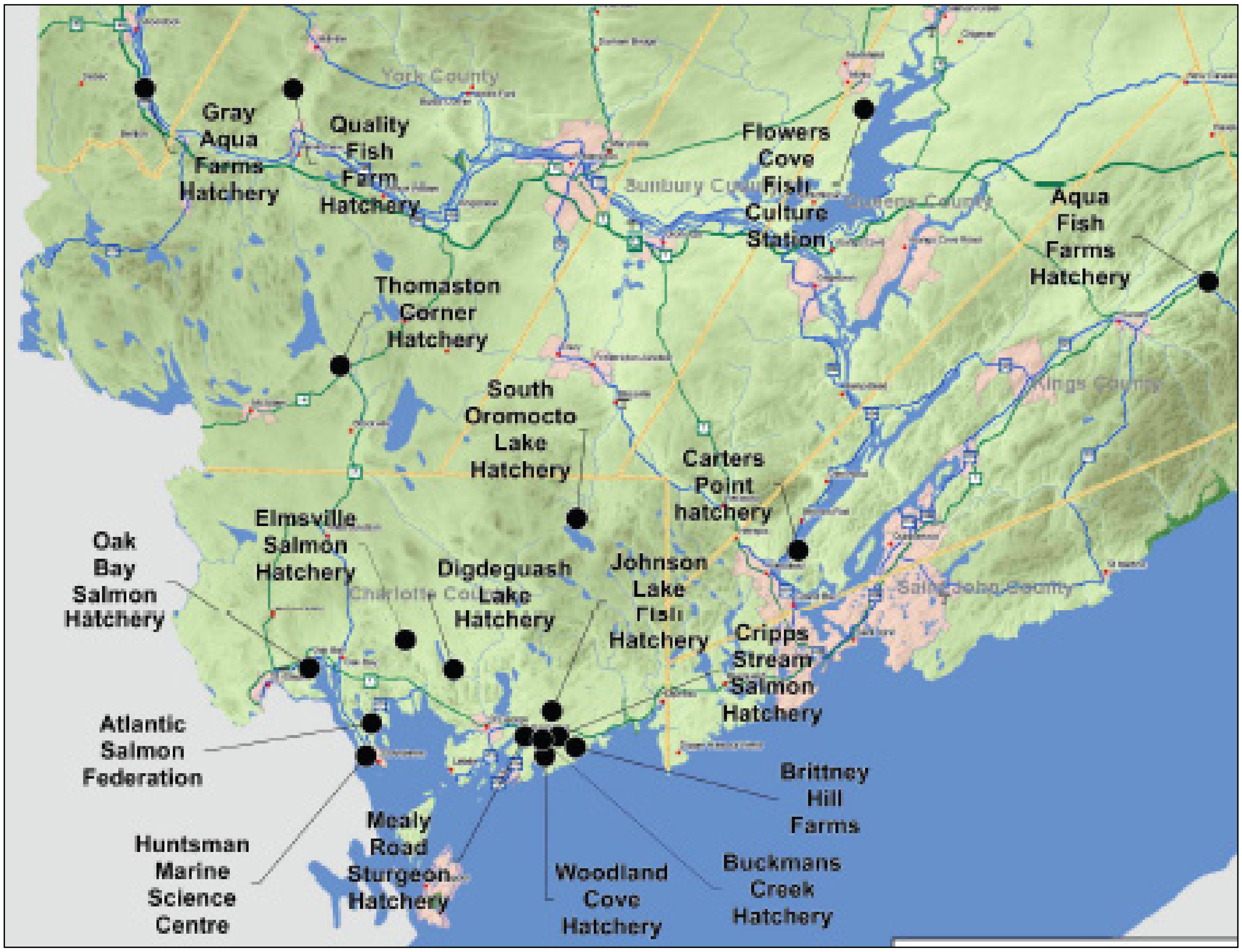


Figure 14: Location of 18 hatcheries (excluding Mactaquac and one on Grand Manan Island) operational in OBoF watersheds. (Courtesy of New Brunswick Department of Environment and Local Government, 2013).

