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Assessment of the Recovery Potential for the Outer Bay of Fundy Population of Atlantic Salmon (*Salmo salar*): Habitat Considerations

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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.

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ABSTRACT

This document addresses the habitat considerations pertinent to the development of Fisheries and Oceans Canada's Recovery Potential Assessment of Atlantic Salmon of the Outer Bay of Fundy (OBoF) Designatable Unit 16 (DU 16). Considerations include: residence requirements, habitat requirements, spatial extent of the habitat, spatial constraints, habitat suitability, options for habitat allocation, and research recommendations.

Adult Atlantic Salmon require appropriate river discharge and unimpeded access to reach spawning areas, as well as holding pools and coarse gravel/cobble substrate on which to spawn. Eggs, alevins and juveniles require clean, uncontaminated water with a pH generally >5.3 for appropriate development, as well as steady, continuous water flow and areas with appropriate cover during winter and summer to deal with temperature extremes. Smolts need appropriate water temperature, photoperiod and river discharge as cues to migrate and require unimpeded access throughout the length of the river. Immature and mature Atlantic Salmon in the marine environment require access to sufficient prey resources to support rapid growth.

There is an estimated 49.7 km^2 of productive habitat available to Atlantic Salmon within DU 16, 81% of which is within Canada. Of the combined Canada-USA area, 90% is within the Saint John River Basin; 10% is attributed to nine smaller basins westward to, and including, the St. Croix Canada-USA boundary waters. Within the Saint John River, 21.5 km^2 is upriver of Mactaquac Dam and 23.2 km^2 is downriver of Mactaquac Dam. The tidal habitat within the mainstem of the Saint John River Basin is 140 km in length; the estuarine habitat (included in tidal portion) is approximately 60 km in length; the marine habitat is widespread from the Bay of Fundy and Gulf of Maine, to the Atlantic coasts of Nova Scotia, Newfoundland, Labrador and Greenland, including the Labrador Sea.

The upper portion of accessible productive habitat (21.5 km^2) of the Saint John River is fragmented by four major hydroelectric dams (Mactaquac, Beechwood, Tinker, and Tobique Narrows) and headponds within Canadian jurisdiction. Each has provisions for upstream but not downstream fish passage. Three dams and flowages (headponds/reservoirs) with upstream but mostly no downstream passage facilities obstruct salmon accessing the majority of habitat in the St. Croix River; one dam with an ineffective downstream by-pass and adjacent pool and weir fishway is located at tide-head on the Magaguadavic River.

Freshwater habitat suitability is largely judged on current abundances of juveniles at electrofishing sites and, to a lesser extent, the availability of stream gradients measured from ortho-photo maps. The assessment of the habitat's future suitability under biologically based recovery objectives is problematic given increasing river temperatures, decreasing stream discharges, new ecosystems and fish communities established within headponds and some rivers, and escapes from the aquaculture industry. These elements add new uncertainties to the prediction or measurement of success without considering new norms for juvenile abundance and, possibly, revisions to current conservation requirements.

Options for allocation of 'important' habitat assume that hydroelectric dams and open pen aquaculture will persist. Similarly, the effects of climate change, urbanization, forestry and agriculture, and the spread and increase in abundance of non-native 'cool' water predators of salmon will likely increase and, therefore, there is likely only to be a decrease in pliable salmon habitat. With this in mind, prioritization criteria for important habitat largely follow criteria developed for the recovery targets related to distribution and favour habitat that is as accessible, productive, and 'free as possible' of known threat impacts. Prioritization should, where possible, seek to preserve a cross section of today's population characteristics and geographic distribution in the faint hope that robustness and adaptive potential of populations will be available for persistence and possible recovery.

Research recommendations are provided in the identification of habitat important or manageable for maintenance or recovery of salmon.

Évaluation du potentiel de rétablissement de la population de saumons de l'Atlantique (*Salmo salar*) de l'extérieur de la baie de Fundy : considérations liées à l'habitat

RÉSUMÉ

Le présent document porte sur les considérations liées à l'habitat pertinentes pour l'élaboration de l'évaluation du potentiel de rétablissement du saumon de l'Atlantique de l'unité désignable 16 (UD 16) de l'extérieur de la baie de Fundy par Pêches et Océans Canada. Ces considérations comprennent : les exigences en matière de résidence et d'habitat, l'étendue spatiale de l'habitat, les contraintes spatiales, la qualité de l'habitat, les options pour l'attribution de l'habitat et les recommandations en matière de recherche.

Le saumon de l'Atlantique adulte a besoin d'un débit fluvial approprié et d'un accès sans obstacle aux frayères ainsi que de bassins de retenue, de substrats de gravier et de galets de forte taille pour pondre. Les œufs, les alevins et les juvéniles ont besoin d'eau propre, non contaminée, avec un pH généralement supérieur à 5,3 pour une croissance adéquate, de même qu'un débit d'eau constant et continu et des zones avec une couverture convenable pendant l'hiver et l'été pour faire face à des températures extrêmes. Les saumoneaux ont besoin d'une eau à la température appropriée, d'une photopériode et d'un débit fluvial adéquats en guise de signaux pour la migration, de même que d'un accès sans obstacle sur toute la longueur du cours d'eau. Dans le milieu marin, les saumons de l'Atlantique immatures et matures ont besoin d'avoir accès à un nombre suffisant de ressources en proies pour soutenir une croissance rapide.

On estime que 49,7 km^2 d'habitat productif sont accessibles au saumon de l'Atlantique à l'intérieur de l'UD 16, dont 81 % sont situés au Canada. De la zone répartie entre le Canada et les États-Unis, 90 % se trouvent dans le bassin du fleuve Saint-Jean et 10 % sont attribués à neuf bassins plus petits vers l'ouest, y compris les eaux limitrophes de la rivière Ste-Croix entre le Canada et les États-Unis. Dans le bassin du fleuve Saint-Jean, 21,5 km^2 se trouvent en amont et 23,2 km^2 en aval du barrage de Mactaquac. Dans le cours principal du bassin du fleuve Saint-Jean, l'habitat sous l'influence des marées fait 140 km de longueur et l'habitat estuarien (inclus dans la partie soumise aux marées) environ 60 km. L'habitat marin s'étend de la baie de Fundy et du golfe du Maine jusqu'aux côtes atlantiques de la Nouvelle-Écosse, de Terre-Neuve, du Labrador et du Groenland, y compris la mer du Labrador.

La partie supérieure de l'habitat productif accessible (21,5 km^2) du fleuve Saint-Jean est fragmentée dans la zone de compétence canadienne par quatre grands barrages hydroélectriques (Mactaquac Beechwood, Tinker et Tobique Narrows) et par des bassins d'amont. Dans chacun d'entre eux, des dispositions ont été prises pour le passage du poisson vers l'amont, mais pas vers l'aval. Trois barrages et réservoirs (bassins d'amont/réservoirs) avec des passes à poissons vers l'amont, mais la plupart du temps sans installations pour le passage vers l'aval, entravent l'accès des saumons à la plus grande partie de l'habitat dans la rivière Ste-Croix. Un barrage avec une déviation vers l'aval et une passe migratoire avec bassin en gradins inefficaces est situé à la limite extrême des eaux de marée sur la rivière Magaguadavic.

La qualité de l'habitat d'eau douce est principalement évaluée en fonction du taux d'abondance actuel des juvéniles aux sites de pêche à l'électricité et, dans une moindre mesure, en fonction de la disponibilité des déclivités de cours d'eau mesurées à partir de cartes orthophotographiques. Il est difficile d'évaluer quelle sera la qualité de l'habitat à l'avenir en réponse aux objectifs de rétablissement fondés sur des critères biologiques, en raison de l'augmentation de la température des cours d'eau et de la diminution de leur débit, des nouveaux écosystèmes et des communautés de poissons établies dans les bassins d'amont et dans certaines rivières et des poissons évadés des établissements aquacoles. Ces éléments ajoutent de nouvelles incertitudes à la prédiction ou à la mesure du succès sans tenir compte des nouvelles normes relatives à l'abondance des juvéniles et, possiblement, des modifications apportées aux exigences actuelles en matière de conservation.

Les options pour l'attribution de l'habitat « important » supposent que les barrages hydroélectriques et l'élevage en parcs en filet se poursuivront. De même, il est probable que les effets du changement

climatique, de l'urbanisation, de la foresterie et de l'agriculture, ainsi que la propagation et l'augmentation de l'abondance des prédateurs de saumons en eau froide non indigènes augmenteront et que, par conséquent, on constatera une diminution de l'habitat propice du saumon. Dans cette optique, les critères d'établissement des priorités pour l'habitat important respectent en grande partie les critères élaborés pour les objectifs de rétablissement liés à la répartition et favorisent l'habitat qui est accessible, productif et, dans la mesure du possible, épargné par les effets des menaces connus. L'établissement des priorités doit, dans la mesure du possible, chercher à protéger un échantillon des caractéristiques et de la répartition géographique de la population actuelle, dans le mince espoir que la solidité et le potentiel d'adaptation des populations seront préservés pour la persistance et le possible rétablissement de l'espèce.

Les recommandations des recherches sont fournies dans la détermination de l'habitat important ou gérable pour le maintien ou le rétablissement du saumon.

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 (*Salmo salar*) as 'endangered' (COSEWIC 2010). It addresses habitat considerations (Terms of Reference [ToRs] 6, 7, 8, 10, 11, 12, 13, and 15 in Appendix 1). This geographic area has been characterized in the past by Fisheries and Oceans Canada and the Québec Ministère des Ressources naturelles et de la Faune (DFO and MRNF 2008) and labeled Conservation Unit 17 (CU 17). 'DU' labels, assigned by COSEWIC, are used here and although some references to CU labels remain, they describe the same area for this population.

In this document, the term 'habitat' is used in the manner defined for aquatic species by the *Species at Risk Act* (SARA) as:

> "spawning grounds, and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where species formerly occurred and have the potential to be reintroduced."

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 late October and early November, the fertilized eggs incubate in gravel nest pits (also termed: redds) through winter and hatch in April, emerge as fry, and grow as parr feeding on invertebrate drift. Parr smoltify mostly after two or three years en route to the sea, whereas post-smolts in their first year, and as maturing adults in subsequent months, they grow rapidly to maturity. Adults 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.

OBoF salmon are unique relative to their Inner Bay of Fundy (IBoF) counterparts in that they have a higher incidence of maturation as Two-Sea-Winter (2SW) salmon, a lower incidence of females among One-Sea-Winter (1SW) salmon, and the post-smolts and adults conduct extensive migrations to the North Atlantic. They also group separately from IBoF salmon and most other populations at multiple allozyme loci and have, therefore, been considered a distinct regional grouping (DFO and MRNF 2008; COSEWIC 2010).

OBoF salmon live in rivers flowing into the New Brunswick side of the Bay of Fundy between the USA-Canada border and the City of Saint John. On the basis of DFO and MRNF (2008), COSEWIC (2010) identified 17 rivers within the OBoF DU in which salmon or parr "are or were present within the last century". Seven rivers flow independently into the Bay, while the other ten are within the lower Saint John River Basin. The rivers of the Saint John River below Mactaquac Dam are directly influenced by tidal/estuarial waters. The Saint John River and the remaining nine outer Fundy complex rivers discharge into the Bay of Fundy, an area of immense high tides (8 m) (Kidd et al. 2011). In the Saint John River, these factors project the head-of-tide approximately 140 km upstream from the river's mouth to a point between the City of Fredericton and the Mactaquac Dam (figures 1, 11) and an estuary extending upstream from the Reversing Falls to the upper end of Long Reach (approximately 60 km in length), as defined by the salt water intrusion (Kidd et al. 2011; Delpeche et al. 2010; Hughes Clarke and Haigh 2005). More recent documentation (Chaput et al. 2011) suggests that there are 11 salmon 'rivers[1]' within the Saint John River Basin and nine 'rivers' independently discharging into the

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[1] DFO and MRNF (2008) and most recently Reddin et al. (2010) in Chaput et al. (2011) defined a river as a "fluvial system which has its mouth flowing directly into tidal water".

Bay. Discrepancies between the two estimated numbers of salmon ‘rivers’ can in part be attributed to inclusion/exclusion of ‘creeks’, ‘streams’ (Gazetteer of Canada 1956) or tributaries, and the absence of a common stream-order based classification (Kidd et al. 2011; NB Aquatic Data Warehouse 2008) of a ‘river’.

This document addresses salmon habitat issues in the 11 rivers within the Saint John River Basin and the nine southwestern basins of New Brunswick discharging into the Bay of Fundy and Passamaquoddy Bay between the Saint John River Basin and the USA-Canada border (Figure 1). The specific rivers addressed (Table 1), which differ slightly from those reported in COSEWIC (2010) and Chaput et al. (2011), form the basis of much of what has been documented for the OBoF DU. Because of the natural separation in habitat experienced by salmon during their life history, freshwater and tidal influenced/estuarine/marine habitats are addressed separately in most instances.

RESIDENCE REQUIREMENTS[2]

Evaluate residence requirements for the species, if any.

Under the Canadian SARA, a residence is defined as a dwelling-place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating (SARA*,* section 2.1). The Draft Operational Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk[3] uses the following four conditions to determine when the concept of a residence applies to an aquatic species:

1. There is a discrete dwelling place that has structural form and function, similar to a den or nest;
2. An individual of the species has made an investment in the creation, modification or protection of the dwelling-place;
3. The dwelling-place has the functional capacity to support the successful performance of an essential life-cycle process such as spawning, breeding, nursing and rearing, and
4. The dwelling place is occupied by one or more individuals at one or more parts of its life cycle.

Spawning redds (used by eggs and alevins), home stones (used by parr), and holding pools (used by kelts and returning adults) were evaluated against these conditions. Under the above terms, Atlantic Salmon eggs and yolk-sac fry (alevins) may be considered to have residences. Redds most closely match the criteria as: these are constructed and defended, have the structural form and function of a nest, the female has invested energy in its creation, are essential for successful incubation and hatching of the eggs, and contain hundreds to several thousand eggs from a female salmon. Home stones and holding pools do not adequately satisfy above definitions and are not proposed as residence requirements.

REDDS

Redds provide hydraulic eddies that capture expelled eggs and, after being covered with gravel (0.6-6.4 cm in diameter; Semple 1991) by the adult female salmon, provide interstitial space for water flow and oxygen for the incubation of the eggs and development of alevins prior to emergence (Gibson 1993). Redds also protect eggs and alevins from disturbance such as ice scour, bedload transport, and physical impact by debris, currents, changing water levels and

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[2] Adapted from Bowlby et al. (2014).

[3] From the November 2011 draft of “Operational guidelines for the identification of residence and preparation of a residence statement for an aquatic species at risk: *Species at Risk Act* (SARA)”.

predators (Danie et al. 1984) between late October/early November and mid-May/early June. They typically consist of a raised mound of gravel or dome under which most of the eggs are located, and an upstream depression or 'pot' (Gaudemar et al. 2000). Burial depths are about 10 to 15 cm. Redds are typically constructed in water depths of 17 to 76 cm and velocities between 26 to 90 cm/sec (Beland et al. 1982).

HABITAT REQUIREMENTS

Provide functional descriptions (as defined in DFO 2007) of the required properties of the aquatic habitat for successful completion of all life-history stages.

Bowlby et al. (2014) generalized the functional characteristics of freshwater and marine habitats necessary for the successful completion of the life cycle of Atlantic Salmon:

> “Adult Atlantic Salmon require appropriate river discharge conditions and unimpeded access upstream to reach spawning areas, as well as holding pools and coarse gravel/cobble substrate distributed throughout a river system on which to spawn. Eggs, alevins and juveniles require clean, uncontaminated water with a pH > 5.0 for appropriate development, as well as steady, continuous water flow and areas with appropriate cover during winter and summer to deal with temperature extremes. Smolts need appropriate water temperature and river discharge as cues to migrate and require unimpeded access throughout the length of the river. Immature and mature Atlantic Salmon in the marine environment require access to sufficient prey resources to support rapid growth, where prey distributions are likely correlated with temperature or other oceanographic variables.”

Bowlby et al. (2014) also noted that failure to consider all of these components when identifying priority habitats for allocation could lead to a disconnect between that which is protected and what is necessary from a population-level perspective. Attributes of important salmon habitat, relevant to different life stages of most salmon populations (Outer Bay included), are provided in tables 2 and 3.

FRESHWATER[4]

Freshwater habitat use by Atlantic Salmon is diverse, widely documented and the subject of substantial reviews (e.g., Bjornn and Reiser 1991; Gibson 1993; Bardonnet and Baglinière 2000; Armstrong et al. 2003; Rosenfeld 2003; Amiro 2006; Bowlby et al. 2014). The major freshwater habitat types that have been identified include: feeding, wintering, spawning, early life-stage nursery and rearing, and upstream migration habitat (Gibson 1993; Armstrong et al. 2003).

Freshwater habitat quality can be affected by:

1. seasonal temperatures,
2. stream discharge,
3. water chemistry (e.g., pH, nutrient levels, oxygen concentration),
4. turbidity,
5. invertebrate abundance,
6. physical perturbations (e.g., impoundments, deforestation), and
7. connectivity, among other factors (Gibson 1993; Armstrong et al. 2003).

Of these, connectivity generally continues to be the most debilitating and subsequently, best quantified impact on salmon habitat in DU 16. Other factors, such as those caused by climate

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[4] Text adapted from Amiro et al. (2008), COSEWIC (2010), Dadswell (2004), and Bowlby et al. (2014).

change (e.g., seasonal temperatures, stream discharges), agriculture, forestry and increasing population and urbanization, are also recognized as debilitating but their impacts are largely unquantified.

Atlantic Salmon streams are generally clean, cool and well oxygenated, characterized by moderately low (2 m/km [0.2%]) to moderately steep (11.5 m/km [1.15%]) gradients (Elson 1975), with 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). Amiro (1993) and Amiro et al. (2003) identified stream gradients ranging from 0.5 to 1.5% to be an indicator of quality habitat. 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.

For Atlantic Salmon, the highest population densities and productivities are associated with rivers that have moderate summer temperatures (≤22°C) (Breau et al. 2011) and moderate (25 cm/sec) flows (Jones 1949; Elson 1974; Gibson 2002). Parr growth occurs 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. Downstream smolt migration is postulated to be effected by photoperiod, temperature and changes in water flow which usually occurs in the spring during night at water temperatures of 8-10°C. The same environmental parameters have an influence on the somewhat unique fall migration of pre-smolt on the Tobique River (Jones et al. 2006; Jones and Flanagan 2007).

Spawning beds are often gravel areas with moderate current, a depth of 0.5–2 m (Fleming 1996, 1998) and well oxygenated (>4.5 mg/L dissolved oxygen) (Davis 1975), continuously flowing cold water. Commonly used water depths for redd (nest) construction are from 0.15 m to >1.0 m, but are generally between 0.15 to 0.76 m (Beland et al. 1982; Moir et al. 1998 *in* Bowlby et al. 2014). Water velocity at spawning sites ranges from 0.15 m/s to 0.9 m/s, with preferred values clustering around 0.3-0.5 m/s (Beland et al. 1982; Crisp and Carling 1989; Moir et al. 1998 *in* Bowlby et al. 2014). Egg and alevin stages are spent in the interstitial spaces of the gravel nest, while fry (age 0+), parr (age 1+ and older), smolts and post-smolts (early marine stage) range across freshwater fluvial, lacustrine and estuarine environments (tables 2 and 3).

In winter (when daily water temperatures are below 8-10ºC), parr may occupy interstitial spaces in the substrate (Cunjak 1988; Cunjak et al. 1998) and/or move to lacustrine habitats (Robertson et al. 2003). Juveniles (and individual adults) may often use several habitat types during their freshwater residency (Erkinaro and Gibson 1997; Bremset 2000) for demographic (Saunders and Gee 1964), and ecological reasons (Morantz et al. 1987; Bult et al. 1999). Again, connectivity among habitat types is an important determinate of growth, survival, and lifetime reproductive success. Juvenile salmon typically maintain relatively small feeding territories in streams, which can be relocated when individuals undergo larger-scale movements to seek improved foraging conditions, refuge (thermal or seasonal) and/or precocious spawning (McCormick et al. 1998). Parr establish individual territories in riffle-pool regions of streams in depths of 20-100 cm and feed mainly on insects, particularly those in the drift and airborne over the water (Gibson and Cunjak 1986). 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 of 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. Because parr maintain and defend home territories, their population regulation is somewhat density dependant (Rago and Goodyear 1987).