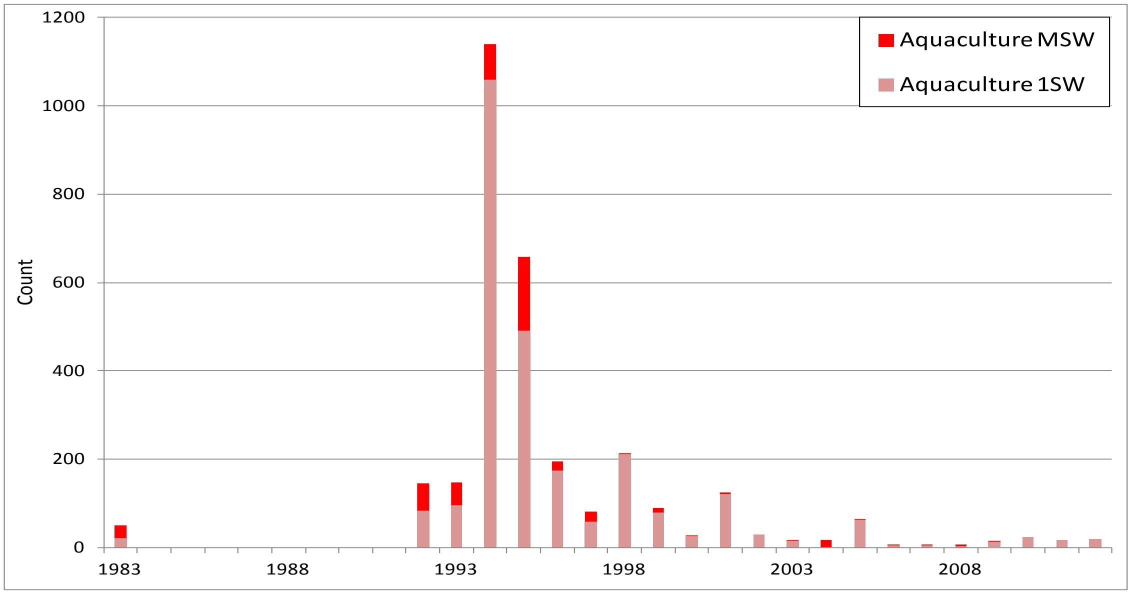


Figure 15: Suspected aquaculture-escape origin adult salmon counted at the Magaguadavic sorting facility by sea winter (SW) age during 1983-2012 (adapted from Jones et al. 2014).

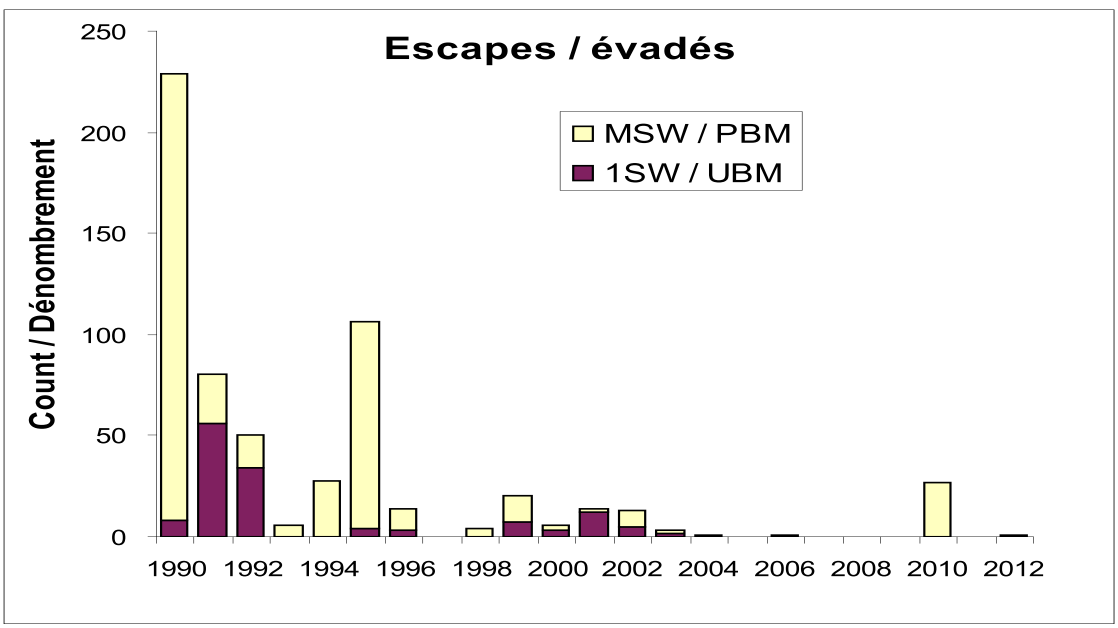


Figure 16: Suspected aquaculture-escape origin adult salmon counted at the DFO Mactaquac sorting facility 1990-2012 (Jones et al. 2014).

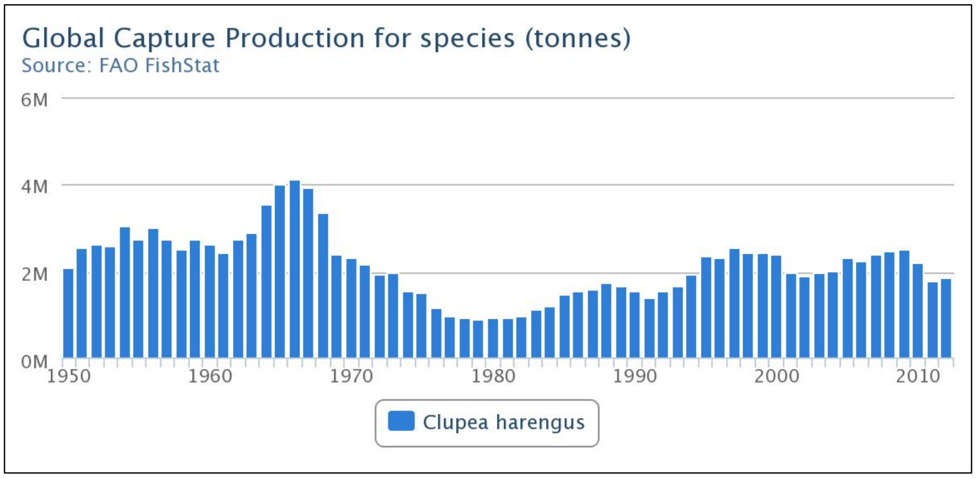


Figure 17: The [global harvest of Atlantic Herring](#) ([Clupea harengus](#)) in tonnes between 1950 and 2012.

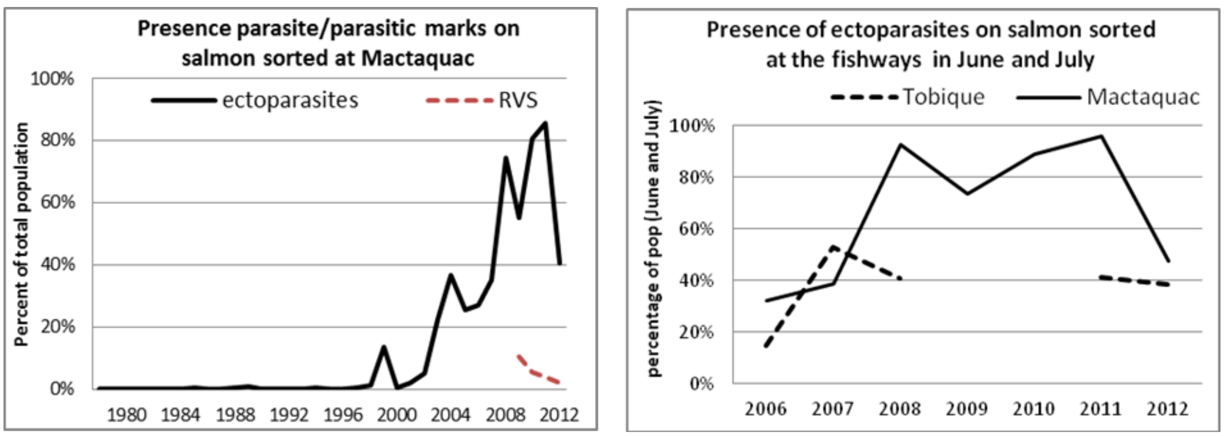


Figure 18: The percentage of the population with the presence of external parasites or suspected parasitic scars observed while sorting Atlantic Salmon at the Mactaquac Biodiversity Facility, 1978-2012, and Tobique Narrows fishway, 2006-2012.