Ultimately, home ranges in freshwater are abandoned when pre-smolt and smolt begin to migrate to the marine environment. In the Tobique tributary of the Saint John River, migrating wild pre-smolts are captured in October-November, while smolts at the same site generally pass between very-late April and early June (Jones et al. 2010). Fall telemetry studies have shown that some pre-smolts from the Tobique River migrate past Tobique Narrows Dam and overwinter in the main stem of the Saint John River (Carr 1999; Jones and Flanagan 2007). Wild smolt migration on the Nashwaak River occurs within a similar time frame as those of the Tobique (Jones et al. 2010); the incidence of fall migrating pre-smolts on the Nashwaak River is largely undocumented. Spring-run smolts have been observed schooling at or in the forebays of the Tobique, Beechwood and Mactaquac hydro dams (Saint John River) and in forebays of dams at St. George (Magaguadavic River) and Milltown (St. Croix River). The propensity for migration underscores the importance of habitat connectivity, not only to allow adults to reach spawning grounds, but also for seasonal movements of juveniles and smolts to access coastal waters.

The migratory phase of adults within rivers appears to be largely dependent on river discharge and to a lesser degree, temperature. Low flows have been widely observed to delay entry of returning spawners to freshwater environments (Stasko 1975; Brawn 1982). High flows generally stimulate an increased tendency to move upstream (Bowlby et al. 2014), although responses of salmon to changes in discharge are variable and there is no median flow or flow pattern that is consistently preferred (Thorstad et al. 2011 *in* Bowlby et al. 2014). While returning adults of DU 16 ascend from the Bay of Fundy to their natal rivers between May and October (Jones et al. 2006, 2010), spawning does not occur until late October-early November. When not actively ascending, they typically occupy holding pools where they may spend weeks to months in a single pool. These pools:

1. dissipate energy and provide adult salmon with resting areas out of the current (thus minimizing energy expenditure prior to spawning),
2. provide cover and shelter from predators, and
3. can provide a thermal refuge if the pools are fed by groundwater (Bowlby et al. 2014).

In general, little is known about the freshwater habitat used by post-spawning adult salmon (kelts). Bowlby et al. (2014) note that one component may exit a river relatively quickly after spawning, while another component overwinters in deep water habitats and descends the river in the spring (Bardonnet and Baglinière 2000; Hubley et al. 2008) or overwinters in estuaries (Cunjak et al. 1998). The proportion of the population that remains in the river during winter likely depends on the availability of pools, lakes, and still waters in the watershed (Bardonnet and Baglinière 2000).

Observations of kelts in forebay areas of dams on the Saint John River in both spring and fall, and the presence downriver of extensive headponds and in-river tidal areas, supports the contention that most Saint John River kelts overwinter in the ice-covered river or estuary. Black salmon or kelt (overwintered adult salmon) angling data from a former spring fishery on the Nashwaak River (and other rivers within the DU) in April and May indicate that a number of post spawning adult salmon overwinter within the river (O’Neil and Swetnam 1984). This would be similar to the findings on the smaller St. Mary’s River, Nova Scotia where 24 fall-acoustically-tagged fish all left the river in late-April/early-May the following year (Bowlby et al. 2014). Recent tagging of kelts captured in early April on the Hammond River (Saint John Basin) with pop-up satellite archival tags (PSATs) indicates use of the tidal influenced/estuarine habitat in the lower Saint John River for upwards of four weeks prior to entering the Bay of Fundy (Gilles Lacroix, DFO, pers. comm.[5]).

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[5] Ocean migration data for OBoF kelts published in the Canadian Journal of Fisheries and Aquatic Sciences, issue 70, pages 1-20 (2013) subsequent to first tabling of this document in consideration of the Recovery Potential Assessment (RPA) for DU 16 Atlantic Salmon, February 2013.

The migratory behavior exhibited by Atlantic Salmon makes them particularly vulnerable to the negative effects of large man-made obstructions prevalent in the OBoF DU. Hydroelectric dams, even those equipped with upstream fish passage facilities, reduce the connectivity and production of salmon by restricting or delaying mature fish from reaching spawning habitat. Most dams within DU 16 lack downstream passage facilities leaving downstream migrating adults and juveniles to the vagaries of delays in headponds and at dams, mortality in descending spillways or through turbines, and predation in headponds, e.g., Ruggles and Watt (1975).

In general, most obstructions less than 3.4 m (Powers and Orsborn 1985) are surmountable by adult salmon as are water falls less than 5 m in height that have a vertical drop into a plunge pool with a depth 1.25 times the height (Shearer 1992). Natural obstructions greatly decrease the freshwater range of Atlantic Salmon in the OBoF DU, while intermittently passable falls are thought to contribute to annual variability in salmon production in the Digdeguash River.

TIDAL INFLUENCED/ESTUARINE/MARINE[6]

Estuarine habitat of Atlantic Salmon is principally a function of a salmon rivers' morphology at its confluence with salt water and the extent to which freshwater dilutes that salt water. Virtually all salmon rivers of the Saint John River Basin are of low gradient where they meet tidal waters and the extent of the estuary is daily influenced by the magnitude of the tides and their incursion into those rivers. Moore et al. (1995) found that smolts apparently require no period of acclimation when moving from freshwater to saltwater and, thus, it can be assumed that estuarine habitat is not a requisite for immediate survival. That being said, however, smolts encountering extensive estuaries such as the lower Saint John River where passage can last up to 10 days (means of six to seven days) (Lacroix 2008) before reaching the Bay may benefit by way of some pre-oceanic growth and the potential for reduced predation once at sea.

Marine habitat requirements for OBoF Atlantic Salmon are less well known than those for freshwater. The lack of information is due, in part, to the difficulty in collecting data and tracking salmon at sea. Nonetheless, there is a body of tag data (Ritter 1989; Ruggles and Ritter 1980; ICES 1990, 2008; Lacroix 2008; Lacroix and Knox 2005; Penney 1983; Whoriskey et al. 2006; Lacroix, pers. comm.[5]) that places OBoF salmon in the Bay of Fundy, Scotian Shelf, Grand Banks, Newfoundland and Labrador coasts, and the Labrador Sea (Table 3) where other investigators have described 'preferred' habitats and prey of Atlantic Salmon.

Most anadromous fishes have a species-specific range of environmental conditions, which they select as optimum during their feeding migrations while at sea (Dadswell 2004). Leggett (1977) defined this behaviour as the physiological optimizing strategy. Environmental conditions include, but are not limited to, water temperature, salinity, depth, ocean currents, light regimes and the presence of suitable prey organisms. In addition, the north-south geographical position of their natal river influences how anadromous fishes select conditions within the species optimal range while at sea (Dadswell 2004).

Water Temperature

It is generally thought that water temperature is the main controlling environmental variable for smoltification (although photoperiod is also important) as it regulates metabolic rate. The smolt transformation process is accompanied by changes in metabolic rate, with increases in energy demands underpinning the need for the fish to immediately begin feeding (DFO and MRNF 2008). On the basis of catch rates, ocean-feeding Atlantic Salmon post-smolts are associated with sea-surface temperatures (SSTs) between 6-14°C with the largest numbers of fish captured around a median of 9-10°C (Holm et al. 2000). Ocean surveys for adult Atlantic

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[6] Taken/adapted from Dadswell (2004) and Amiro et al. (2008).

Salmon indicate that the temperature optimum is lower for post-smolt and MSW fish, ranging from 2-9°C with an optimum of 4-5°C (Reddin and Shearer 1987). Power (1981) and Reddin and Shearer (1987) indicate that Atlantic Salmon avoid sea temperatures below 2°C. Reddin (2006) more recently concluded that the marine temperature ‘preference’ for Atlantic Salmon ranges between 1-13°C, with high preference for 4-10°C areas. Based on analyses by Reddin and Friedland (1993) of SSTs associated with various catch rates for Atlantic Salmon sampled in the North Atlantic, Amiro et al. (2003) ascribed four categories of SST preference by Atlantic Salmon:

1. <1°C and >13°C (unfavorable but not lethal);
2. 1 to 4°C (low preference cool),
3. >4°C and <10°C (high preference), and
4. 10 to 13°C (low preference warm).

Jacobsen et al. (2001) demonstrated that the more northerly Norwegian and Russian stocks of Atlantic Salmon migrated past the Faroe Islands in mid-winter when SSTs were lower than those of early spring when the more southern Irish and Spanish stocks were abundant. They suggested that the southern stocks may have preference for warmer temperatures than northern stocks (Jacobsen et al. 2001).

Reddin (2006) summarized earlier work in which he determined that there was a significant correlation between mean week of catch and the first week of occurrence of the 4°C isotherm in geographically indexed coastal waters around Newfoundland and Labrador. Thus, salmon appear to orientate at least partly by following a thermal field (Reddin et al. 2000). The migration of salmon in relation to SSTs compares well with the findings of Ikonen (1986) in the Gulf of Bothnia and with those of Westerberg (1982).

Deployment of data storage tags (DSTs) to 11 kelts, between mid-May and very-early June in Newfoundland, revealed that kelts at large for up to four months experienced temperatures ranging from a low near 0 to over 25°C, although most of the time was spent at sea in temperatures of 5 to 15°C (Reddin et al. 2004). Rapid changes in temperature informed of frequent dives, generally to colder waters. DSTs applied to post-smolts in Newfoundland rivers during the same period as kelts, two of which were at large for eight to ten weeks, experienced temperatures from <0 to nearly 20°C, although most of the time was spent in water from 8 to 15°C (Reddin et al. 2006). Temperature profiles indicated that they dove to depths of 25-50 m, possibly in search of prey. Data for individual fish indicate the variability may be associated with the temperature bounds ascribed by Amiro et al. (2003).

Recent deployment of PSATs, with four to six month ‘pop-off’ delays, on Hammond River spring kelts indicated that kelts experienced a temperature range of -1 to 20°C but exploited the narrower range of 5-10°C (Lacroix, pers. comm.[5]). More recent studies suggest, however, that the availability of appropriate forage (Chaput and Benoît 2012), and in the case of post-smolts, spring wind patterns (Friedland et al. 2012) may influence their whereabouts more so than SSTs.

Salinity

Little information exists concerning salinity selection by ocean-feeding Atlantic Salmon (Dadswell 2004). Salmon move, as smolts or kelts from freshwater to brackish estuaries and usually, to the full saltwater. The length of time spent in or near the home estuary is thought to be as brief as one to two tidal cycles and may limit opportunities for predation. However, post-smolts and salmon often move in and out of lower salinities during coastal migration (Hansen et al. 1987; Hansen and Quinn 1998 *cited in* Dadswell 2004). On the high seas, however, in regions where salmon are involved in feeding-growth migrations, salinities are high (e.g., 35.0-35.5 ppt). Holm et al. (1996 *cited in* Dadswell 2004) found that wild post-smolts, after two to three months of ocean migration in the Norwegian Sea, were only found in salinities above 35 ppt, while hatchery-reared post-smolts released at the mouth of a Norwegian river were found to move in and out of lower salinities (30-34‰) during their migration at sea (Hansen et al. 1987; Jonsson et al. 1993). Dadswell et al. (2010, *citing* Holm et al. 2003 and Lacroix and Knox 2005) noted that emigration of salmon post-smolts is directed along routes of increasing salinity concentration and towards preferred temperature.

Ocean Currents

Tidal currents and wind appear to be a factor in the rapid movement of post-smolts tracked away from estuaries towards the open sea (Hedger et al. 2008; Friedland et al. 2012; Martin et al. 2009). Post-smolts of OBoF origin likely move, in part, in the interface of southern Atlantic currents and counter coastal currents (Figure 2) in reaching the south, and east coasts of Newfoundland and Labrador Sea before likely wintering in the Labrador Sea (Reddin 2006). In the spring, adult salmon of North American origin are generally concentrated in abundance off the eastern slope of the Grand Bank and less abundantly in the southern Labrador Sea and over the Grand Bank (COSEWIC 2010). In summer, feeding 1SW Atlantic Salmon move northward, possibly transported by the West Greenland Current of the North Atlantic sub-polar gyre (Figure 2), along/off the West Greenland coast and, in less abundance, to the northern Labrador Sea and occasionally the Irminger Sea (COSEWIC 2010; Jensen 1990; Stasko et al. 1973; Reddin et al. 1984, and Reddin 2006). Based on tag recoveries, salmon returning from West Greenland appear in Labrador and Newfoundland fisheries consistent with transport in the Labrador Current on the westerly side of the sub-polar gyre. Based on Caesium-137 (^{137}Cs) levels in salmon returning to Canada, Dadswell et al. (2010) proposed that 25% of 1SW salmon returning to Canada had been, and spent time, east of the Faroe Islands (for details, *refer to* Figure 1 in Dadswell et al. 2010). A review of the entire International Council for the Exploration of the Sea (ICES) database for salmon tagged in North America and Europe, however, suggested that the occurrence of salmon to the east of Greenland was an infrequent event (Reddin et al. 2012).

Ocean Depth

During ocean-feeding migrations, salmon move offshore over ocean depths of up to 5,000 m. Templeman (1967 and 1968 *cited in* Dadswell 2004) reported that the best catches of Atlantic Salmon off the Grand Banks and Greenland in surface drift nets were over depths in excess of 1000 m. Reddin (1985) reported that fishing on and off the Grand Banks in May, using 3000^{+} m of surface drift gill net, caught a total of 341 salmon per set, of which 87% were captured over ocean depths in excess of 1000 m. Lear (1976, *cited in* Dadswell 2004) reported on 54 salmon captured in otter trawls on the Grand Banks in the period 1933-74. Of these, 50% were taken along the southern margin of the Banks and, since most were taken in spring (May-June), were thought to be salmon migrating to home rivers in eastern North America to spawn. Lacroix (pers. comm.[4]) found that kelts fitted with PSATs spent most of their time near the surface (depth <2 m) while migrating, followed by a diurnal cycle of repeated diving to >50 m during daytime once feeding grounds were reached. There were also occurrences of deep diving in the 100-500 m range along fronts and at the edge of shelves. Renkawitz et al. (2012) implanted ultrasonic depth tags into hatchery-reared smolts from the Penobscot River. In the Penobscot Estuary, 86.7% of the total detections were in the top 5 m of the water column while in the Penobscot Bay, 98.2% of the total detections occurred in the top 5 m.

Light

Atlantic Salmon are found in the upper regions of the ocean pelagic zone (Dadswell 2004). Templeman (1967) found that all Atlantic Salmon caught in surface fishing drift gillnets off Greenland and in the Labrador Sea were taken in the upper 3 m of the water column (net was 4.9 m deep) and the majority of salmon (74%) were in the upper meter. Salmon caught by long line off the Faroes were tagged with pressure-sensitive hydroacoustic tags and tracked for periods up to 16 hours (Jakupsstovu et al. 1985) and remained between 3-6 m in depth during most of the tracking. Post-smolts taken in pelagic trawls were captured in the upper 5 m of the water column (Shelton et al. 1997; Holm et al. 2000). Renkawitz et al. (2012) found that of the total detections in the top 5 m of the water column, 99.3% were at dawn, 83.7% during day, 86.4% during night, and 94.6% at dusk conditions. In Penobscot Bay, 98.2% of the total detections occurred in the top 5 m. More recent observations and interpretations of temperatures recorded by DSTs suggest that kelts in coastal Newfoundland waters have descended at night to depths of 25 m or more, ostensibly for feeding (Reddin et al. 2004). The most recent use of PSATs indicate that kelts repeatedly dive to depths between 25 to 50 m in the Bay of Fundy and North Atlantic with occurrences of deep diving in the 100-500 m range (Lacroix, pers. comm.[5])

Friedland (1998) reviewed ocean climate influences on salmon life history events including those related to age at maturity, survival, growth and production of salmon at sea (COSEWIC 2010) and concluded that ocean climate and ocean-linked terrestrial climate events affect nearly all aspects of salmon life history. For example, higher sea-surface temperature (SST) has been implicated in increasing the ratio of grilse to MSW salmon (Saunders et al. 1983; Jonsson and Jonsson 2004), perhaps through growth rates (Scarnecchia 1983). Also, Scarnecchia (1984), Reddin (1987), Ritter (1989), Reddin and Friedland (1993), Friedland et al. (1993, 1998, 2003a and 2003b), and Beaugrand and Reid (2003) showed significant correlations between salmon catches/production and environmental cues, including those related to plankton productivity.

Forage[7]

> “Prey of ocean-feeding Atlantic Salmon consists of pelagic and mesopelagic fishes, crustaceans and squid and varies with salmon age and ocean depth. When they first enter seawater post-smolts feed mainly on insects floating on the surface but they switch to planktonic crustacean after a few weeks at sea (Dutil and Coutu 1988; Jacobsen and Hansen 2000). On the high seas and as they grow older, Atlantic Salmon progressively switch from a diet dominated by planktonic crustaceans to one dominated by fish and squid (Jacobsen and Hansen 2000, 2001). Stomach contents of salmon collected over depths in excess of 1000 m consist predominantly of various species of mesopelagic fishes (*Paralepis*, Myctophidae), planktonic crustaceans (*Themisto*, Euphausiidae) and the squid *Gonatus fabricii* (Templeman 1967; Lear 1972; Hansen and Pethon 1985). Over shallower depths salmon stomachs contain planktonic crustaceans, Capelin, Sand Lance and Herring (Lear 1972; Jacobsen and Hansen 2000). During homeward migration salmon food organisms in stomachs change from deepwater fishes (mesopelagics), to nearshore fishes (Herring, Sand Lance) and finally they cease to feed before entering freshwater (Lear 1972; Jacobsen and Hansen 2000).
>
> Based on the occurrence and weight of food in stomach contents both Lear (1972) and Jacobsen and Hansen (2000) concluded that Atlantic Salmon feed almost continuously while at sea, and are voracious and opportunistic feeders that will feed on whatever type of pelagic food item is available in their environment. Between 50-80% of Salmon off the Faroes during winter contained food (Jacobsen and Hansen 2001). Weight of food in ocean feeding salmon at various locations in the Northwest Atlantic varied from 10-30 g/kg body weight (Lear 1972). Numerous studies on feeding salmon throughout the North Atlantic gyre region (off Labrador and Newfoundland, off the Faroes, Norwegian Sea, off Greenland) report consistent results: salmon fed on similar prey items, the majority of salmon contained food, stomachs were full and there was a high

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[7] Entire section taken from Dadswell (2004).

diversity of prey items (Lear 1972; Hansen and Pethon 1985; Jacobsen and Hansen 2000)".

SPATIAL EXTENT OF HABITAT

Provide information on the spatial extent of the areas that are likely to have these properties.

FRESHWATER

Based largely on the presence of juvenile and to a lesser extent, adult Atlantic Salmon, OBoF salmon of DU 16 utilize habitat of most rivers of southwest New Brunswick draining into the Bay of Fundy (Figure 1).

The Saint John River is the second longest in northeastern North America and has a basin area of over 55,000 km^2. It begins in northern Maine, travels northeast into northern New Brunswick while being fed by tributaries in eastern Quebec and then flows southeast through New Brunswick to the Bay of Fundy. Fifty-one percent of the Saint John River Basin is in New Brunswick, 36 percent is in Maine, and 13 percent is in Quebec (SJRBB 1975; Cunjak and Newbury 2005 *cited in* Kidd et al. 2011). Approximately 16,000 km^2 of the Basin is above Grand Falls, NB and has historically been inaccessible to Atlantic Salmon (Cunjak and Newbury 2005).