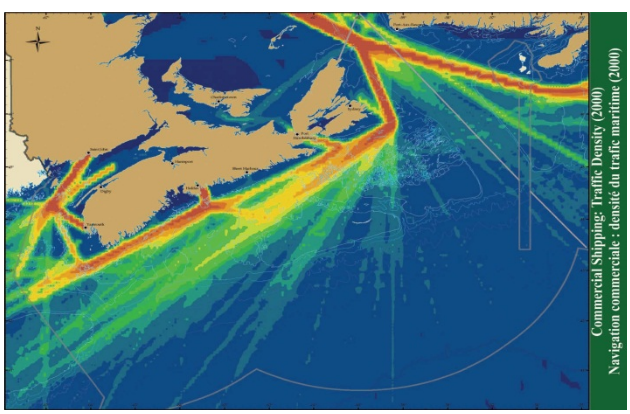


Figure 19: Relative shipping traffic density in Atlantic Canada (red=most traffic)). Adapted from Scotian Shelf: An Atlas of Human Activities (DFO 2005).

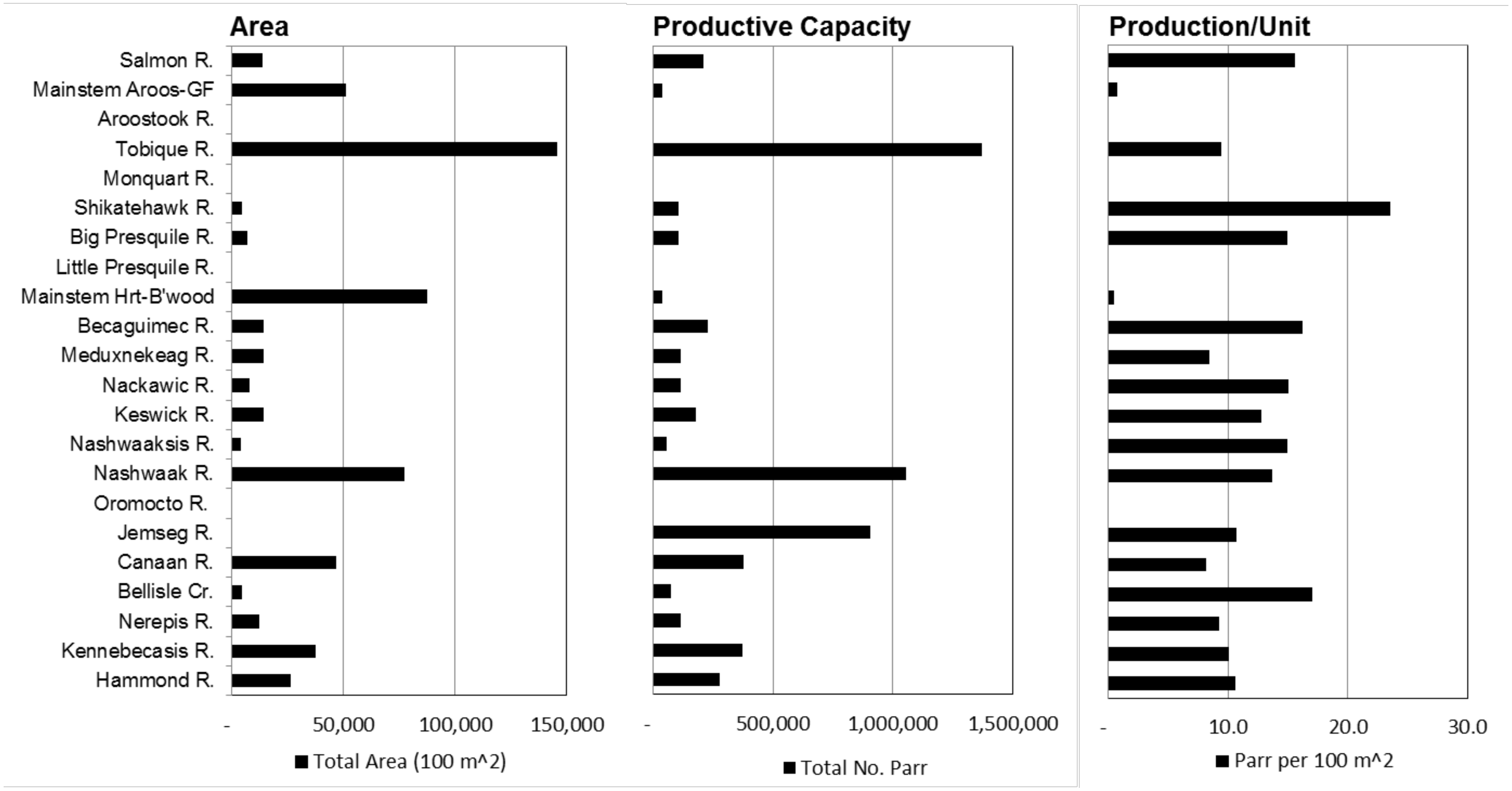


Figure 20: Area, productive capacity of age-1+ and older Atlantic Salmon parr and production of parr per unit area for rivers draining to the SJR determined using grade (measured from ortho-photo maps) as a proxy for habitat quality for stream reaches (Amiro et al. 2003).