There are 11 salmon rivers (considering Saint John River above Mactaquac as one system) within the Saint John River Basin and nine other rivers distributed westward of the City of Saint John to the USA-Canada boundary (aka, outer Fundy complex rivers), most with spawning and rearing habitat potentially available to Atlantic Salmon (Table 1). In addition, estimates of productive capacity are provided for the habitat of 16 tributaries, two mainstem sections of the Saint John River upriver of Mactaquac Dam, and ten tributaries to the Jemseg River downstream of Mactaquac Dam. Three tributaries to the Saint John River upriver of Mactaquac with productive habitat originate in the USA and much of the habitat in the St. Croix River is within the mainstem East Branch boundary waters (Table 1).

Marshall et al. (1997) documented the extent of much of the productive habitat for Atlantic Salmon in DU 16 (Canada) (Table 1) on the basis of gradients >0.12%, as determined by Amiro (1993) using gradient, stream width, and distance from the mouth all measured on ortho-photo maps and aerial photographs. The bases for estimates of productive habitat for other rivers are provided in Appendix 2. Current temperature and stream discharge regimes, impacts due to obstructions, agriculture, urbanization, etc., affect the productive capacity of the Saint John, St. Croix and Magaguadavic rivers habitat relative to what it was (Clarke et al. 2014).

In total, there are an estimated 404,575 units (100 m^2) of productive habitat available to Atlantic Salmon within DU 16 (including area accessible by known fish passage measures at dams) (Table 1). This area does not include area rendered non-productive by man-made dam reservoirs discussed below and in Clarke et al. (2014), or the 92,726 units within US boundaries (Table 1). Within the Saint John River, 14.4 km^2 (36%) is upriver of Mactaquac Dam and 23.2 km^2 (57%) is downriver of Mactaquac Dam. Only 2.8 (7%) km^2 is found in the outer Fundy complex rivers. Man-made barriers on the Monquart, Nackawic, and Musquash rivers exclude salmon from approximately 1.3 km^2 of productive habitat in DU 16 (Table 1). Excluded from Table 1 are approximately 75 units of habitat below the Monquart dam which were recently reported by Jones et al. (2014) to support high densities of juvenile salmon.

TIDAL INFLUENCED/ESTUARINE/MARINE

The earliest insights into the marine habitat of Saint John River salmon emanate from the work of Huntsman (1938) who between 1913 and 1924 tagged 1,215 kelts and documented their return from fisheries in the Bay of Fundy. More recent perspectives on the use of habitat in the

North Atlantic are as well based on external Carlin tags applied mostly to hatchery-origin smolts, mostly from wild-origin parents, reared and tagged at the Mactaquac Biodiversity Facility and returned from fisheries. These perspectives are available in Gray (1973), Ruggles and Ritter (1980), Pippy (1982), Ritter (1989), and various working and study groups of ICES, especially ICES (1990) and ICES (2008). In the absence of any significant tagging data for other Canadian salmon populations to the west of the Saint John River, including the Magaguadavic and St. Croix rivers, it is assumed that all populations of the Outer Bay frequent the same North Atlantic habitat as do the Saint John River populations. This is supported by the evidence that the headwaters adjacent Penobscot River salmon population (Baum 1997) has been recovered in most of the same North Atlantic fisheries as those salmon of the Saint John River.

Ritter (1989) currently provides the most detailed documentation of the occurrence of Saint John River post-smolts, 1SW, 2SW and repeat spawning salmon in coastal areas of Atlantic Canada and the offshore (40-60 km) fishing banks of West Greenland. These data (tables 4, 5, 6, 7; *refer* to Figure 3) are for hatchery-reared smolts originating from wild Saint John River salmon that were Carlin-tagged and released from Mactaquac Dam 1967-1984, i.e., years when, with the exception of the Saint John River and outflow (1972-1980 and 1984 onwards; recovered through 1987) and Nova Scotia (1985 onwards), commercial fisheries for salmon in the North Atlantic were widely prosecuted and recovered tagged fish.

Post-smolt Habitat

Recoveries of Carlin-tagged post-smolts are sparse for the Saint John but returns of nearly one half of the total (Ritter 1989; Table 4 this document) were in the low head weirs of the 'Lower Fundy shore' of Nova Scotia (see Figure 4; *refer to* Figure 1 in Ritter 1989), suggests that like Inner Bay stocks, the Saint John River stock in particular, can be directed and possibly even entrained in the mid-Fundy gyre created by the intrusion of deep Atlantic shelf waters into the Bay (Figure 5a). These nutrient rich waters hug the Nova Scotia coastline as they advance eastward, then turn and flow westward along the New Brunswick side of the Bay before mingling with the outflow of the Saint John River (Figure 5b) and discharging into the Gulf of Maine. Interestingly, few of the Saint John River returns were from the "Lower Fundy New Brunswick", i.e., Passamaquoddy Bay region. The remaining recapture locations are consistent with a presumed 'migration' of post-smolts eastwardly along/off of the western, south and eastern shores of Nova Scotia, the south coast of Newfoundland and then northward along/off the eastern and northeast coasts of Newfoundland towards Labrador and the Labrador Sea (Figure 3). On the basis of recaptures of tagged post-smolts from rivers in Maine, the OBoF, the Atlantic coast of Nova Scotia and some rivers in Newfoundland and Labrador, Ritter (1989) concluded that some post-smolts likely overwinter in the Labrador Sea and Grand Banks area. Reddin (2006) noted that many post-smolts were in the Labrador Sea within four months of leaving their home rivers and that in the fall of 1988 were caught at about half the average catch rate of 1SW fish in Greenland, i.e., the population was likely "quite large" (Reddin and Short 1991).

Unlike the Saint John River post-smolts which can directly enter the southwestward running Bay of Fundy currents within a large plume of Saint John River water extending outwards 15 and more kilometers (Figure 5b), the St. Croix, Dennis Stream, Waweig, Bocabec, Digdeguash, and Magaguadavic post-smolts in particular, can only access the Bay of Fundy after encountering the counter-clockwise circulation patterns within the Passamaquoddy Bay/Quoddy Region (Lacroix et al. 2004). Lacroix followed smolts electronically tagged in 1995 and 1996 from the St. Croix and Magaguadavic rivers.

> "The majority of post-smolts moved quickly through the [*Passamaquoddy*] bay (2–6 d) and left by a direct route (range, 74–85%), usually during an ebb tide. Post-smolts that were slow to leave (maximum, 12 d) moved across the bay from the head of one passage [*eastern*] to another [*western*]. The presence of salmon farms both in the

> estuary and along the migration route of fish from one of the rivers did not delay migration, but most losses of smolts and post-smolts from that river occurred in areas near the salmon farms where potential predators were abundant. Herring weirs in the Bay entrapped and delayed some post-smolts from both rivers, and they caused a few losses when post-smolts failed to exit".

Marine temperatures within Passamaquoddy Bay are shown on average to be similar to those of the Bay of Fundy and within the 'preferred' range for post-smolts (Figure 6; Amiro et al. 2003).

In 2001 and 2002, Lacroix (2008) investigated the movements of IBoF post-smolts within the Bay of Fundy, by applying electronic tags to smolts of Mactaquac and Nashwaak River origins. Arrays of receivers were placed:

1. at exits from the Bay, i.e., between Grand Manan Island and New Brunswick/Maine, and as well, Grand Manan to Digby Neck, Nova Scotia,
2. across the outer entrance to the Quoddy Region (Passamaquoddy Bay) area of the aquaculture industry (2001 only), and
3. between New Brunswick and Nova Scotia east of the Saint John array (Figure 7).

Monitoring of tagged smolts from the Saint John occurred between late April and late July; the passage of post-smolts with transmitters through the Bay was continuously monitored to "September - October" (Lacroix 2008). Based on releases of 40 wild-origin and 20 hatchery-origin Nashwaak River smolts and 41 Mactaquac Biodiversity Facility-origin smolts; hatchery smolts on average reached the outer array within a week while the wild Nashwaak River smolts averaged closer to three weeks but were released one to two weeks earlier than their hatchery counterparts. Each group exhibited a comparable distribution to Inner Bay post-smolts at the Outer Bay array and no post-smolts of Outer Bay origin (only seven were ever detected anywhere in 2001) entered the Quoddy Region. About 50% on average, of the tagged smolts were detected leaving the Saint John River and 37% were detected as post-smolts at the outer arrays (Figure 8). Of the 37 post-smolts detected at the outer arrays, 32 were never seen again and presumed to be distant migrants; the remaining five were again detected at the outer array suggestive of the same resident behaviour as those of IBoF origin. However, none were detected at the array east of Saint John.

Post-smolts of OBoF origin tended to exit the Bay rapidly from late-May to early-June and directly through Grand Manan Basin, distant to the either Grand Manan or Nova Scotia although a small proportion of slow migrants (range 9-35 days) were observed (figures 5d, 6b *in* Lacroix 2012*)*. SSTs across the central portion of the outer array, to which most post-smolts would have been exposed in June, 2002, ranged from 8-10°C; the salinity was 30-31‰. SSTs in 2001, when only 7 post-smolts originating from 20 tagged smolts passed through the array, ranged from 8-12°C; salinities ranged from 28-30.5‰ (Figure 8c,d *in* Lacroix 2012).

To extend knowledge of the migration routes, condition and habitat of post-smolts from the Bay of Fundy, Lacroix and Knox (2005) marked and released approximately 900,000 hatchery-origin smolts from Mactaquac Dam on the Saint John River and captured, marked and released several thousand wild smolts migrating from several rivers of the Bay of Fundy, and conducted surface trawling surveys in the Bay of Fundy and Gulf of Maine between 2001-2003. Respective dates of surveys were May 30 - June 13, May 26 - June 15, and June 4 - 18, dates which were selected to correspond to the time of peak smolt migration from rivers of the Bay of Fundy. No captures were made either to the east of the Saint John River or in the vicinity of Passamaquoddy Bay. Total captures numbered 398 post-smolts of which 161 and 237 were of wild and hatchery origin, respectively (Table 3 *in* Lacroix and Knox 2005). Only five captures were positively identified as being of Saint John River origin but since the hatchery-origin smolts are likely to be heavily weighted to a Mactaquac Biodiversity Facility origin it is probable that the distribution of captures across the outflow of the Bay reflects the routing and habitat of Saint John River post-smolts en-route to the North Atlantic (Figure 9a). The path of post-smolts from the Passamaquoddy Bay is unknown: an eastern exit could result in their passage through the Grand Manan Basin like those of the Saint John River, while those exiting the western passage could have entered the south westward flowing Maine coastal current. Post-smolts of the more westerly and down current Dennys and Penobscot rivers in Maine were, however, among those captured in the northeastern Gulf of Maine in 2002 and 2003 (Figure 9a and Lacroix et al. 2012).

Based on post-smolt captures and SSTs during trawling in the last days of May and first half of June, Lacroix (2012 and Figure 9b) suggested a habitat in the OBoF and eastern Gulf of Maine extending to the Scotian Shelf that was characterized by SSTs in the 4-10°C range and which contracted with the onset of summer.

The stomachs of 60 post-smolt handling mortalities over the three years of trawling in the OBoF and Gulf of Maine indicated that most abundant food items were the crustaceans *Themisto* spp. (Amphipoda, Hyperiidae) and *Megancyctiphanes norvegica* and *Thysanoessa inermis* (Euphausiidae, or krill) (Lacroix and Knox 2005). Fish (mostly larval and age-0) occurred in many stomachs, especially Sand Lance *Ammodytes* spp. with lesser frequencies of unidentified fish remains and larval Herring. Food items varied in their frequency between years and location of capture. Diets were the least diversified when surveys were confined to the Gulf of Maine where they were comprised of *Themisto* spp. and *Megancyctiphanes norvegica.*

One-Sea-Winter (1SW) Salmon (Maturing and Non-maturing)

The locations of tag recoveries from 1SW salmon of Saint John River origin (Table 5) are suggestive of the marine habitat utilized by salmon of DU 16. One-sea-winter (1SW) salmon are those that return to spawn following a single winter at sea (also termed Grilse). Maturing and non-maturing life strategies are apparent although the bounds between the two are unclear. Pippy (1982) describes a simplistic process in which Maritime-origin salmon caught in the Newfoundland fishery were said to be maturing, if at a swimming speed of 32 km/day they could reach their natal river by spawning time (other assumptions and calculations are not shown in the report). Dadswell et al. (2010) indicate that homeward-bound salmon are capable of covering upwards of 3,000 km per month (100 km/day). Either of these swimming speeds would put virtually all of the insular Newfoundland tag-recovered fish within the Saint John River by October. However, summary evidence of 1SW catches from within the traditional drift net fishery in the outflow of the Saint John River, 1970-73 (Penney 1983) indicates that virtually 100% of the 1SW catch was completed by the end of July. As well, 50% of hatchery-origin returns were captured 100 km upriver at Mactaquac Dam by the end of July, i.e., prior to the rise of river temperatures above 20°C and low river discharges which generally curtail migration to the dam during the latter part of July and early August.

The above swimming speeds suggest that salmon captured off Nova Scotia in any month are likely to be destined to return in the same year. A similar argument could be made for those captured through July along the south and southeast coast of Newfoundland, i.e., Areas J to G and F to E, respectively (up to approximately 1,000 km distant; figures 3 and 10). May and June captures on the east coast of Newfoundland (Areas F to N) have the potential to reach home waters and, therefore, could be maturing. Those captured in July and later on the east coast of Newfoundland are then most likely non-maturing as are those inarguably, off Labrador and Greenland. This scenario would be consistent with the findings of Idler et al. (1981) *cited in* Reddin (2006), that in late summer and autumn, non-maturing 1SW salmon are found inshore along the northeast Newfoundland and Labrador coasts, at West Greenland, in the Labrador Sea and in the Irminger Sea including the East Greenland Coast. Reddin (2006) reports only a few sets of experimental nets during the winter months and these were all to the east of the

Grand Banks where catch rates were zero to low. He, therefore, suggested that since salmon were found in the Labrador Sea in the fall and then in the following spring (i.e., now as 2SW fish) that North American salmon probably overwinter there.

As well, a small early-run component of Saint John River headwaters, known as the ‘Serpentine Run’ (Saunders 1988) returns in the fall of its second summer at sea (1SW) and on the basis of tagging experiments at Westfield in the lower river estuary, is thought to over winter there before ascending the river as the first salmon arrivals (technically 2SW salmon but smaller) at Mactaquac Dam the following spring.

Two-Sea-Winter (2SW) Salmon

The virtual absence of tag returns from 2SW salmon in any fisheries, save those near the home river (Table 6), suggests that 2SW fish (the 1SW non-maturing component overwintering in the Labrador Sea or points south, such as the Grand Banks) migrate homeward in March, April and early May when ice conditions precluded traditional fisheries. Routes are unknown but are hypothesized to retrace their northward movements as post-smolts.

Repeat Spawning Salmon (Kelts)

The habitat of repeat spawning salmon (Marshall and MacPhail 1987) can be surmised to be similar to that of any of the post-smolt, 1SW or 2SW components (Table 7). It can be presumed that kelts initially follow the route of post-smolts towards Newfoundland and with routing thereafter depending on the life strategy, i.e., a consecutive repeat spawner might be limited in distance to the south coast of Newfoundland before returning while an alternate year repeat spawner and any repeat staying out more than one winter could overwinter in the Labrador Sea and by nature of its routing, be exposed to the coastal habitat and the former fisheries of Newfoundland, Labrador and Greenland as 1SW and 2SW fish. Small scale plots of the recovery locations for various life strategies of 1SW, 2SW (incl. repeat spawners) and older Saint John River salmon (1967-2007) are provided in ICES (2008) and Reddin et al. (2012).

Fortunately, details of the habitats of kelts are now becoming available through the use of four to six month duration PSATs. Five tags were applied to Hammond River kelts in the spring of 2009 [another seven were applied in 2010-2011] for comparison with those applied to IBoF kelts in the fall. Tracking of two fish over four to six months in 2009 resulted in data recoveries on the northwestern edge of the Labrador Sea and the eastern edge of the Grand Banks (Lacroix, pers. comm.[5]). Respective travel times were 124 and 102 days. The data from a third kelt was recovered from the outer edge of the Laurentian Channel after 59 days.

SPATIAL CONSTRAINTS

> *Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.*

FRESHWATER

The larger rivers of the OBoF salmon population have a century or more of industrial development that has constrained the connectivity of Atlantic Salmon and their habitat. Obstructing dams, regulated flows, headponds, other altered habitats, and inputs of point-source pollutants, such as sewage wastewater have been ascribed the cause of connectivity issues on the mainstem Saint John River (and some tributaries) between Mactaquac Dam and Grand Falls (Kidd et al. 2011). They are as well largely accountable for degradation of major sections of the St. Croix and to a lesser extent the Magaguadavic river basins. The major dams and headponds, (and a few storage reservoirs) and their critical impact on the connectivity of habitat in each of the aforementioned basins are summarized in tables 8, 9 and 10. Concise descriptions of these and additional dams and obstructions are addressed in Clarke et al.

(2014). The location of dams and headponds/reservoirs addressed in this document are shown in figures 11, 12 and 13. Potential and known sources of pollution are described in Clarke et al. (2014), but are principally mainstem issues not currently thought to constrain the pathways of migrating salmon as do dams, or significantly impinge on the present estimates of productive habitats.

Saint John River

Within the Saint John River Basin there are over 200 dams or water control structures, more than 100 sources of municipal wastewater and another 70 or more non-municipal effluent sources. There are 15 saw and pulp-and-paper mills, 21 food processing facilities, 19 aquaculture facilities and approximately 40 waste handling and rock handling facilities (Kidd et al. 2011). In 2005, Cunjak and Newbury (2005) reviewed the issue of habitat fragmentation and poor survival of diadromous species in the basin and concluded that, between the hydroelectric dams and industrial pollution on the main stem, the Saint John River probably represented the worst case of fragmentation in eastern Canada. Water quality, however, is generally better since 2000 than it was in the 1960s - likely the result of more and better treatment of municipal and industrial waste water (Kidd et al. 2011).

Essentially all of today's constraints to salmon production occur within the middle Saint John River basin between Mactaquac Dam and Grand Falls. This section and its' tributaries is estimated to comprise 35.7% of the DU 16 habitat (Table 1). Hydroelectric dams at Mactaquac and Beechwood on the mainstem Saint John River, at Tinker on the Aroostook and at Tobique Narrows on the Tobique River can be accorded most of the blame (Figure 11). The impact on water quality by currently treated effluents from e.g., paper mills at Edmundston and Nackawic, food processing plants at Grand Falls and Florenceville and, numerous municipal sewerage collection facilities are on a relative scale, un-assessed but thought to be of much lesser impact (Clarke et al. 2014).

Each of the Mactaquac, Beechwood, Tobique Narrows and Tinker dams is equipped with an upstream fishway that either leads to the entrapment of migrants for upstream transport or, directly to the upstream side of the dam (Table 8). Fishways are known to prevent the passage of some and delay of most fish (Roscoe and Hinch 2010), and despite recent improvements of some fishways on the Saint John River (Hubley et al. 2001) none would be assumed to be more than 90% effective in passing fish. None have specific downstream fish passage facilities although some operators manage turbine use so as to draw large accumulations of downstream migrating smolts to a forebay area for passage through a gate well/turbine. Delays due to the absence of downstream passage or spill, or spill in proximity to locations where smolts and adults naturally collect on the face of the dam are common. Smolt passage through turbines entails some mortality which varies with type of turbine. Estimates of mortality through the slower moving Kaplan turbines range from 10% at Mactaquac Dam to 18.3% at Tobique Dam (Washburn and Gillis Assoc. Ltd. 1996; Ritter and Marshall 1992; MacEachern, unpublished data [1961]). Kelts being larger and, therefore, having a greater risk of being contacted by a turbine blade would be expected to have a higher incidence of mortality.