APPENDICIES

APPENDIX 1

Terms of Reference

Recovery Potential Assessment for Atlantic Salmon (Outer Bay of Fundy Designatable Unit)

Context

When the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designates aquatic species as threatened or endangered, Fisheries and Oceans Canada (DFO), as the responsible jurisdiction under the *Species at Risk Act* (SARA), is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, population or designable unit (DU), threats to its survival and recovery, and the feasibility of its recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for the consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

The Outer Bay of Fundy DU of Atlantic Salmon was evaluated as Endangered by COSEWIC in November 2010. The rationale for designation is as follows: “This species requires rivers or streams that are generally clear, cool and well-oxygenated for reproduction and the first few years of rearing, but undertakes lengthy feeding migrations in the North Atlantic Ocean as older juveniles and adults. This population breeds in rivers tributary to the New Brunswick side of the Bay of Fundy, from the U.S. border to the Saint John River. Small (one-sea-winter) and large (multi-sea-winter) fish have both declined over the last 3 generations, approximately 57% and 82%, respectively, for a net decline of all mature individuals of about 64%; moreover, these declines represent continuations of greater declines extending far into the past. There is no likelihood of rescue, as neighbouring regions harbour severely depleted, genetically dissimilar populations. The population has historically suffered from dams that have impeded spawning migrations and flooded spawning and rearing habitats, and other human influences, such as pollution and logging, that have reduced or degraded freshwater habitats. Current threats include poor marine survival related to substantial but incompletely understood changes in marine ecosystems, and negative effects of interbreeding or ecological interactions with escaped domestic salmon from fish farms. The rivers used by this population are close to the largest concentration of salmon farms in Atlantic Canada.” There has been no previous RPA for this DU.

In support of listing recommendations for this DU by the Minister, DFO Science has been asked to undertake an RPA, based on the National Frameworks (DFO 2007a and b). The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per section 73, 74, 75, 77 and 78 of SARA. The advice generated via this process will also update and/or consolidate any existing advice regarding this DU.

Objectives

- To assess the recovery potential of the Outer Bay of Fundy DU of Atlantic Salmon.

Assess current/recent species/ status

1. Evaluate present status for abundance and range and number of populations.
2. Evaluate recent species trajectory for abundance (i.e., numbers and biomass focusing on mature individuals) and range and number of populations.

3. Estimate, to the extent that information allows, the current or recent life-history parameters (total mortality, natural mortality, fecundity, maturity, recruitment, etc.) or reasonable surrogates; and associated uncertainties for all parameters.
4. Estimate expected population and distribution targets for recovery, according to DFO guidelines (DFO 2005, and 2011).
5. Project expected population trajectories over three generations (or other biologically reasonable time), and trajectories over time to the recovery target (if possible to achieve), given current parameters for population dynamics and associated uncertainties using DFO guidelines on long-term projections (Shelton *et al.* 2007).
6. Evaluate **residence requirements** for the species, if any.

Assess the Habitat Use

7. Provide functional descriptions (as defined in DFO 2007b) of the required properties of the aquatic habitat for successful completion of all life-history stages.
8. Provide information on the spatial extent of the areas that are likely to have these habitat properties.
9. Identify the activities most likely to threaten the habitat properties that give the sites their value, and provide information on the extent and consequences of these activities.
10. Quantify how the biological function(s) that specific habitat feature(s) provide to the species varies with the state or amount of the habitat, including carrying capacity limits, if any.
11. Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.
12. Provide advice on how much habitat of various qualities / properties exists at present.
13. Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present, and when the species reaches biologically based recovery targets for abundance and range and number of populations.
14. Provide advice on feasibility of restoring habitat to higher values, if supply may not meet demand by the time recovery targets would be reached, in the context of all available options for achieving recovery targets for population size and range.
15. Provide advice on risks associated with habitat “allocation” decisions, if any options would be available at the time when specific areas are designated as critical habitat.
16. Provide advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available.

Scope for Management to Facilitate Recovery

17. Assess the probability that the recovery targets can be achieved under current rates of parameters for population dynamics, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.
18. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the pre-COSEWIC assessment, the COSEWIC Status Report, information from DFO sectors, and other sources.
19. Quantify to the extent possible the likelihood that the current quantity and quality of habitat is sufficient to allow population increase, and would be sufficient to support a population that has reached its recovery targets.
20. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

Scenarios for Mitigation and Alternative to Activities

21. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all feasible measures to minimize/mitigate the impacts of activities that are threats to the species and its habitat (steps 18 and 20).

22. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat (steps 18 and 20).
23. Using input from all DFO sectors and other sources as appropriate, develop an inventory of activities that could increase the productivity or survivorship parameters (steps 3 and 17).
24. Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures in step 21 or alternatives in step 22 and the increase in productivity or survivorship associated with each measure in step 23.
25. Project expected population trajectory (and uncertainties) over three generations (or other biologically reasonable time), and to the time of reaching recovery targets when recovery is feasible; given mortality rates and productivities associated with specific scenarios identified for exploration (as above). Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.
26. Recommend parameter values for population productivity and starting mortality rates, and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.

Allowable Harm Assessment

27. Evaluate maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery of the species.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Documents

Participation

- DFO Science
- DFO Ecosystem Management, DFO Fisheries and Aquaculture Management, and DFO Policy and Economics
- Parks Canada
- Province of New Brunswick
- Aboriginal communities/organizations
- Fishing and aquaculture industries
- Non-governmental organizations
- Academics

References

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 pp.

DFO. 2005. A framework for developing science advice on recovery targets for aquatic species in the context of the Species at Risk Act. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/054.

DFO. 2007a. Revised Protocol for Conducting Recovery Potential Assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/039.

DFO. 2007b. Documenting habitat use of species at risk and quantifying habitat quality. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/038.

DFO. 2011. A Complement to the 2005 Framework for Developing Science Advice on Recovery Targets in the Context of the Species At Risk Act. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/061.

Shelton, P.A., B. Best, A. Cass, C. Cyr, D. Duplisea, J. Gibson, M. Hammill, S. Khwaja, M. Koops, K. Martin, B. O'Boyle, J. Rice, A. Sinclair, K. Smedbol, D. Swain, L. Velez-Espino, and C. Wood. 2007. Assessing recovery potential: long-term projections and their implications for socio-economic analysis. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/045.

APPENDIX 2

A threats table for the freshwater, estuarine and marine environments, summarizing human activities or sources of environmental change that either negatively impact Atlantic Salmon populations (i.e., cause reduced abundance) or cause reduced quality and/or quantity of habitat in the OBoF region is provided in Table A4. Definitions for terms contained within this table, as well as the approach assigning the overall Level of Concern for each Threat are provided below.

Definition of able Headings and Column Values

Threat Category: The general activity or process (natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioral changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur.

Specific Threat: The specific activity or process causing stress to Atlantic Salmon populations in the OBoF DU, where stress is defined as changes to ecological, demographic, or behavioral attributes of populations leading to reduced viability.

Level of Concern: Signifies the level of concern for species persistence if a threat remains unmitigated; where a High level of concern reflects threats that are likely to lead to substantial declines in abundance or loss of populations in the absence of mitigation, a Medium level of concern reflects threats that are likely to limit populations to low abundance and thus increase extinction risk, while a Low level of concern reflects threats that might lead to slightly increased mortality but are expected to have a relatively small impact on overall population viability. This criterion is based on the evaluation of all other information in the table with an emphasis on the extent of the threat in the DU and the number of populations likely to be affected at each level of Severity (see definition below).

Location or Extent: The description of the spatial extent of the threat in the DU was largely based on the criteria developed for the Conservation Status Report Part II (DFO and MRNF 2009), where Low corresponds to < 5% of populations affected, Medium is 5-30%, High is 30-70% and Very High is > 70%.

Occurrence and Frequency: Occurrence: Description of the time frame that the threat has affected (H - historical), is (C - current) or may be (A - anticipatory) affecting Atlantic Salmon populations in the Outer Bay of Fundy DU. Historical – a threat that is known or is thought to have impacted salmon populations in the past where the activity is not ongoing; Current – a threat that is known or thought to be impacting populations where the activity is ongoing (this includes situations in which the threat is no longer occurring but the population-level impacts of the historical threat are still impacting the populations); Anticipatory – a threat that is not presently impacting salmon populations but may have impacts in the future (this includes situations where a current threat may increase in scope). Frequency: Description of the temporal extent of the threat over the course of a year (seasonal, recurrent, continuous).