In addition to the direct fragmentation/connectivity issues at the dams, there are the equally or more important issues that their presence imposes on habitat upstream and downstream (Table 8). It is estimated that at least 145 km of former mainstem riverine habitat was lost to the formation of the Mactaquac and Beechwood headponds. At least another 20 km of former riverine habitat was lost to the Aroostook (Canada only) and Tobique headponds (Table 8). Lost to juvenile and adult salmon are the substrate, holding pools and frequently associated cold water inputs from springs, junctures with tributaries, 'edge' habitats (Newbury and Bates 2006 *cited in* Kidd et al. 2011), channels and currents that afford protection and most importantly, clear directional currents to guide upstream or downstream migration. While headponds may provide respites for pre-smolts (Carr 1999; Jones and Flanagan 2007), they offer little else and with little current can impose significant delays and sometimes disorientation ("fall back" of adult salmon) (Marshall 1975), as well as complete changes in the ecosystem. Specific and adverse changes in the Saint John River headponds has been the establishment and proliferation of significant populations of Smallmouth Bass (*Micropterus dolomieu*) (Chaput and Caissie 2010), Muskellunge (*Esox masquinongy*) and Chain Pickerel (*Esox niger*) - all potential predators of smolts and pre-smolts.

Prior to construction of the Mactaquac Dam and headpond, delays through the headpond and turbines were expected to impact significantly on wild salmon production[8]. Delays in upstream passage of adult salmon through the Mactaquac headpond and inefficiencies of fishways at Beechwood and Tobique dams were expected to impact spawner distribution and angling (Ritter and Marshall 1992). To compensate for lost production as a consequence of Mactaquac and the earlier built Beechwood and Tobique facilities, federal fisheries authorities opted for the construction by New Brunswick Power of the Mactaquac Fish Culture Station[9] *[now Biodiversity Facility],* and as mitigation for the obstructed passage at Mactaquac, a fish trapping and trucking operation (a fishway around the dam was deemed to be impractical). The capacity of the Fish Culture Station was negotiated between New Brunswick Power and the DFO at 500,000 smolts – a number that recognized the inadequacies of hatchery smolts relative to wild smolts (John Ritter, retired Research Manager DFO, pers. comm.). Negotiations were influenced by a report largely developed by Lindroth et al. (unpublished report[10]), which recommended that the "loss of smolts successfully passing Mactaquac be compensated for by the release of 300,000 hatchery smolts (figure not comprising losses due to Tobique and Beechwood power plants)".

Riverine habitat downstream of dams is affected by rapid changes in discharge and temperature which can, as in the case of 1-2 m depth fluctuations below Beechwood Dam (Washburn and Gillis Assoc. Ltd. 1996), detract from the productive capacity and up or downstream migration of salmon (Table 8). These effects can be further compounded by variable discharges from the Grand Falls power house.

In total, dams and headponds affect all 154,530 units of productive salmon habitat upriver of Mactaquac Dam in Canada (Table 1). The most upstream habitats are affected the greatest given that salmon destined for the Tobique or Aroostook rivers can be impacted at three dams and headponds and potentially fail to reach their tributary of origin. The habitat in tributaries upstream of Mactaquac Dam but below Beechwood Dam has a higher probability of utilization by their originating stock (and possibly adults from other tributaries) unless the adults were trucked above their tributary of origin. The cumulative effect of the impacts of successive dams and headponds is best illustrated by trials conducted by DFO and summarized for Washburn and Gillis Assoc. Ltd. (1996). These trials consisted of the release of a total of 150,000 coded wire tagged smolts to sites upstream of Grand Falls, Tobique Narrows, Tinker Dam and Beechwood, and downstream of Tobique Narrows, Beechwood and Mactaquac over three years (1990-1992). Returns to Mactaquac of 1SW fish released above three dams, two dams and one dam relative to those released below Mactaquac Dam yielded relative survivals of 55, 73 and 84%, respectively.

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[8] The Mactaquac hydroelectric facility opened with two functioning turbines; an additional four units were added by 1979.

[9] Operational costs of the facility, as well as the trapping and trucking operations were to be assumed by Fisheries and Oceans Canada.

[10] Unpublished report "The Mactaquac project and St. John River salmon" prepared for the N.B. Electric Power Commission, Fredericton, NB, by by A. Lindroth, C.W. Argue, and A.L. Pritchard (Draft May 2, 1967). Aavailable from the DFO Library, Bedford Institute of Oceanography, Dartmouth, NS.

St. Croix River

The international St. Croix River has a length of 185 km and comprises an estimated 4% of the salmon habitat of DU 16 (Canadian waters). Unlike the Saint John River where three of the four salmon habitat-impacting hydroelectric developments were initiated in the last half of the 20th century and included upstream fish passage, development of mills on the St. Croix River (many dams are now gone) began 150 or more years earlier with little serious consideration given to promotion of fish passage even though rudimentary structures were attempted. The lack of attention to fish passage, discard of waste from saw, textile and paper mills, tanneries and municipalities had salmon near extirpation as early as 1849 (Marshall 1976) or 1825 (Sochasky 1995). Restoration attempts over the ensuing 125 or more years were sporadic and unsuccessful largely because of failed international co-operation in controlling pollution, and incorporating or building reasonably efficient fishways in previous dams, now removed, and at the remaining Milltown, Woodland and Grand Falls dams (Table 9; Figure 12). Recent thoughts toward restoration of the salmon resource began in 1955 when the issue was referred to the International Joint Commission (IJC), which over a span of more than 25 years prompted and monitored improvements to pollution control and the provision of adequate fish passage by parties on both sides of the international boundary (Marshall 1976). The final hurdle to restoration, the pool and weir fishway at the Milltown Dam, was completed by NB Power in 1982 (Anon. 1988).

In 2008, there were an estimated 38 impoundments (FB Environmental 2008) including six major dams, three dams on the mainstem producing hydroelectric power, three dams providing the water storage for their operation and a fourth small storage dam on the Canoose River, New Brunswick (Table 9). The constraints to connectivity in the St. Croix are somewhat like those of the Saint John River. They included three dams and power houses with less than 100% effective upstream passage, the absence of adequately designed downstream fish passage, the loss of guiding currents in two of three headponds/flowages and variable discharges through turbines that cause the flooding or dewatering of habitat. One major difference from the Saint John River is that essentially all of the productive salmon habitat in the St. Croix lies upstream of the three major hydro dams (Mohannes Stream excepted). Other differences include: the much smaller scale of power generated, water available, and size of headponds. Nevertheless, upstream (Anon. 1988) and downstream passage is judged to be no more effective than that on the Saint John River. The short and shallow Woodland Flowage with its recreationally important Smallmouth Bass population (Table 9) and the 180 m denil fishway from the mainstem St. Croix River to Grand Falls Flowage may in fact constitute more of a constraint to connectivity than comparable issues addressed on the Saint John River.

Magaguadavic River

The Magaguadavic River originates in Magaguadavic Lake in the southwest part of NB and flows south-easterly 97 km to Passamaquoddy Bay, off of the Bay of Fundy near St. George (Carr et al. 1997; Carr and Whoriskey 1998) (Figure 13). There are 103 named tributaries and more than 55 lakes within the drainage area (Carr and Whoriskey 1998); however, the estimated salmon habitat is little more than 1% of the total for DU 16. The St. George Dam sits atop a falls at the head-of-tide and dates back to 1903. Records from the National Archives of Canada Volume 813, through various files[11], relate the saga of stocking with salmon and failed attempts in 1916-1917 to build an ‘elevator’ fishway in the gorge, the introduction of 140 Smallmouth Bass in 1925, the completion of a conventional pool and weir fishway in 1929 and ice damage in 1930.

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[11] Copies obtained and provided by Rod Bradford, DFO, Maritimes Region.

The same files indicate that in 1917 “the river was never in the least a salmon river on account of the impediment put there by the nature of the falls” (C.B./D 719-6-7). As well, on August 28, 1927, a letter from the Deputy Minister noted “the falls at the mouth of the Magaguadavic River has always been an absolute obstruction to the passage of salmon” (C.B./IAR 719-6-7). Earlier documentation by Wellington Davis, Overseer, noted that he never saw salmon in the Magaguadavic during his tenure, 1894-1899 (T2852-164). Hence, it would appear that the Magaguadavic salmon were introduced through stocking – likely from early hatcheries supplementing the Saint John River.

While upstream passage has been achieved with varying effectiveness (low in years of disrepair resultant of harsh ice conditions in the gorge), downstream passage had been achieved to some degree by a sluiceway which, when tested, appeared to be somewhat effective (Martin 1987). A surface by-pass with an assessment facility was incorporated into the new powerhouse/dam that was operational in 2004 (Jones et al. 2006). The headpond, although 17.5 km in length, is little more than a low gradient sinuous stream largely confined by pre-dam high water river banks and supportive of a Smallmouth Bass population. The issue of lost connectivity due to absence of current under modest flows is unlikely to deter adults that successfully ascended the fishway from reaching the productive salmon habitat.

TIDAL INFLUENCED/ESTUARINE/MARINE

There are no strong cases for spatial constraints of Atlantic Salmon in the marine environment. Lacroix et al. (2004) tracked acoustically tagged smolts from the Magaguadavic and St. Croix rivers and described the success of post-smolts moving out of Passamaquoddy Bay and into the several passages leading to the Bay of Fundy as being "reasonable" (range, 71–88%). The presence of salmon farms both in the St. Croix Estuary and along the migration route from the Magaguadavic River outflow did not delay migration, but most losses of smolts and post-smolts from that river occurred in areas near the salmon farms where potential predators were abundant.

The influence of warming sea temperatures in recent years may be thought to be a constraint on salmon accessing former feeding areas (Lacroix et al. 2004), encountering new predators, etc., factors over which managers have little control. Todd et al. (2008) assessed the detrimental effects of recent ocean surface warming on growth and condition of Atlantic Salmon and concurred with Reist et al. (2006) that the effects of ocean climate on Atlantic Salmon growth and survival are both pervasive and complex, i.e., probably more complex than a spatial configuration constraint.

HABITAT SUITABILITY/SUFFICIENCY

> *Provide advice on and quantify 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.*

FRESHWATER

The occurrence of juvenile salmon in most tributaries of the Saint John River and tidal impacted rivers of the lower Saint John River Basin (Table 1) in 2009 (Figure 14) suggests an element of suitability for juvenile salmon, particularly on the Tobique, Shikatehawk, and Becaguimec tributaries upriver of Mactaquac Dam and the Keswick, Nashwaak, Canaan, Kennebecasis and Hammond rivers downstream of Mactaquac. Juvenile densities have been greater at long-standing index sites (Jones et al. 2010), as have wild adult escapements, particularly prior to 1993 when wild returns to Mactaquac Dam (Jones et al. 2010) were a factor of five to ten times their current abundance. Similar declines of adult escapement and juvenile densities have been observed on the Nashwaak River below Mactaquac Dam where large dams and headponds are not a factor. This suggests that factors other than connectivity may be more of an issue in the generally low densities and low utilization of habitat.

Densities of salmon in the outer Fundy complex rivers in 2009 (Figure 14) were found to be low to non-existent except at several sites in the Digdeguash, Pocologan and Dennis Stream and on the Magaguadavic (Jones et al. 2014; Jon Carr, Atlantic Salmon Federation, pers. comm.). In the latter however, results were influenced by the presence of juvenile escapes from private hatcheries supporting the aquaculture industry. No data were collected from the St. Croix River in 2009 as efforts to re-establish salmon in the presence of Smallmouth Bass in that system ended in 2006 (Lee Sochasky, *formerly with the* St. Croix Waterway Commission, pers. comm.). No time series of juveniles at index sites have been maintained by DFO on the outer Fundy complex rivers.

The current presence or absence of salmon and use of gradient as a proxy for productivity/ ‘suitability’ of habitat for juvenile salmon in historically salmon producing rivers provides a somewhat simplistic insight into suitability now and when [or if] the species reaches biologically based recovery targets. A comparison of tributaries and rivers in the Saint John River Basin for which ortho-gradient data had been collected suggests that on a per unit area basis, the smaller streams with lower total capacity have the greatest potential and most suitable habitat to maximize juvenile productivity, e.g., Shikatehawk Stream, Salmon River (Victoria County), Bellisle Creek, Becaguimec Stream, and Big Presquile River (Figure 15). Current conservation requirements are based on the premise that all utilizable salmon habitat be seeded at a rate of 2.4 eggs/ m^2 which for the total area upriver of Mactaquac Dam is set at approximately 34.6 million eggs (Marshall et al. 1997). The current conservation target upriver of Mactaquac Dam does not include the productive estimates in the Aroostook River, the mainstem between Hartland and Beechwood Dam or inaccessible habitat (Table 1) and as suggested by Figure 14, not all habitats are equal. For additional productive habitat (at least Canadian waters), threat impacts and other criteria outlined in Jones et al. (2014) are considered when establishing recovery targets.

Suitability of habitat can also be viewed from the perspective of Elson 'norms'[12] for juvenile abundance in streams as a “whole” (Elson 1967). For example, since 1993 on the Tobique River, which accounts for almost 19.4% of the habitat for DU 16, there has only been one year in which an Elson ‘norm’ for fry, and no years in which the ‘norm’ for parr was attained (Jones at al. 2010) - most years were less than 20% of the ‘norm’. The attainment of the ‘norm’ for parr, as a measure of suitability however, could be a lofty goal given the ‘norms’ weighting towards higher values for the Miramichi River[9]. The lower values for the Tobique River component in the ‘norm’ may well have been the result of habitat alteration in the 1950s, including the construction of the Tobique Narrows hydroelectric dam, controlled discharges for power generation from four storage reservoirs (Table 8) and an indirect result of DDT spraying in 1953, and 1955-58 (Elson 1967). Some smaller and relatively pristine streams such as the Shikatehawk below Beechwood Dam (1.1% of the DU 16 habitat) have yielded much higher densities than the norms (Jones et al. 2004; Marshall et al. 1999). Recently, Gibson et al. (2009) applied an equilibrium model to the Tobique population to analyze dynamics, identify stressors and predict the population level response to potential recovery actions. The study indicated that

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[12] Elson norms of 24 underyearlings, 20 small parr and 12 large parr per 100 yd^2 [29 age-0 and 38 age-1 and older fish/100 m^2] are the unweighted means of juvenile salmon determined for the Miramichi's Northwest Miramichi, Dungarvon, Renous and Cains rivers, 1950-1962, as well as Saint John's Tobique and Nashwaak rivers, 1957-1961 in sites not subjected to DDT spraying. The Miramichi sites outnumber Saint John River sites by a ratio of about two-to-three to one and revealed densities for underyearlings, small parr and large parr that are 2.5, 6.3 and 1.3 times greater, respectively, than those of the Tobique and Nashwaak rivers.

recovery efforts would need to focus on multiple threats, i.e., improving both freshwater habitat and fish passage in order to produce a viable population.

With the exception of the Nashwaak River, much less is known about adult escapement and subsequently, the inferred suitability of habitat downstream of Mactaquac Dam. Compared to escapements upstream of Mactaquac Dam, the time series for adults for the Nashwaak River is shorter, and since 1993 when recent monitoring began, the river has never achieved conservation egg depositions. In the decade preceding 1993, fry densities did achieve the Elson 'norm' but over the last 15 or so years, have failed in most instances to meet 50% of the 'norm'. However, over the period of 1982 to present, parr densities largely failed to achieve more than 50% of the 'norm' (Jones et al. 2010). That there is an apparent discrepancy in 'norm' achievements for fry and parr suggests potential productivity limitations on the Nashwaak River. Estimated smolt production for the years 1998-2008 ranged from 0.10 to 0.53/ 100 m^2 and averaged 0.3/100 m^2, which is well below the 2-5 smolts/ 100 yd^2 (2.4- 6.0/ 100 m^2) expected on average by Elson (1975) from a spawning intensity of 140 eggs/ 100 yd^2 (more recently taken as 2.4 eggs/ m^2).

This is again suggestive that the available habitat is limiting, and may be unable to respond to greater escapements resultant of any increases in marine survival. Hence, recovery initiatives in the Nashwaak River and elsewhere downstream of Mactaquac Dam would as well require a focus on freshwater habitat, which like the Tobique River, was impacted by DDT spraying 1958-1962 (Elson 1967) and continued forest harvesting.

Based on past and recent evidence on productivity in rivers upstream and downstream of Mactaquac Dam (Jones et al. 2014), it is expected that most, if not all, accessible systems could support an increase in juvenile salmon populations assuming that trapping and trucking operations continue around Mactaquac Dam. Whether available Saint John River habitat can support recovery target populations of 2.4 eggs/ m^2 is unclear since monitored sites have not recently met conservation targets. The potential for supporting target juvenile populations is expected to decrease as habitat is/populations are effectively restricted by dams and/or degraded by individual or compounded threats (Clarke et al. 2014).

The effects of low marine survival among Canadian stocks since 1992 (COSEWIC 2010), increased occurrence of warm water predators of salmon in headponds and the main Saint John River downriver of Mactaquac Dam (Kidd et al. 2011) and a changing climate and possible limitations on existing habitat [13], e.g., reduced summer river discharges and oxygen levels co-incident with increased water temperatures (Kidd et al. 2011), will require a further reassessment of 'recovery objectives' and 'conservation requirements'.

An exploratory inspection of the relative abundances of non-salmon species captured by electrofishing at the same index sites on the Tobique tributary in 2009-2010 and 1973-1978 is suggestive of a relatively stable fish community occupying salmon habitat during the last four decades (Figure 16), i.e., the potentially reduced capacity of the habitat may yet be unaffected by some more recent events. A cursory view of the data for 2010 and 1973-1978 on the

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[13] Natural Resources Canada (*as cited in* Kidd et al. 2011) predicts that western New Brunswick will have a 2 to 4°C increase in summer [air] temperatures in addition to an approximate 2°C increase in winter temperatures by 2050 (Kidd et al. 2011). As well, there will likely be more very hot days and fewer very cold ones; and in the Saint John River Basin, an expected increase in precipitation and its intensity. Higher temperatures are expected to result in higher rates of summer evapotranspiration, such that there will be less water flowing through the Saint John River and its' tributaries during the summer months than there is today (*as cited in* Kidd et al. 2011). As well, there is already evidence of a decline in annual water flow in the Saint John River associated with warming temperatures. Bruce et al. (2003) *cited in* Kidd et al. (2011) reported that from 1900 to 2000 the average annual temperature in the basin raised by 1°C, with much of this increase occurring after 1970. They also noted a corresponding 13% decrease in the average annual flow of the Saint John River Basin at Fort Kent near Grand Falls from 1970 to 2000.

Nashwaak River yielded similar results with the exception and expectation of a strong presence of American Eels (*Anguilla rostrata*). Smallmouth Bass were not present in electrofishing sites of either river, neither recently nor in the 1970s. Adult bass are currently resident in the Tobique and Nashwaak rivers downstream of the lower most electrofishing sites but no comparable observations are reported for the 1970s (Clarke et al. 2014). Catches of juvenile Smallmouth Bass in rotary screw traps on both these rivers would suggest the adults are successfully spawning and indicate self-sustaining populations now exist in lower reaches of these two watersheds. During an extensive survey in 2009, within the Saint John River Basin, Smallmouth Bass have been recorded in electrofishing sites on the Meduxnekeag, Monquart, Shogomoc, Pokiok, Eel, Shikatehawk, Big and Little Presquile rivers and Gibson Creek (Clarke et al. 2014); none were revealed in the electrofishing data from the 1970s.

For rivers of the outer Fundy complex, the potential salmon habitats of the Magaguadavic and St. Croix rivers are the best documented, although with less understanding and comparability to the rivers and tributaries of the Saint John River Basin. Together they account for little more than 5.4% of the estimated habitat of DU 16. Both have connectivity issues resultant of hydroelectric dams (tables 9 and 10) and habitat that is contested by Smallmouth Bass and Chain Pickerel and as well on the Magaguadavic, escaped juvenile salmon from private hatcheries supporting the Passamaquoddy Bay aquaculture industry. The absence of historical juvenile indices of abundance and gradient classification of the habitat precludes an informed assessment of ‘suitability’.

The Magaguadavic River has received several hundred annual wild returns inside of the last two decades and returns have all but ceased recently (Jones et al. 2014). This suggests the potential to support increased numbers of salmon. As described above, a lack of reliable historic indices and prevalence of threats (Clarke et al. 2014) make it difficult to quantify likelihood of this system’s ability to support sufficient populations for recovery. The St. Croix River’s habitat was so violated by dams, mill effluents and forest product waste that the native stock was long ago extirpated. Most recent efforts at reintroducing juvenile salmon of Penobscot and St. Croix River (remnant/strays) origins, 1981-2006 (Appendix VI *of* Jones et al. 2010), and surplus down-east (Maine) captive-reared broodstock, 2001-2002, met with little success and were abandoned in 2006 (Sochasky, pers. comm.). Cursory survey data, 2001-2003, indicated that it would be very difficult to establish juvenile salmon populations in large mainstem reaches (75% of the estimated salmon habitat) that have abundant predators/competitors (e.g., Smallmouth Bass) and water temperatures that may exceed suitability criteria in the summer (Randy Spencer, Dept. of Marine Resources, State of Maine, pers. comm.). Less is known about the presumed salmon habitat on the Magaguadavic River but the evidence that it is now inhabited by Smallmouth Bass (Carr and Whoriskey 2009) and juvenile (and adult) hatchery escapes (Carr and Whoriskey 2006) present significant challenges to the successful establishment of wild Atlantic Salmon.

Estimated salmon habitat of the outer Fundy complex rivers, exclusive of the Magaguadavic and St. Croix, account for only about 1.5% of the total for DU 16. The occurrence of small numbers of juveniles (Figure 14) do little more than indicate some level of habitat suitability for salmon; there is no knowledge of their stock origins (e.g., progeny of escapes) or of the current or future potential of these habitats. Based on electrofishing surveys of 2009, recent assessment of known threats and other criteria used to define recovery targets, the Digdeguash River may contain the most currently suitable habitat of the outer Fundy complex systems.

TIDAL INFLUENCED/ESTUARINE/MARINE

As indicated earlier there have been no strong cases for spatial constraints outside of the river. However, the survival to adults of smolts released from the Mactaquac Biodiversity Facility and those estimated to have migrated from the Nashwaak River are considerably less than what they were two and three decades ago (Jones et al. 2010) suggesting that the availability of suitable habitat in the estuaries or at sea has diminished. This could conceivably occur as a consequence of a number of threats delineated and discussed by Clarke et al. (2014). Among the most probable threats would appear to be climate change and its' potential to shift oceanic conditions, e.g., to alter growth in freshwater, which in turn could result in increased predation of post-smolts by traditional predators in estuaries and at sea or lead to timing mismatches with physical and biological (food) conditions in estuaries and at sea.

As alluded to under 'Spatial Constraints 'of habitat, the influence of warming sea temperatures in recent years may be a constraint on salmon accessing feeding, encountering new predators, etc., and is equally applicable to 'Habitat Suitability/Sustainability'. Again, Todd et al. (2008) assessed the detrimental effects of recent ocean surface warming on growth and condition of Atlantic Salmon and concurred with Reist et al. (2006) that the effects of ocean climate on Atlantic Salmon growth and survival are both pervasive and complex, i.e., probably more complex than a spatial configuration constraint. It is also possible that traditional migration corridors have become increasingly less supportive to life cycle completion.

Shifts in Oceanographic Conditions[14]

> "Large-scale changes to atmospheric and oceanographic conditions have been observed throughout the marine range of Atlantic Salmon in North America. For example, the Western Scotian Shelf experienced a cold period during the 1960s, was warmer than average until 1998, and then significantly cooled after a cold water intrusion from the Labrador Sea (Zwanenburg et al. 2002). The Eastern Scotian Shelf cooled from about 1983 to the early 1990s and bottom temperatures have remained colder than average since then (Zwanenburg et al. 2002). Sea-ice cover in the Gulf of St. Lawrence and off Newfoundland and Labrador in the winter of 2009-2010 was the lowest on record for both regions since the beginning of monitoring in 1968/69.
>
> The North Atlantic Oscillation (an atmospheric circulation pattern centered over Iceland) has been shifting from mostly negative to mostly positive values from the 1970s to the early 2000s (Visbeck et al. 2001). Positive NAO values are associated with low pressure, strong westerlies with high air temperatures in continental Europe, and high penetration by the North Atlantic (NAO) Current into the Nordic Seas. Although recent years have seen a return to low NAO values, climactic models favour a shift in the mean state of atmospheric circulation towards positive NAO conditions, likely due to anthropogenic impacts (Osborn 2011). Winter NAO is strongly negatively correlated with sea-surface temperature and thus could influence Atlantic Salmon overwintering behaviour and mortality rates at sea. Most research that has found a correlation between Atlantic Salmon catches (Dickson and Turrell 2000), sea-age at maturity (Jonsson and Jonsson 2004), or adult survival and recruitment (Peyronnet et al. 2008) with winter NAO values has been from European populations, although there are weakly correlated examples from North America (e.g., Friedland et al. 2003). However, partitioning marine mortality into that experienced predominantly in freshwater and near-shore environments (first year) and that experienced in more distant marine environments (second year) demonstrated a strong correlation between NAO and survival in the second year for alternate-spawning Atlantic Salmon from the LaHave River (Hubley and Gibson 2011)."

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[14] Taken directly from Bowlby et al. (2014).

Changed Predator or Prey Abundance[12]

> "The abundance and distribution of prey species and predators is thought to be an important factor affecting marine growth and survival of Atlantic Salmon populations (Thorstad et al. 2011). Recent evidence of a whole ecosystem regime shift in the Eastern Scotian Shelf demonstrates that significant change to the ecological communities experienced by wild Atlantic Salmon populations at sea is likely, particularly if individuals use areas farther from the coast. The Eastern Scotian Shelf ecosystem has shifted from dominance by large-bodied demersal fish, to small pelagic and demersal fish, and macroinvertebrates; a change that is also thought to be occurring in surrounding regions (i.e. Western Scotian Shelf), albeit at a slower pace (Choi et al. 2005). One of the most worrying aspects of this shift is that strong trophic interactions between the remaining top predators, as well as fundamentally altered energy flow and nutrient cycling, appear to be maintaining the new ecological state, making it unlikely that the community will shift back to historical conditions (Choi et al. 2005). It has been hypothesized that changes in the abundance and distribution of small pelagic fishes affects food availability and thus marine survival of Atlantic Salmon (Thorstad et al. 2011), or that increased Grey Seal (*Halichoerus grypus*) populations (as seen on the Eastern Scotian Shelf (Zwanenburg et al. 2002)) may lead to significantly higher predation pressure. However, empirical evidence of either impact has yet to be determined for Southern Upland Atlantic Salmon."

Lacroix (pers. comm.) noted that marked changes in the diving behavior and temperature of kelts tagged with PSATs indicated that large pelagic fish with thermoregulation capabilities (e.g., Porbeagle, *Lamna nasus*) predated several tagged kelts of Inner Bay origin in the Gulf of Maine.

OPTIONS FOR HABITAT ALLOCATION

> *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.*

The functional characteristics of freshwater and marine habitats that are required to ensure the successful completion of the life cycle of Atlantic Salmon are detailed above. Bowlby et al. (2014) offered that failure to consider all of these components when identifying priority habitats for allocation could lead to a disconnect between that which is protected and what is necessary from a population-level perspective. Adult Atlantic Salmon require appropriate river discharge conditions and unimpeded access to reach spawning areas, as well as holding pools and coarse gravel/cobble substrate distributed throughout a river system on which to spawn. Eggs, alevins and juveniles require clean, uncontaminated water with a pH >5.3 for appropriate development, as well as steady, continuous water flow and areas with appropriate cover during winter and summer to deal with temperature extremes. Smolts need appropriate water temperature, photoperiod and river discharge as cues to migrate and require unimpeded access throughout the length of the river. Immature and mature Atlantic Salmon in the marine environment require access to sufficient prey resources to support rapid growth, where prey distributions are likely correlated with temperature or other oceanographic variables.

FRESHWATER[15]

Habitat allocation in freshwater should be focused on protecting the functional characteristics of habitats so as to minimize extinction risk for OBoF Atlantic Salmon populations. This task will be challenging given that habitat fragmentation in the Saint John River Basin (not unlike the rivers

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[15] Text patterned after Bowlby et al. (2014).

of the outer Fundy complex [Clarke et al. 2014]) is described by Cunjak and Newbury (2005) as perhaps the worst case in eastern Canada. A further complication is that river specific stocks of DU 16 in existence prior to 1880 have since been exposed to one or more of: 1) river escapements of mature fish from the aquaculture industry (Clarke et al. 2014), 2) hatchery introductions of Atlantic Salmon originating peripheral to DU 16, 3) homogenization by long time hatchery practices, and 4) misplacement through practices of trucking spawners long distances around multiple dams.

In the case of hatchery practices, approximately 174 million salmon "fry", "advanced fry" and "fingerlings", i.e., unfed fry, fry and age-0+ summer parr were stocked in the Saint John River between 1880 and 1984 (unpublished summaries[16]). Age-1+ parr stocked between 1935 and 1984 numbered 2.2 million while smolts of all ages, which were released between 1968 and 1984 numbered 4.2 million fish. Additional fish were stocked in most of the outer Fundy complex rivers. Most disconcerting by present day practices is that river-specific stocks went unrecognized with early egg sources for Saint John River releases, originating at various times from River Philip, Nova Scotia and the Morell River, Prince Edward Island and the Restigouche, and Miramichi rivers in New Brunswick. There was also widespread use of the Saint John River mixed stock collected in the lower river, at Mactaquac Dam or from a limited number of other locations. The probable high mortality of early fry distributions likely limited the impact of mixed stock distributions on river/tributary specific stocks (Marshall et al. 1995a) but the same may not be true for the release of older-aged juveniles of mixed stock origins over the last 50 years. That said, multi-locus genetic studies of populations within the Saint John showed significant variation among tributaries – differences, which were greater than between most river systems in North America (Verspoor et al. 2005a). While genetic considerations are important, priorities for allocation of habitat in fresh water of DU 16 can only be based on rivers and tributaries that currently exhibit a capacity for natural spawning and the nurturing of juvenile salmon.

High priority should be accorded to those rivers of the Saint John River Basin exhibiting high productivity e.g., >10.1 juvenile salmon per 100 m^2 (Figure 14), have full connectivity with an estuary and the Bay of Fundy, are least likely to be influenced by escapes from hatcheries and the Quoddy aquaculture industry, and require the least amount of management. These rivers, if based on electrofishing in 2009 (Figure 14) include the Nashwaak, Canaan, Kennebecasis and Hammond. The Keswick River also demonstrates capable habitat, but its' genetics may well reflect a potpourri of stocks originating upriver of Mactaquac Dam that dropped back from or arrived after the late October closure or failed to successfully navigate the fish collection facility at Mactaquac Dam.

Under a "free-swim" scenario for adults returning to Mactaquac, i.e., fish released to the upriver limits of the Mactaquac head pond, high priority could be accorded to the Tobique, Becaguimec and the apparently highly productive juvenile habitat of the Shikatehawk River (Figure 15). It, like the Keswick River may however, also be home to a number of tributary stocks that dropped back from or arrived after the closure each fall of the fish collection facility at Beechwood Dam. The Tobique River and its' tributaries offer extensive opportunities if, as in the case of the 'Serpentine' stock, Tobique-specific programs continue under the auspices of the Mactaquac Biodiversity Facility and if releases of water from storage reservoirs and downstream hydroelectric dams can be effectively managed. The prioritization of the habitat of the remaining tributaries accessed by spawners under 'free-swim' would, of necessity, take into account the recovery target criteria set out in Jones et al. (2014).

In the absence of measures of gradient classified stream habitat comparable to that of the Saint John River Basin, significant densities of juvenile salmon in 2009 (Figure 14; hatchery fish being

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[16] Summary of annual distributions to the Saint John River as listed in the annual reports of the various federal Departments responsible for fish culture (1880-1984).

excepted) and an assessment of the relative uniqueness of genetic lineages (evidence of swamping by aquaculture fish per Bourret et al. 2011), there is less basis on which to prioritize habitat of the non-Saint John River OBoF rivers. However, to achieve geographic representation of the entire DU while following other prioritization criteria discussed above, the Digdeguash River would receive highest priority for recovery among the outer Fundy complex systems. The St. Croix River has significant connectivity issues; the original stocks were long ago extirpated and Smallmouth Bass appear to be the dominant resident of the main stem habitat. The Magaguadavic River has similar issues to those of the St. Croix River plus the escape of juvenile aquaculture fish from hatcheries located within the drainage. The habitat of the remaining rivers of the outer Fundy complex, Digdeguash excepted, are estimated to be small and the genetics of those stocks, Waweig and Dennis Stream[17] excepted, are unknown but have been influenced, as have all outer Bay rivers, by hatchery fish, which likely emanated from facilities in the Saint John River Basin and presumed escapes from the aquaculture industry.

The above attempts at prioritization presuppose that in the short and likely longer term, hydroelectric dams and open water aquaculture will persist. Similarly, the effects of climate change, urbanization, forestry and agriculture and, the spread of ‘warm’ water predators of salmon will increase and, therefore, there is likely only to be decreases in habitat available to salmon of DU 16. The prioritization does however seek to preserve a cross section of population characteristics as they exist today in the hope that robustness and adaptive potential of populations will be available for persistence and possible recovery.

ESTUARINE

The risk in allocating tributary rivers and rivers of the Saint John River Basin for the recovery of the entire DU (reference preceding paragraphs) is that all habitats are dependent on a single functional lengthy tidal estuary (that portion of the lower Saint John impacted by either tidal water and/or salt water intrusion), a corridor for safe passage of smolts and kelts migrating to the Bay of Fundy and adults returning to spawn. The 60 km estuary is believed to serve as an area of extended residency for adults in particular (Marshall et al. 1995b) and on average a 5-6 day residency for smolts (Lacroix 2008). Recent investigations (Lacroix 2008) suggest high mortality among electronically tagged smolts, but the reasons are unknown. The habitat is greatly affected by multiple anthropogenic threats (Clarke et al. 2014), is in the longer term being impacted by rising freshwater temperatures, and increased annual but seasonally more variable discharges (Kidd et al. 2011).

MARINE[18]

Outside of the estuarine and early ocean rearing areas including the Passamaquoddy Bay and outer extent of the Bay of Fundy and Gulf of Maine, marine habitats used by Atlantic Salmon populations of DU 16 cannot as yet be delineated at a scale relevant to typical administrative boundaries. Based on the tagging data, marine habitats encompass coastal areas from the Bay of Fundy to Greenland and they are seasonally and annually variable depending on factors such as oceanographic conditions or prey distributions. Although the available tagging data give some indication of the seasonal location of OBoF salmon, they do not capture annual variability or the true extent of potential movement (e.g., into off-shore areas) due to sampling limitations. Recent tagging of several salmon with PSAT tags (Lacroix, pers. comm.[5]) did not reveal

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[17] Treatises by, e.g., Spidel et al. (2003); Verspoor (2005); Verspoor et al. (2005b); King et al. (2000); King et al. (2001); and Cordes et al. (2005), which include or reference rivers of CU 17 (DU 16), tend to be based on few samples and little background as to factors that may have influenced results.

[18] This section has been extracted in near entirety from Bowlby et al. (2014).

succinct areas that should be considered for marine habitat allocation because these data were incomplete and marine conditions too variable over time.

RESEARCH RECOMMENDATIONS

> *Recommend research or analysis activities that are necessary in order to complete these habitat-use Terms of Reference if current information is incomplete.*

While current information is incomplete, it is unlikely that the effort to develop new and or supporting information, particularly with respect to current suitability of habitat and choice of river habitats, will lead to dramatically different outcomes than those proposed herein. That said, there is a need to develop more realistic expectations of ‘norms’ for juvenile populations and reassess conservation requirements in a changing environment in order to better manage expectations for recovery and conduct appropriate assessments. Recommendations include:

1. An historical perspective of the stocking of Atlantic Salmon in DU 16, so as to impart the past potential for hatcheries to have affected current genetics;
2. A synthesis of recent genetic studies of salmon from rivers of DU 16, northeastern New Brunswick and Maine with respect to the presence of unique lineages and rivers/ habitats for prioritization of importance;
3. Estimates of parr productive capacity for river/tributaries using proportionate ortho-grades determined for the Shikatehawk River, i.e., discounting of lower gradients, which are more prone to cumulative impacts of forestry, agriculture, siltation, road crossings, a warming climate, urbanization, etc., thereby yielding an alternate proxy for prioritizing expectations;
4. An overlay of juvenile densities since 2009 on Figure 14 for a more robust visual of the most utilized/better performing habitats;
5. Assessments of historical trends in stream flow, ice and snow in rivers/tributaries where salmon habitat has been identified (i.e., additional to the mainstem studies on the Saint John) as they affect in-river salmon productivity and possible synchronicity with conditions in ocean feeding areas;
6. Statistical analyses of present and past fish biodiversity at electrofishing sites to determine if there have been changes which might impact the expectations for salmon production;
7. Summary details of the tracks, end points and possible fate of PSAT tags affixed to Hammond River kelts in the springs of 2009-2011 so as to document at-sea locations and metrics of the habitat utilized (since published, see footnote 4);
8. Area estimates of the outer Fundy complex rivers to be consistent with measures for the bulk of the river/tributaries of the Saint John River Basin;
9. Investigation of population dynamics, predicted freshwater carrying capacity in terms of norms for juvenile abundance, and estimated recovery potential for tributaries/rivers of the Saint John River Basin with and without habitat connectivity issues;
10. Identification of cool water seeps, cold water plumes, and temperature profiling of the various systems in DU16 to generate an inventory of thermal refuges important as staging areas during migratory phases; and
11. Assemblage of existing isopleth maps of climate variables such as temperature, frost-free days, growing season, precipitation, etc., for New England and Atlantic Canada that with forecasts of a changing climate (reference footnote 11) might be suggestive of the probabilities of persistence of Atlantic Salmon in regions/river basins within DU 16.

DISCUSSION

In total there is an estimated 49.7 km^2 of productive habitat available to Atlantic Salmon within DU 16 Canada and USA. Eighty-one percent is within Canada. Of the combined Canada-USA area, 90% is within the Saint John River Basin. Within the Saint John River, 21.5 km^2 is upriver of Mactaquac Dam and 23.1 km^2 is downriver of Mactaquac Dam. Only 5.0 km^2 (10%) is found in rivers west of the Saint John River. Man-made barriers totally exclude salmon from only 1.3 km^2 of productive habitat in DU 16. The tidal habitat of the Saint John River Basin, head of tide to the reversing falls, is 140 km in length; that of the outer Fundy complex, exclusive of the St. Croix River, is by comparison relatively inconsequential. The marine habitat is widespread from the Bay of Fundy and Gulf of Maine, to the Atlantic coasts of Nova Scotia, Newfoundland, Labrador and Greenland including the Labrador Sea but is poorly understood.

In the absence of a consideration of ‘threats’ to the freshwater habitat (Clarke et al. 2014), the major spatial constraint is connectivity resultant of large hydroelectric dams and headponds in the Saint John River Basin as well as the St. Croix and Magaguadavic river basins. Major dams and headponds affect 48% of the estimated accessible productive freshwater habitat on the Saint John River; 52% of that in DU 16. Indeed, hydroelectric dams and industrial pollution on the mainstem of the Saint John River probably represent the worst case of fragmentation in eastern Canada (Kidd et al. 2011).

Based on juvenile densities and measurement of grades, the suitability of existing habitat is variable and in consideration of connectivity and threats from Smallmouth Bass and aquaculture fish, favours that of the Saint John River Basin. The degree of suitability and future suitability are problematic. The current presence or absence of salmon and use of gradient as a proxy for productivity/‘suitability’ for production of juvenile salmon provides only a cursory insight into suitability now and when [or if] the species reaches biologically based recovery targets. Conservation requirements in the current environment require review and the use of Elson 'norms' for juvenile abundance in streams may be too lofty a goal, particularly where fry norms may on occasion be met but rarely translate into parr norms (Jones et al. 2010). Most problematic is the suitability of existing freshwater habitat under predicted increases in atmospheric temperatures and current reductions in stream flow in the Saint John River. Large-scale changes have already been observed in atmospheric and oceanographic conditions throughout the marine range/habitat of Atlantic Salmon in North America with sea-ice cover in the Gulf of St. Lawrence and off Newfoundland and Labrador in 2009/2010 winter being the lowest on record for both regions since the start of the time series in the late 1960s.