Severity: Describes the degree of impact a given threat may have or is having on individual Atlantic Salmon populations subjected to the threat given the nature and possible magnitude of population-level change. See Table A1 for definitions/examples of how severity has been evaluated.

Table A1: Definitions/examples of how severity has been evaluated.

Category	Definition/Examples
Negligible	• Habitat alteration within acceptable guidelines that does not lead to a reduction in habitat quality or quantity. • No change in population productivity.
Low	• Minor or easily recoverable changes to fish habitat (e.g. seasonal or changes <12 months). • Little change in population productivity (< 5% decline in spawner abundance).
Medium	• Moderate impact to fish habitat with medium term for habitat recovery (3-5 years). • Moderate loss of population productivity (5-30% decline in spawner abundance).
High	• Substantial damage to fish habitat such that the habitat will not recover for more than 5 years. • Substantial loss of population productivity (> 30% decline in spawner abundance).
Extreme	• Permanent and spatially significant loss of fish habitat • Severe population decline with the potential for extirpation.

Causal Certainty: Two-part definition. Part 1: Reflects the strength of the evidence linking the threat (i.e., the particular activity) to the stresses (e.g., changes in mortality rates) affecting populations of Atlantic Salmon in general. As such, evidence can come from studies on any Atlantic Salmon population. Part 2: Reflects the strength of the evidence linking the threat to changes in productivity for populations in the OBoF DU specifically. See Table A2 for definitions/examples of how causal certainty has been evaluated.

Table A2. Definitions/examples of how causal certainty has been evaluated.

Causal certainty	Description
Negligible	Hypothesized.
Very Low	< 5%: Unsubstantiated but plausible link between the threat and stresses to salmon populations.
Low	5% - 24%: Plausible link with limited evidence that the threat has stressed salmon populations.
Medium	25% - 75%: There is scientific evidence linking the threat to stresses to salmon populations.
High	76% - 95%: Substantial scientific evidence of a causal link where the impact to populations is understood qualitatively.
Very High	> 95%: Very strong scientific evidence that stresses will occur and the magnitude of the impact to populations can be quantified.

Procedure for consistently assigning Level of Concern ranking for OBoF DU

Following suggestions from the OBoF Atlantic Salmon RPA meeting to consistently assess the Level of Concern (LoC) for each threat, a ranking matrix was developed with threat Severity and Extent as inputs. Numbers were assigned to each of the levels (described above) of severity and level of extent. This allows the level of each category to be multiplied together to produce a score from 1-16 as demonstrated in Table A3.1 below. As the LoC category has 3 levels, the nine scores in Table A3.1 were divided as follows: 1,2,3 (Low); 4,6,8 (Medium); and 9,12,16 (High). Threats assigned a 'Negligible' Severity, as defined above, were assigned a LoC of Low, regardless of the Extent. Applying the scored categories of Table A3.1 allows LoC rankings to be made as shown in Table A3.2. This approach offers a consistent approach for assigning the overall LoC for each threat based on the definitions for the Extent and Severity categories. Other threat table categories (i.e., causal certainty, Frequency, and Rationale) provide additional context of the LoC ranking within the OBoF DU.

Table A3.1: Level of Concern scoring matrix.

			Severity				
			Neg.	**Low**	**Medium**	**High**	**Extreme**
		Multiplier	**n/a**	**x1**	**x2**	**x3**	**x4**
Extent	**Low**	**x1**	n/a	1	2	3	4
	Med	**x2**	n/a	2	4	6	8
	High	**x3**	n/a	3	6	**9**	**12**
	V.High	**x4**	n/a	4	8	**12**	**16**

Note: Low Scores= 1,2,3; Medium Scores= 4,6,8; and **High Scores= 9,12,16**.

Table A3.2. Level of Concern rank assignment matrix (based on scoring from Table A3.1).

		Severity				
		Negligible	**Low**	**Medium**	**High**	**Extreme**
	Low	LOW	LOW	LOW	LOW	MEDIUM
Extent	**Med**	LOW	LOW	MEDIUM	MEDIUM	MEDIUM
	High	LOW	LOW	MEDIUM	**HIGH**	**HIGH**
	V.High	LOW	MEDIUM	MEDIUM	**HIGH**	**HIGH**