Recent evidence of a whole ecosystem regime shift in the Eastern Scotian Shelf habitat demonstrates that significant change to the ecological communities experienced by wild Atlantic Salmon populations at sea is likely, particularly if individuals use areas farther from the coast. The Eastern Scotian Shelf ecosystem has shifted from being dominated by large bodied demersal fish, to being dominated by small pelagic and demersal fish as well as macroinvertebrates, a change that is also thought to be occurring in surrounding regions (i.e. Western Scotian Shelf), albeit at a slower pace (Choi et al. 2005).

Options for habitat allocation are, by necessity, restricted to freshwater and should consider the maintenance of genetic diversity in the least inhibiting and most apparent productive and persistent environments. This is in spite of the fact that genetic diversity has likely been compromised by extirpations on the St. Croix River and perhaps other rivers, and on the Saint John River, a century or more of hatchery stocking, 40 years of trapping, trucking and fallback at dams. Hence, existing habitats supporting the higher juvenile densities would appear to be the first choice for protection, particularly those habitats without connectivity issues and other significant threats (Clarke et al. 2014).

Original lineages of the St. Croix River were extirpated more than a century ago and evidence will likely indicate that those stocks of the Magaguadavic River were in fact sourced from the Saint John or other Maritime rivers. Hence, options for allocation/protection of habitat on the outer Fundy complex rivers are of low priority as stocks are unlikely unique, now exposed to aquaculture escapes and are increasingly resident to competitive populations of Smallmouth Bass.

While current information to assess habitat use and importance for recovery is incomplete, it is unlikely that the effort to acquire new and or supporting information, particularly with respect to the rating of habitat for current and future expectations of juvenile production, will be suggestive of significantly different habitats as being important. The obstacles to recovery of rivers west of the Saint John River Basin would seem to support the current and future absence of federal efforts to maintain Atlantic Salmon therein. The physical constraints on, and sheer magnitude of the Saint John River Basin and inability to focus on many river specific stocks, (even with the support of the Mactaquac Biodiversity Facility) will limit the habitats on which recovery can be manipulated. In fact, a recent prognosis within a report on the environment of the Saint John River (Kidd et al. 2011) suggests that the Atlantic Salmon population will be limited by warming climate, which will in turn limit survival and reproductive success. Given that stocks of DU 16 are the most southern in Canada and that neighbouring ‘listed’ stocks and their genetic diversity in Maine are only being maintained through extensive stocking of hatchery-reared juveniles (Fay et al. 2006 *in* Lacroix et al. 2012), it is highly improbable that Atlantic Salmon of the Saint John River [and all of DU 16] will ever recover beyond the residual numbers currently in the Saint John River Basin (Kidd et al. 2011).

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TABLES

Table 1: Drainage area and freshwater habitat area (100 m^2 units) estimates within DU 16. The drainage area and potential habitat area on the Saint John River above Grand Falls is excluded.

		DU 16 (CANADA ONLY)			CANADA and U.S. WATERS				U.S. ONLY		
Location Tributary Sub-tributary		**Area (100 m²) units ACC. Prod. (>0.12%)**	**% of Prod. Habitat DU 16**	**Area (100 m²) units INACC. Prod.**	**Drainage Area (km²)**	**% Drainage Area in NB**	**Area (100 m²) units ACC. Prod. (>0.12%)**	**% of Prod. Habitat in Drainage**	**Est. Area (100 m²) units Prod.**	**Area (100 m²) units INACC. Prod.**	**Prod. Habitat Ref. or Proxy Riv.**
Saint John River, Upriver of Mactaquac Dam											
1	Upriver of Mactaquac Dam										
1.1	Salmon R.	12,754	3.2%	0	573	100%	12,754	2.6%	0	0	1
1.2	Mainstem-Aroostook to Grand Falls	5,400	1.3%	0	100	0	5,400	1.1%	0	0	1
1.3	Aroostook R.	1,221	0.3%	0	6,327	2%	61,037	12.3%	59,816	0	2
1.4	Tobique R.	78,562	19.4%	0	4,330	100%	78,562	15.8%	0	0	1
1.5	Muniac Str.	3,907	1.0%	0	173	100%	3,907	0.8%	0	0	Shikatehawk
1.6	River de Chute	2,026	0.5%	0	179	100%	2,026	0.4%	0	0	Big Presquile
1.7	Monquart Str. (inacc.- dam)	0	0.0%	5,110	191	100%	0	0.0%	0	0	1
1.8	Shikatehawk Str.	4,540	1.1%	0	201	100%	4,540	0.9%	0	0	1
1.9	Big Presquile Str.	1,887	0.5%	0	601	28%	6,810	1.4%	4,923	0	1
1.10	Little Presquile Str.	1,632	0.4%	0	144	100%	1,632	0.3%	0	0	Big Presquile
1.11	Mainstem-Hartland to Beechwood	0	0.0%	0	204	100%	0	0.0%	0	0	1
1.12	Becaguimec Str.	10,700	2.6%	0	527	100%	10,700	2.2%	0	0	1
1.13	Meduxnekeag R.	2,169	0.5%	0	1,327	18%	8,300	1.7%	6,131	4,022	1, 2
1.14	Eel R.	5,443	1.3%	0	586	100%	5,443	1.1%	0	0	Meduxnekeag
1.15	Shogomoc R.	2,250	0.6%	0	242	100%	2,250	0.5%	0	0	Meduxnekeag
1.16	Pokiok R.	2,124	0.5%	0	229	100%	2,124	0.4%	0	0	Meduxnekeag
1.17	Nackawic R. (40% inacc.-dam)	7,656	1.9%	5,104	478	100%	7,656	1.5%	0	0	1
1.18	Mactaquac R.	2,045	0.5%	0	220	100%	2,045	0.4%	0	0	Meduxnekeag
	Total Upriver of Mactaquac Dam	**144,316**	**35.7%**	**10,214**	16,630	n/a	215,186	43.3%	70,870	4,022	1
Saint John River, Downriver of Mactaquac Dam											
2	Keswick R.	10,100	2.5%	0	522	100%	10,100	2.0%	0	0	1
3	Nashwaaksis R.	2,570	0.6%	0	194	100%	2,570	0.5%	0	0	1
4	Nashwaak R.	56,920	14.1%	0	1,708	100%	56,920	11.4%	0	0	1
5	Oromocto R.	27,148	6.7%	0	2,026	100%	27,148	5.5%	0	0	Nerepis
6	Jemseg R.	63,298	15.6%	0	3,590	100%	63,298	12.7%	0	0	1
6.1	Portobello Cr. Gr. Lk	1,350	0.3%	0	78	100%	1,350	0.3%	0	0	1
6.2	Noonan Br., Gr. Lk	2,688	0.7%	0	155.1	100%	2,688	0.5%	0	0	Portobello
6.3	Burpee Mill Str., Gr. Lk.	2,190	0.5%	0	99	100%	2,190	0.4%	0	0	1
6.4	Little R. Gr Lk	10,160	2.5%	0	432	100%	10,160	2.0%	0	0	1
6.5	Newcastle Cr., Gr. Lk	5,220	1.3%	0	227	100%	5,220	1.0%	0	0	1
6.6	Gaspereau R. Gr. Lk	18,240	4.5%	0	445	100%	18,240	3.7%	0	0	1

		DU 16 (CANADA ONLY)			CANADA and U.S. WATERS				U.S. ONLY		
Location	Tributary Sub-tributary	Area (100 m²) units ACC. Prod. (>0.12%)	% of Prod. Habitat DU 16	Area (100 m²) units INACC. Prod.	Drainage Area (km²)	% Drainage Area in NB	Area (100 m²) units ACC. Prod. (>0.12%)	% of Prod. Habitat in Drainage	Est. Area (100 m²) units Prod.	Area (100 m²) units INACC. Prod.	Prod. Habitat Ref. or Proxy Riv.
6.7	Salmon R. Gr. Lk	16,280	4.0%	0	1,420	100%	16,280	3.3%	0	0	1
6.8	Coal Cr., Gr. Lk.	3,720	0.9%	0	251	100%	3,720	0.7%	0	0	1
6.9	Cumberland Bay Gr. Lk	1,150	0.3%	0	95	100%	1,150	0.2%	0	0	1
6.10	Youngs Cove Gr. Lk.	2,300	0.6%	0	90	100%	2,300	0.5%	0	0	Cumberland
7	Canaan R.	23,870	5.9%	0	2,168	100%	23,870	4.8%	0	0	1
8	Bellisle Cr.	3,900	1.0%	0	369	100%	3,900	0.8%	0	0	1
9	Nerepis R.	6,760	1.7%	0	504	100%	6,760	1.4%	0	0	1
10	Kennebecasis R.	20,690	5.1%	0	1,573	100%	20,690	4.2%	0	0	1
11	Hammond R.	16,620	4.1%	0	514	100%	16,620	3.3%	0	0	1
	Total Downriver of Mactaquac Dam	**231,876**	**57.3%**	**0**	12,969	n/a	231,875	46.6%	0	0	1
	Total Saint John River	**376,192**	**93.0%**	**10,214**	599	n/a	447,061	89.9%	70,870	4,022	-
Outer Fundy complex rivers											
12	Musquash R. (innac- dam.)	.	0.0%	2,750	467	100%	.	0.0%	0	0	Lepreau
13	New R.	604	0.1%	0	152	100%	604	0.1%	0	0	-
14	Pocologan R.	226	0.1%	0	57	100%	226	0.0%	0	0	5
15	Magaguadavic R.	5,630	1.4%	0	1,861	100%	5,630	1.1%	0	0	4
16	Digdeguash R.	4,220	1.0%	0	459	100%	4,220	0.8%	0	0	4
17	Bocabec R.	427	0.1%	0	108	100%	427	0.1%	0	0	-
18	Waweig R.	556	0.1%	0	140	100%	556	0.1%	0	0	-
19	Dennis Str.	537	0.1%	0	136	100%	537	0.1%	0	0	-
20	St. Croix R.	16,183	4.0%	0	4,235	38%	38,039	7.6%	21,856	0	6, 7, 8, 9
	Total outer Fundy complex	**28,383**	**7.0%**	**2,750**	7,615	n/a	50,239	10.1%	21,856	0	-
	TOTAL DU	**404,575**	**100.0%**	**12,964**	37,214	0	497,301	100.0%	92,726	4,022	-

Notes:

1-Marshall et al. 1997; 2-Baum 1982; 3-Anon. 1978a; 4-Anon.1978b; 5-Dalziel 1956; 6-Marshall and Cameron 1995; 7-Anon. 1988; 8-Fletcher and Meister 1982; 9-Havey 1963.

[a] The North Branch of the Meduxnekeag River is inaccessible past the two natural falls at Oakville, New Brunswick near the US border. The majority of the inaccessible estimate presented is within US borders (Baum 1982).

[b] An impassable falls on the Dunbar Stream, approximately 0.8 km from the confluence with the Nashwaak River, is a natural barrier to salmon and offers another 1,486 unit of potential salmon rearing habitat migration.

[c] Reliable productive estimate for Lepreau River (Anon. 1978a) used as proxy for Musquash River.

[d] Majority of habitat estimates are in International waters (29,097). The US section includes the habitat that solely lies in US waters (7,308) plus half the international estimate.

Table 2: Summary of features, functions, and attributes of important OBoF salmon freshwater habitat.

Geographic Location	Life-Stage (age from egg deposition in months)	Function	Features	Attributes
High Priority Rivers of the OBoF DU include: **SJR above Mactaquac Dam** *(Shikatehawk, Becaguimec, and Tobique),* **Canaan,** **Nashwaak,** **Hammond,** **Keswick,** **Kennebecasis,** and **Digdeguash**	Eggs (0-5 months)	Egg deposition and incubation (Nov-Mar)	Redds	Substrate: loose gravel and cobble (0.6-6.4cm and 6.4-25.0cm in diameter, respectively) Water depth: 0.15 to >1m (generally: 0.15-0.76m) Water velocity: 0.15-0.9m/sec, 0.3-0.5m/sec (preferred) Well oxygenated (>4.5 mg/L DO), continuous, upwelling cold water flow Gradient >0.12% Silt loads <0.02% pH >5.3
	Alevin (6-7 months)	Early development (Apr-May)	Redds	Substrate: loose gravel and cobble (0.6-6.4cm and 6.4-25cm in diameter, respectively) Water depth: 0.15 to >1m (generally: 0.15-0.76m) Water velocity: 0.15-0.9m/sec, 0.3-0.5m/sec (preferred) Gradient >0.12% Silt loads <0.02% pH >5.3
	Fry (7-14 months)	Growth (May-Nov)	Food availability Cover	Substrate: Bed complexity, connectivity among habitat types Temp ≤22°C Depth: 0.2-1m Current: moderate (25cm/sec) Prey: Invertebrate drift Gradient >0.12%, Silt loads <0.02%, pH >5.3
	Parr (1+:15-26 months) (2+:27-38 months) (3+:39-50+ months)	Growth (May-Nov)	Food availability Cover Riparian buffer Ice-free pool area	Substrate: bed complexity, connectivity among habitats types Temp ≤22°C Depth: 20-100 cm, Prey: insects Water Current: variable - at high flow, may prefer pools; at lower flow, may prefer riffles Gradient >0.12% Silt loads <0.02% pH >5.3
		Overwintering (Dec-Apr)	Interstitial spaces, Ice free pool areas or lacustrine habitats	Substrate: bed complexity Temp <8-10°C (start of autumnal shift in habitat and behavior) Gradient >0.12%, Silt loads <0.02%, pH >5.3
	Pre-smolt (24, 36 and 48 months)	Migration (Tobique: Oct-Nov)	Corridor to estuary, Cover	Substrate: bed complexity, connectivity among habitats types Flow: high water velocity Temp ≤22°C, 8-10°C (preferred) Gradient >0.12% Silt loads <0.02% pH >5.3
		Overwintering (Dec-Apr)	Interstitial spaces, Ice free pool areas or lacustrine	Substrate: bed complexity Prey: fish eggs in early winter Gradient >0.12%, Silt loads <0.02%,

Geographic Location	Life-Stage (age from egg deposition in months)	Function	Features	Attributes
			habitats, and available food in early winter	pH >5.3
	Smolt (30, 42, and 54 months)	Migration (Tobique/Nashwaak: Apr-Jun)	Corridor to estuary, Cover	Substrate: bed complexity, connectivity among habitats types Temp ≤22°C, 8-10°C (preferred) Gradient >0.12% Silt loads <0.02% pH >5.3
	Adult (44, 58,70 months)	Upstream Migration and Searching (May-Oct)	Corridor to spawning ground	Substrate: bed complexity, connectivity among habitats types River discharge: Moderate-Higher preferred Obstructions <3.4m Waterfalls: <5m with plunge pool 1.25 times the height Temp ≤22°C Gradient >0.12%
		Resting and residency (May-Oct)	Holding pools Thermal Refugia Cover Riparian buffer	Substrate: boulders (adequate size and density) Overhanging banks and Shading Temp ≤22°C
		Spawning (Oct-Nov)	Gravel bars, upstream side of riffles	Substrate: loose gravel and cobble (0.6-6.4cm and 6.4-25cm in diameter, respectively) Current: moderate (0.15-0.9 m/s) Temp ≤22°C Depth: 0.5-2m (areas of decreasing depth) Well oxygenated (>4.5 mg/L DO), continuous, cold water flow Gradient >0.12% Silt loads <0.02% pH >5.3
	Kelt (45, 59, and 71 months)	Overwintering (Winter/Spring)	Ice-free pools, lakes, and still waters	Depth: deep water with sufficient water volume under ice.
		Migration (Winter/Spring)	Corridor to estuary	River discharge: water flow of sufficient volume/depth to allow unimpeded access to estuarine habitat.

Table 3: Summary of features, functions, and attributes of important OBoF salmon tidal influenced, estuarine, and marine habitat.

Geographic Location	Life-Stage (age from egg deposition in months)	Function	Features	Attributes
Estuaries of high priority rivers. **_(SJR* above Mactaquac Dam,Canaan, Nashwaak, Hammond, Keswick, Kennebecasis, and Digdeguash)._** *SJR Estuary begins at reversing falls in Saint John Harbour covers the main stem approx. 60km upstream to Long Reach NB	Smolts	Downstream Migration (Apr-Jun)	Corridor through the estuary	Water flow: spring flows Depth: in the top 5m of water column Temp ≤22°C, 8-10°C (preferred) Salinity: little acclimation, as brief as 1-2 tidal cycles
		Feeding (pre-oceanic growth)	Available food	Prey: insects floating on surface
	Kelts	Downstream Migration (Winter/spring)	Corridor through the estuary	Water flow: sufficient to allow unimpeded access Temperature: -1-20°C , 5-10°C (preferred) Salinity: increasing salinity, little acclimation, as brief as 1-2 tidal cycles Prey: Not identified
		Overwintering (Winter/spring)	Ice-free pools, lakes, and still waters	Depth: deep water with sufficient water volume under ice.
	Adults	Upstream Migration (May-Oct)	Corridor through the estuary	Connectivity among habitats types Water flow: moderate to high flow (no consistent preferred flow) Volume/depth: not identified Temperature: high temperature can impede migration Salinity: decreasing salinity
		Overwintering (SJR estuary- Serpentine) (fall of second summer at sea (1SW)	Ice-free pools, lakes, and still waters	Depth: deep water with sufficient water volume under ice.
OBoF-Gulf of Maine	Post-smolts (+7 months from smolt)	Migration	Corridor to feeding grounds	Appropriate spring wind patterns Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: directed along routes of increasing salinity Depth/Light regimes: upper 5m of the water column Ocean currents: interface of Atlantic current and counter coastal current or mid-Fundy gyre
		Feeding	Available food	Prey: planktonic crustaceans, Themisto spp.(Amphipoda, Hyperiidae*), Megancyctiphanes norvegica, Thysanoessa inermis* (Euphausiidae, or krill), and fish (sand lance *Ammodytes* spp.) Temperature: SST 6-14°C, 9-10°C (preferred)
	Kelts (+1 month from spawning)	Migration	Corridor to feeding ground	Temperature: SST 0-25°C, 5-15°C (preferred) Salinity: 35-35.5ppt Depth/Light regimes: <2m with repeat diving up to >50m and between 100-500m along shelves Ocean currents: presume to

Geographic Location	**Life-Stage (age from egg deposition in months)**	**Function**	**Features**	**Attributes**
				follow post-smolts in interface of Atlantic current and counter coastal current or mid-Fundy gyre
		Reconditioning	Available food	Prey: shallower depth feeding, planktonic crustaceans, capelin, sand lance and herring Depth/Light regimes: diving to 100-500, 25-50m (preferred)
	1SW adults (+6 months from post-smolt)	Migration to freshwater Migration to sea	Corridor to spawning grounds Corridor to feeding grounds	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: 35-35.5ppt Depth: up to 5,000, >1,000 (preferred) Ocean currents: Not identified Light regimes: Not identified Prey: homeward migration, switch to nearshore fishes (herring, sand lance)
		Feeding	Available food	Prey: at >1,000m, mesopelagic fishes (*Paralepis*, Myctophidae), planktonic crustaceans (*Themisto*, Euphausiidae), and squid (*Gonatus fabricii*).
	Repeat Spawners (+12 to 16 months from 1SW adult)	Migration to fresh water	Corridor to spawning grounds	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: 35-35.5ppt Depth: up to 5,000, >1,000 (preferred) Ocean currents: hypothesized to retrace northward movement as post-smolts Prey: homeward migration, switch to nearshore fishes (herring, sand lance)
		Feeding	Available food	Appropriate forage Prey: mesopelagic fishes and squid
Scotian Shelf	Post-smolts	Migration	Corridor to feeding and wintering grounds	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: directed along routes of increasing salinity Depth/Light regimes: upper 5m of the water column Ocean currents: interface of Atlantic current and counter coastal current
		Feeding	Available food	Prey: mesopelagic fishes and squid
	1SW adults 2SW adults (+18 months from post-smolt) and, Repeat Spawners	Migration (*fish capture in any month likely returning as maturing fish)	Corridor to Spawning grounds Corridor to feeding and wintering grounds	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: 35-35.5ppt Depth: up to 5,000m, excess of 1,000m (preferred) Ocean currents: kelts-hypothesized to retrace northward movement as post-smolts. Seaward Migration: not identified Light regimes: not identified
		Feeding	Available food	Prey: mesopelagic fishes and squid
East coast NL -Grand Banks	Post-smolts,1SW adults, 2SW adults and, Repeat Spawners	Overwintering and Feeding	Available food	Temperature: SST 1-13°C, 4-10°C (preferred) Opportunistic feeder: various

Geographic Location	Life-Stage (age from egg deposition in months)	Function	Features	Attributes
				pelagic food items
		Migration (1SW- May-Jun- homeward migration as maturing fish and July-Apr- northward migration as non-maturing fish) (2SW- suspected homeward migration in March, April and early May as mature fish)	Corridor to feeding and wintering grounds Corridor to spawning ground	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: 35-35.5ppt Depth: up to 5,000m, excess of 1,000m (preferred) Ocean currents: northern movement, possibly West Greenland Current of the North Atlantic sub-polar gyre and returning from Greenland in the Labrador Current on westerly side of the sub-polar gyre (hypothesized to retrace northward movement as post-smolts) Light regimes: not identified Appropriate forage
Labrador Sea	Post-smolts,1SW adults, 2SW adults and, Repeat Spawners	Overwintering and Feeding	Available food	Temperature: SST 1-13°C, 4-10°C (preferred) Salinity: not identified Depth/Light regimes: Upper 3m of water column, <1m (preferred) Opportunistic feeder: various pelagic food items
		Migration	Corridor to spawning grounds Corridor to feeding grounds	Ocean currents: northern movement, possibly West Greenland Current of the North Atlantic sub-polar gyre and returning from Greenland in the Labrador Current on westerly side of the sub-polar gyre

Table 4: Location and time of recovery as ***post-smolts*** *from tagged native hatchery smolts emigrating from the Saint John River, 1967-1984 (adapted from Ritter 1989). See Figure 3 for Statistical Areas in Newfoundland and Labrador and 'other recovery locations'.*

Recovery Location	**Month of Recovery**							**Total tags**
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Unk.**	
River mouth	4	0	0	0	0	0	0	4
NB Lower Fundy	0	1	1	1	0	0	0	3
NS Lower Fundy	0	2	17	5	1	0	0	25
NS SW Nova	0	7	5	0	0	0	2	14
NS Eastern Shore	0	4	0	0	0	0	0	4
NS Cape Breton East	0	0	0	0	0	0	0	0
NFLD Area K	0	0	0	0	0	0	0	0
NFLD Area J	0	0	0	0	0	0	0	0
NFLD Area I	0	0	1	1	0	0	0	2
NFLD Area H	0	0	0	0	0	0	0	0
NFLD Area G	0	0	0	0	0	0	0	0
NFLD Area F	0	0	0	0	0	0	0	0
NFLD Area E	0	0	0	0	0	0	0	0
NFLD Area D	0	0	0	0	0	0	0	0
NFLD Area C	0	0	0	0	0	0	0	0
NFLD Area B	0	0	0	1	0	0	0	1
NFLD Area A	0	0	0	0	0	0	0	0
NFLD Area N	0	0	2	0	0	0	0	2
Labrador (Southern)	0	0	0	0	1	0	0	1
Labrador (Northern)	0	0	0	0	0	0	0	0
GRL 1F	0	0	0	0	0	0	0	0
GRL 1E	0	0	0	0	0	0	0	0
GRL 1D	0	0	0	0	0	0	0	0
GRL 1C	0	0	0	0	0	0	0	0
GRL 1B	0	0	0	0	0	0	0	0
GRL 1A	0	0	0	0	0	0	0	0
GRL Unk.	0	0	0	0	0	0	0	0
All locations	**4**	**14**	**26**	**8**	**2**	**0**	**2**	**56**

Note: Unk. Indicates 'unknown'.

Table 5: Location and time of recovery as ***1SW salmon*** *from tagged native hatchery smolts emigrating from the Saint John River, 1967-1984 (adapted from Ritter 1989).*

Recovery Location	**Month of Recovery**								**Total tags**
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Unk.**	
River mouth	0	3	19	1	0	1	0		24
NB Lower Fundy	0	1	0	0	0	0	0		1
NS Lower Fundy	0	3	20	4	0	0	0		27
NS SW Nova	0	8	1	0	0	2	2	1	14
NS Eastern Shore	3	2	0	0	0	1	0	1	7
NS Cape Breton East	0	1	0	0	0	0	0		1
NFLD Area K	0	0	0	0	0	0	0		
NFLD Area J	0	3	1	0	0	0	0		4
NFLD Area I	0	5	5	0	0	0	0		10
NFLD Area H	1	6	6	0	0	0	0		13
NFLD Area G	0	2	2	0	0	0	0		4
NFLD Area F	4	8	5	1	0	0	0		18
NFLD Area E	1	9	6	0	0	0	0	2	18
NFLD Area D	0	12	9	2	0	0	0	1	24
NFLD Area C	4	23	13	0	0	0	5		45
NFLD Area B	0	24	22	0	0	5	7	3	61
NFLD Area A	0	15	68	5	0	1	1	6	96
NFLD Area N	0	1	2	0	0	0	0		3
QC Lwr North Shore	0	0	2	1	0	0	0	1	4
Labrador (Southern)	0	4	29	11	10	0	0	8	62
Labrador (Northern)	0	0	0	2	0	1	0	2	5
GRL 1F	0	0	0	6	0	0	0		6
GRL 1E	0	0	2	1	1	0	0	2	4
GRL 1D	0	0	2	19	3	1	0	4	29
GRL 1C	0	0	12	62	8	0	0	4	86
GRL 1B	0	0	1	44	18	2	1	43	109
GRL 1A	0	0	0	9	19	0	0	2	30
GRL Unk	0	1	1	28	23	9	4	63	129
All locations	**13**	**131**	**228**	**196**	**82**	**23**	**20**	**143**	**836**

Note: Unk. Indicates ‘unknown’.

Table 6: Location and time of recovery as ***2SW salmon*** *(maiden) from tagged native hatchery smolts emigrating from the Saint John River, 1967-1984 (adapted from Ritter 1989).*

Recovery location	**Month of Recovery**								**Total tags**
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Unk.**	
River mouth	11	47	47	1	0	0	0	0	106
NB Lwr Fundy	0	0	3	0	0	0	0	0	3
NS Lwr Fundy	0	3	0	0	0	0	0	0	3
NS SW Nova	0	1	0	0	0	0	0	0	1
NS Eastern Shore	0	0	0	0	0	0	0	0	0
NS Cape Breton East	0	1	0	0	0	0	0	0	1
NFLD Area K	0	0	0	0	0	0	0	0	0
NFLD Area J	0	0	0	0	0	0	0	0	0
NFLD Area I	0	0	0	0	0	0	0	0	0
NFLD Area H	0	0	0	0	0	0	0	0	0
NFLD Area G	0	1	0	0	0	0	0	0	1
NFLD Area F	0	0	0	0	0	0	0	0	0
NFLD Area E	0	0	0	0	0	0	0	0	0
NFLD Area D	0	0	0	0	0	0	0	0	0
NFLD Area C	0	0	0	0	0	0	0	0	0
NFLD Area B	0	0	0	0	0	0	0	0	0
NFLD Area A	0	0	0	0	0	0	0	0	0
NFLD Area N	0	0	0	0	0	0	0	0	0
QC Lwr North Shore	0	0	0	0	0	0	0	0	0
Labrador All locations	0	0	0	0	0	0	0	0	0
GRL All locations	0	0	0	0	0	0	0	0	0
All locations	**11**	**53**	**50**	**1**	**0**	**0**	**0**	**0**	**115**

Note: Unk. Indicates ‘unknown’.

Table 7: Location and time of recovery as Saint John River ***repeat spawning 1SW salmon*** *(any combination of consecutive and alternate spawners) tagged in the preceding spawning migration, 1967-1983 (adapted from Ritter 1989).*

Recovery location	**Month of Recovery**								**Total tags**
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Unk.**	
River mouth	10	5	32	8	1	0	0	0	56
NB Lwr Fundy	0	0	0	0	0	1	0	1	2
NS Lwr Fundy	0	4	2	1	0	0	0	1	8
NS SW Nova	0	2	7	0	0	0	0	0	9
NS Eastern Shore	0	0	6	0	0	0	0	0	6
NS Cape Breton East	0	0	0	0	0	0	0	0	0
NFLD Area K	0	0	1	0	0	0	0	0	1
NFLD Area J	0	8	5	0	0	0	0	0	13
NFLD Area I	0	5	23	1	0	0	0	0	29
NFLD Area H	0	3	18	0	0	0	0	2	23
NFLD Area G	0	0	12	0	0	0	0	2	14
NFLD Area F	0	1	5	0	0	0	0	0	6
NFLD Area E	0	0	2	0	0	0	0	0	2
NFLD Area D	0	0	1	0	0	0	0	0	1
NFLD Area C	0	1	5	0	0	0	0	0	6
NFLD Area B	0	0	0	0	0	0	2	0	2
NFLD Area A	0	0	1	0	0	0	0	0	1
NFLD Area N	0	0	0	0	0	0	0	0	0
QC Lwr North Shore	0	0	0	0	0	0	0	0	0
Labrador (Southern)	0	0	0	1	0	0	0	0	1
Labrador (Northern)	0	0	0	0	0	0	0	0	0
GRL 1F	0	0	0	1	3	0	0	0	4
GRL 1E	0	0	0	0	0	0	0	0	0
GRL 1D	0	0	0	2	0	0	0	0	2
GRL 1C	0	0	0	0	2	0	0	0	2
GRL 1B	0	0	0	1	1	0	0	0	2
GRL 1A	0	0	0	0	0	0	0	0	0
GRL Unk	0	0	0	0	1	0	0	0	1
All locations	**10**	**29**	**120**	**15**	**8**	**1**	**2**	**6**	**191**

Note: Unk. Indicates ‘unknown’.

Table 8: Major anthropogenic structures and their constraints on productive habitat (>0.12% gradient) in the Saint John River system upriver of Mactaquac Dam.

No.	Constraint (approximate date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	Affected
1	Mactaquac dam and generating station (1968)	42.2 m height, 6 Kaplan turbines rated at 112 MW[f] each; fish collection gallery over tail race consists of weir gates, holding pool, crowder, brail pool, hopper and hoist to load tank truck; 17.8 CMS attraction water from pumps in gallery[1,2]. All salmon trucked in well water approx. 6 km to Sorting Facility. *No downstream passage facility*	*Upstream*: dissuasion of some and delays of most in their migration *Downstream*: delays; passage via spill or turbines – acute mortality estimate of 10% in turbines[3]	*Upstream*:113 km mainstem riverine habitat; gradient undetermined[a] but historically with some salmon holding pools islands and potentially side riffles of productive habitat (>0.12% gradient)	*Downstream*: sudden variable river discharges associated with 'peak' power generating; unlikely much productive habitat (>0.12% gradient) above tidal influence
2	Mactaquac Sorting Facilities (1968)	Holding tanks supplied with 8°C well water to hold fish transported from dam; fish 'processed' and held for upriver transport; facility also directly accessed by a small number of hatchery origin fish via migration channel from mainstem	Mactaquac delay nullified by trucking but 'connectivity' to home tributaries compromised by trucking of adults in aerated well water upriver[4] to: 1) Woodstock in Mactaquac Headpond (85km), 2) Beechwood headpond at Perth-Andover (160 km), 3) Tobique Narrows Headpond (180 km), 4) Two Brooks (Tobique), and 5) NBDNRE Protection Barrier Pool (Tobique)	None	None
3	Mactaquac Headpond	8,826 ha water body[3] with imperceptible currents for the most part and altered cool/warm water ecosystem dominated by non-native smallmouth bass and to a lesser degree, Chain Pickerel and Muskellunge	*Upstream*: little impact as adults now trucked around but fallbacks disoriented *Downstream*: smolts delayed and exposure to well established invasive predators	*Upstream*: 113 km mainstem riverine habitat, holding pools, cold water sanctuaries and connectivity; likelihood of intermittent gradients >0.12% productive habitat	

No.	Constraint (approximate date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	Affected
4	Beechwood Dam and generating station (1957)	16.7 m head; 3 Kaplan turbines rated at 35 MW each; fish collection gallery over tail race consists of collection gallery, with pumped attraction water, short transportation channel to a trap in a resting pool and manually operated 'skip hoist' that pulls trap up 47 m inclined plane to headpond[1,4,5]. *No downstream passage facility*	*Upstream*: dissuasion of some and delays of most in their migration. *Downstream*: delays; passage via spill or gate wells and turbines – acute mortality estimate of 10% in turbines[3]	*Upstream*: 32 km mainstem connectivity and likelihood of productive habitat (gradients >0.12%) as per below dam	*Downstream*: sudden variable river discharges and temperatures associated with 'peak' power generating; 8.764 $km^{2/6}$ river substrate; river levels in summer can vary by 1-2 m[9]
5	Beechwood Headpond	1,146 ha water body[3] with weak currents for the most part and altered ecosystem; extends to confluence of Aroostook and Saint John rivers and tailrace of Tobique Narrows Dam; ecosystem dominated by smallmouth bass and to a lesser degree, Chain Pickerel and Muskellunge	*Upstream*: delays in migration possible due to reduced currents, loss of traditional resting areas or holding pools *Downstream*: delays of smolts exposure to well established invasive species[10]	*Upstream*: 32 km holding pools, cold water sanctuaries and connectivity; likelihood of intermittent gradients >0.12% productive habitat not known; minimum of about 5 km^2 riverine habitat (per mainstem section below Grand Falls)	
6	Grand Falls Power house and headpond (1928) [9]	4 Francis turbines at 16 MW each fed thru a 700 m penstock tunnelled under the community from an intake above Grand Falls; headpond of 41 km	*Upstream*: potential disruption due to variable discharges and temps *Downstream*: potential disruption of smolts/adults originating between Tobique and Grand Falls due to variable discharges and temps	None	*Downstream*: potentially disruptive flows and temperatures on 5,400 units (Table 1) of productive habitat down river to Beechwood headpond
7	Tobique Narrows Dam and power house (1953)	23 m height; 2 Kaplan turbines rated at 10 MW each; fish collection gallery over tail race with pumped attraction water leads to 73 pool and weir fishway to headpond[1,4,5]. *No downstream passage facility*[b]	*Upstream*: delays esp. for periods when station not operating, i.e., no tailrace attraction water for fishway. *Downstream*: delays; passage via spill or gate wells and turbines – acute mortality estimate of 18.3% in turbines[3]	*Upstream:* 17.5 km: riverine habitat incl. gorge/rapids. No estimate of productive habitat	*Downstream*: potentially cooler holding water and pools of section lost/diluted by tailrace flow into Beechwood headpond

No.	Constraint (approximate date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	Affected
8	Tobique Narrows Headpond	17.5 km, 415 ha water body[3] with weak currents for the most part and altered ecosystem incl. Smallmouth Bass	*Upstream*: delays in migration *Downstream*: smolts delayed, exposure to well established invasive species	*Upstream*: 17.5 km mainstem riverine habitat and connectivity lost with likelihood of gradients >0.12% productive habitat	
9	Tobique storage: Sisson Reservoir and power house (1965), Trousers Lake, Long Lake, and Serpentine Lake	Total of 4,426 ha headwater storage[3] without fish passage (Sisson has one Francis 11 MW[f] unit operated sporadically)	Variable releases and deviations from normal flows; prescribed minimum flows have put juveniles in proximity to dams at risk	*Upstream*: Unknown but minimal from perspective of salmon habitat[3]	*Downstream:* reaches affected sporadically by unnatural flows and temperature regimes[11] as a consequence of water releases to sustain hydro production at Tobique Narrows
10	Aroostook River: Tinker Dam and power house (1906/1923) [8]	25.3 m height; One Kaplan turbine and four Francis[3] rated at 33.5 MW+ in total; fish collection gallery to side of tail race with pumped attraction water leading to trap with hoist for trucking to a point in Canada upstream of the 600 m long power canal[4] *No downstream passage facility.* Little storage capacity, therefore mostly run-of-river generation	*Upstream*: dissuasion/delays. *Downstream*: delays; passage via spill at diversion dam power canal gate wells and turbines – acute mortality estimate of 11.1% in turbines[3]	*Upstream*: Loss of riverine habitat to at least the Canada – USA border (approx. 2.5 km)[a] *Sidestream*: 915 m rocky gorge	*Downstream*: sudden variable river discharges associated with 'peak' power generating; habitat >0.12% of 1,221 units[6] *Upstream*: see below
11	Tinker power canal and reservoir	Power canal 0.6 km from penstock to diversion dam; diversion 1.7 km downstream of Can-USA border	*Upstream*: delays in migration	*Upstream*: riverine habitat to Can- USA border (approx. 2.5 km)[a] *Sidestream*: 915 m rocky gorge	
12	Aroostook Caribou Dam and power house (1890)	24 km upriver of Tinker, 3.7 m in height; 2 propeller turbines at 0.9 KW total, 13 pool and weir fishway[8]	Unknown	Unknown	

No.	Constraint (approximate date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	**Affected**
13	Hargrove Dam (Monquart Stream) (1966)[9]	21 m head, single turbine[10]. Little capacity for storage. *No fishway and no recent trap and truck initiatives*	*Upstream*: complete barrier	*Upstream*: 0.511 km^2 productive habitat[6]	*Downstream*: potentially disruptive flows and temperatures on 500 m of riverine habitat down river to mainstem of Saint John River
14	Nackawic Dam Nackawic Stream	Derelict dam; gates open but concrete spill way impassable (?)	*Upstream*: complete barrier	*Upstream*: 0.510 km^2 productive habitat[6]	

Notes:
[1]Hubley et al. (2001); [2]Ingram (1980); [3]Washburn and Gillis Assoc. Ltd. (1996); [4]Marshall et al. (1995b); [5]Ingram (1981); [6]Table 1, this document. [7]NB Power-Power generation web location; [8]Warner (1956); [9]Kidd et al. (2011); [10]Carr (2001); [11]Flanagan (2003).
[a]Freight and passenger steamboats once navigated as far as Woodstock.
[b]Turbine/spill managed so as to draw aggregates of smolts to spill area when noticed; similar initiative at Mactaquac Dam to draw smolts into nearest gatewell. Since 2009, during the peak pre-smolt migration period, NB Power has spilled water from 7:00 pm until midnight from Gate 5 (small regulating gate) at Tobique Narrows Dam.
[c]Except in times of high river discharge when facilities operate as ‘run of the river’, all stations are managed to service daily peak demand loads, e.g., morning and evening, discharging water in excess of flowage and then cutting back to replenish water for the next peak.

Table 9: Anthropogenic structures and their constraints on salmon habitat in the St. Croix River.

No.	Constraint (Date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	Affected
1	Milltown Dam and Power House (NB Power operated) (1881)	7.3 m high dam, 1 km above head-of-tide; 7 turbines rated at 3.9 MW[1] total; modern pool and weir fishway (1982) with supplemental water which rises to trap slightly upstream of power house; sluice way to assist downstream migrants relatively ineffective; run of the river power generation	*Upstream*: delays in migration; efficiency estimated at 80%[2] *Downstream*: delays; passage via spill, turbines or relatively ineffective sluiceway – acute mortality est. of 10% in turbines	*Upstream*: approx. 200 m of natural riverine habitat; gradient unknown	*Downstream*: variability in discharge, habitat is relatively unproductive
2	Woodland Mill Dam, power house and paper mill (US operated) (1906)	14.3 m high dam 13.5 km of river upstream[2] of Milltown Dam; produces 11.6 MW power; 227 m denil fishway[1] (1965) zigs then zags from tail water to headpond; essentially run of the river power generation; *No downstream facility per se*	*Upstream*: delays in migration; *Downstream*: delays passage via spill, turbines	*Upstream* 7.5 km of natural riverine habitat; gradient unknown	*Downstream*: occasional chemical spills from paper mill which have resulted in significant fish kills in the past
3	Woodland Flowage	Approx.7.5 km long; 500 ha area max depth 10 m above Woodland dam; principle fishery of Chain Pickerel and Smallmouth Bass[6]	*Upstream*: delays in migration *Downstream*: delays; passage via spill, turbines; predation	*Upstream* 7.5 km of natural riverine habitat; gradient unknown	Reduced current, warming water resulted in success of Smallmouth Bass and Chain Pickerel
4	Grand Falls Dam and Power house (US operated) (1915)	11.6 m high dam 15.1 km of river upstream[2] of Woodland Mill Dam; produces 9.5 MW power; 180 m denil fishway[1](1965) from power house to power canal; No downstream fishway per se	*Upstream*: delays in migration *Downstream*: delays; passage via spill, penstocks and turbines	*Upstream*: approx. 4 km of natural habitat on the East Branch incl. river bed above and below former Grand Falls; gradient unknown	*Downstream*: daily fluctuations resultant of power production and discharge
5	Grand falls Flowage (mostly West Branch in USA)	2,710 ha[5] lake of max depth 13.4 m on mainstem used as storage for operation of Grand Falls power house	*Upstream*: delays in fish finding inflow from the East Branch (Canada-USA) boundary riverine and salmon habitat	*Upstream:* West Branch (USA) length and gradient unknown; East Branch, 4km, gradient unknown	.
6	Vanceboro Dam (US operated Int'l St. Croix River Bd. regulated) (1836)	6.1 m high[2] storage dam at outflow of Spednic Lake to East Branch fitted with vertical slot fishway; Spednic Lake has length of 27 km, area of 6,968 ha, max depth 16 m and average depth 6.15 m[4]	Variable and possibly unnatural effects, on the core salmon producing habitat of the East Branch (53.1 km, 0.11% avg gradient between Dam and Grand Falls Flowage)	*Upstream*: Unknown (few if any salmon now originating upstream of Spednic Lake)	Effects unknown: variable and unnatural effects of flows on East Branch; temperature of Spednic Lake releases unlikely to differ much from pre-impoundment discharges

No.	Constraint (Date instituted)	Description	Impact on salmon migration	Habitat	
				Lost	Affected
7	Forest City Dam (US operated Int’l St. Croix River Bd. regulated) (1908)	2.7 m high[2] storage dam at outflow of East Grand Lake to Spednic Lake fitted with vertical slot fishway; East Grand Lake has length of 35 km, area of 6,441 ha max depth 39 m and average depth 8.5 m[3]	Variable and unnatural effects, could be positive or negative	*Upstream*: Unknown, (few if any salmon now originating upstream of East Grand Lake	Variable and unnatural effects of releases on East Branch, tempered by Spednic Lake; could be positive or negative
8	Canoose Dam (US operated in Canada; Int’l St. Croix River Bd. regulated)	5.2 m high[2] storage dam at outflow to Canoose River, tributary of East Branch St. Croix fitted with pool and weir fishway	Variable flows on salmon habitat in Canoose; unknown salmon habitat above dam; irregular flow releases generally detrimental to salmon production	*Upstream*: Unknown	Variable and unnatural effects of storage releases on Canoose River and ultimately the East Branch
9	West Grand Dam(US operated; Int’l St. Croix River Bd. regulated)	2.4 m head, storage dam with vertical slot fishway on outflow of West Grand Lake (solely in USA)	Unknown but impacts 0.73 km^2 of productive salmon habitat in Grand Lake Stream between West Grand and Big Lake Maine	Unknown	Unknown

Notes:
[1] FB Environmental (2008).
[2] Anon. (1988).
[3] East Grand Lake description [online].
[4] Spednic Lake description [online].
[5] Grand Falls Lake flowage description [online].
[6] Woodland flowage lake survey [online].

Table 10: Anthropogenic structures and their constraints on salmon habitat in the Magaguadavic River.

No.	**Constraint (Date instituted)**	**Description**	**Impact on salmon migration**	**Habitat**	
				Lost	**Affected**
1	St. George (Magaguadavic) dam and power house (1903/1928/1934)	13.4 m high dam[1 2], at head of tide; two Kaplan turbines rated at 15 MW total[3]; pool (43) and weir fishway with resting pools up the side of the gorge to trap at headpond; no attraction water[1] . Surface downstream by-pass and assessment facility was built between the two intakes in the new powerhouse to assist downstream migrants	*Upstream*: delays in migration. *Downstream*: delays; passage via spill, turbines or sluiceway – acute mortality estimate of 25% in turbines	*Upstream*:17.5 km mainstem riverine habitat; gradient undetermined but estimated to have been <0.12%	*Downstream*: fishway attraction water at low tide is upstream of tailrace and ineffective
2	St. George Headpond	Mainstem 17.5 km upstream to a waterfall at Second Falls[2] which is passable to salmon at most river discharges; Smallmouth Bass well established throughout the system	*Upstream*: delays in migration *Downstream*: smolts delayed, exposed to well established invasive species	*Upstream*:17.5 km mainstem riverine habitat; lost, temperatures moderated and gradient undetermined but estimated to have been <0.12% gradient	
3	Storage dams on Mill, Digdeguash and Magaguadavic lakes	Small fishway on Magaguadavic Lake only	Loss of headwater habitat	Significant loss of riverine habitat of unknown productive potential	Temperatures downstream likely subject to moderation

Notes:

[1] Carr and Whoriskey (1998).

[2] Martin (1984).

[3] Jones et al. (2006).

FIGURES

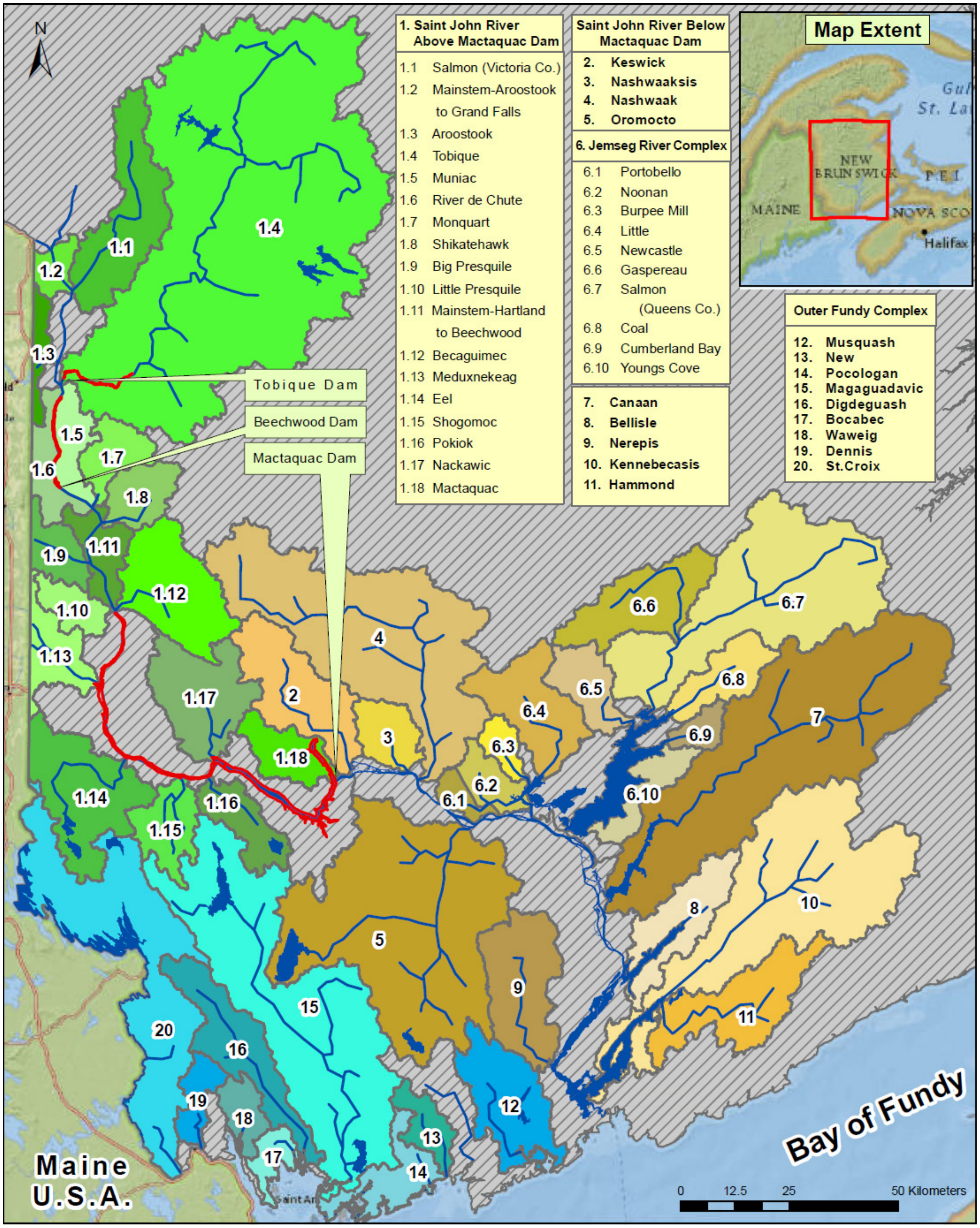

Figure 1: River basins of DU 16 color coded by location (i.e., above Mactaquac in green, below Mactaquac in brown and outer Fundy complex rivers in blue). The sections highlighted in red represent the headponds associated with three hydroelectric dams on the Saint John River.

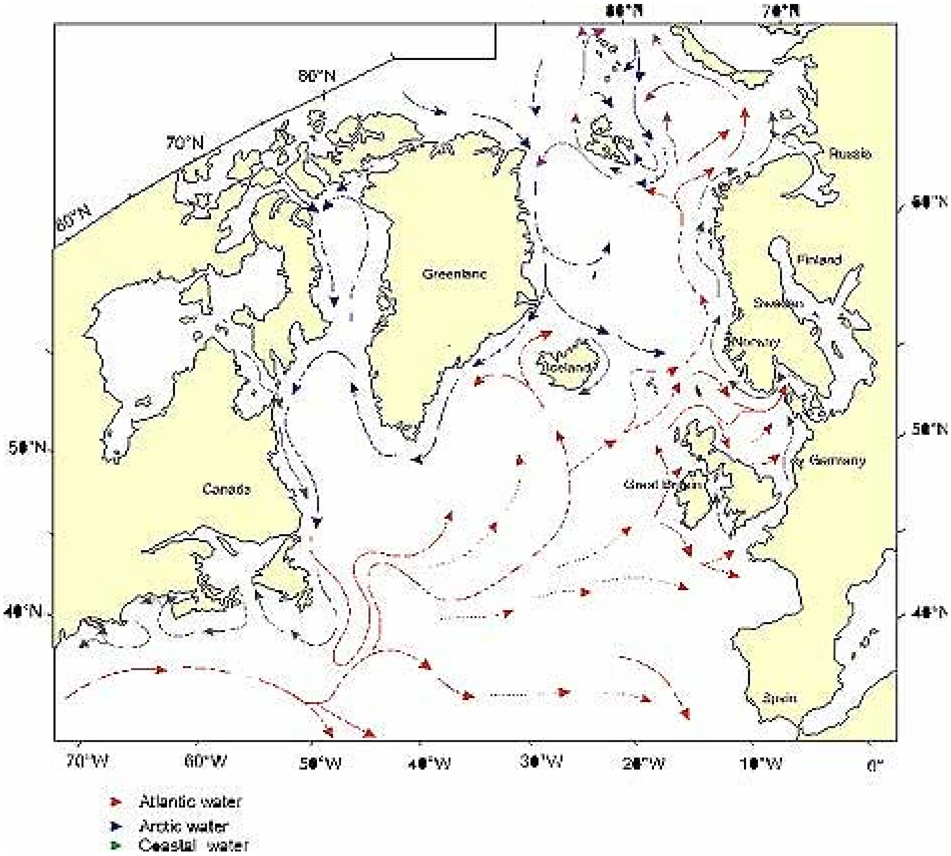

Figure 2: Surface current patterns in the North Atlantic as described by Sundby (from Reddin 2006).

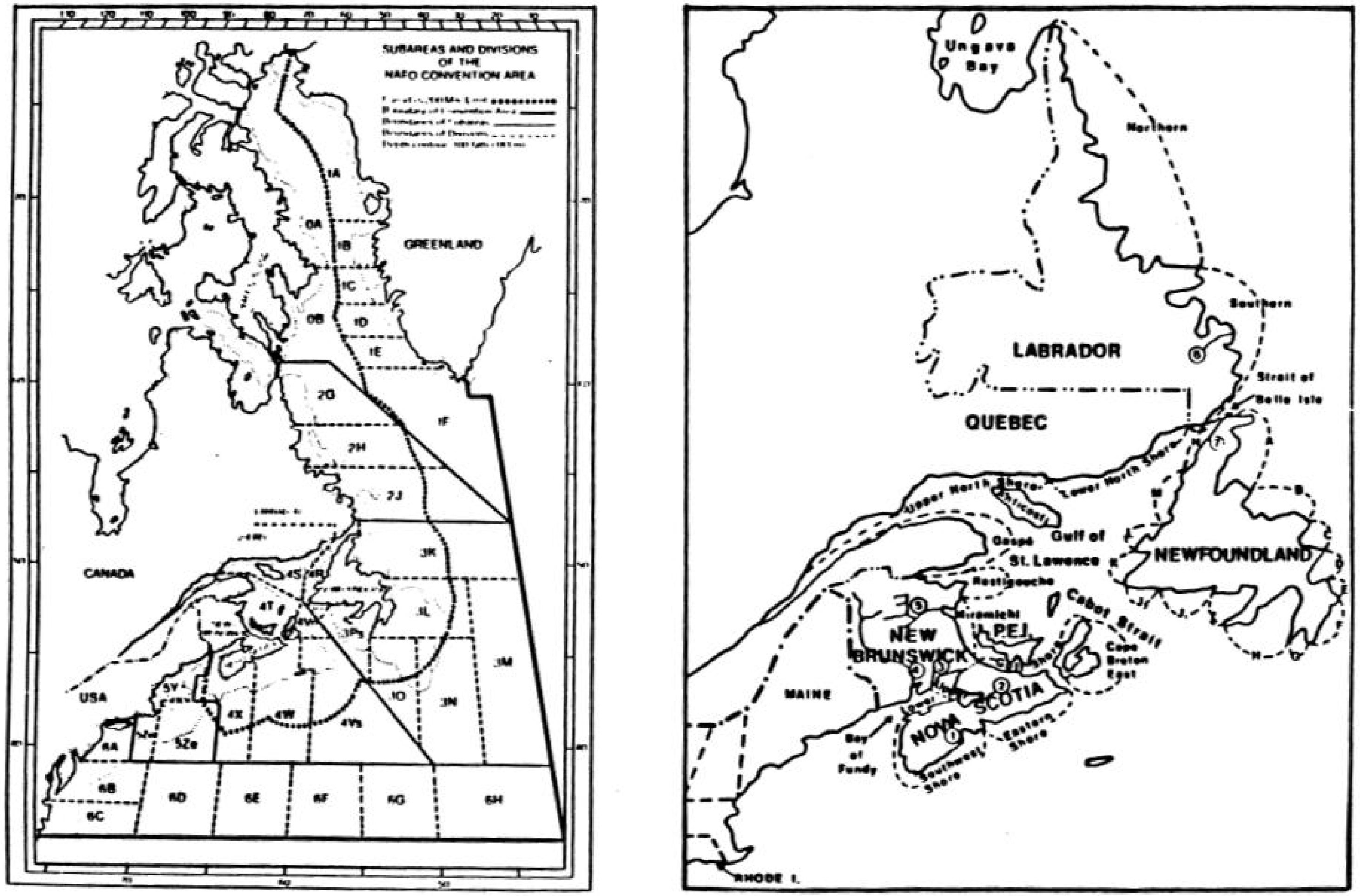

Figure 3: Map of northwest Atlantic (left) and northeast North America showing location of "Areas" and sites referenced in tables 4-7 (from Ritter 1989).

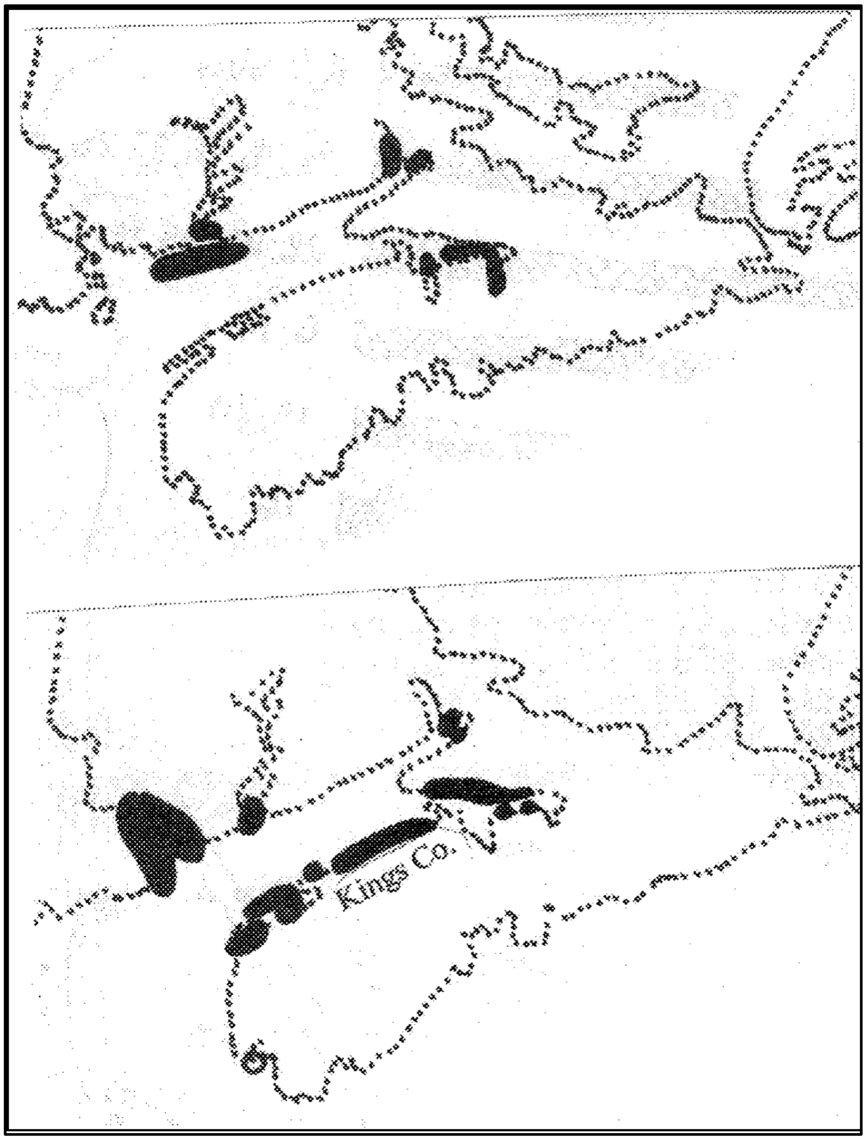

Figure 4: Locations of the historical (1971) Bay of Fundy commercial drift net fisheries for Atlantic Salmon (upper), and weir fisheries (lower) which captured some salmon but were licensed mostly for Herring, as well as some other species. Weirs in Kings County were licensed for and focused on Atlantic Salmon (adapted from Dunfield 1974).

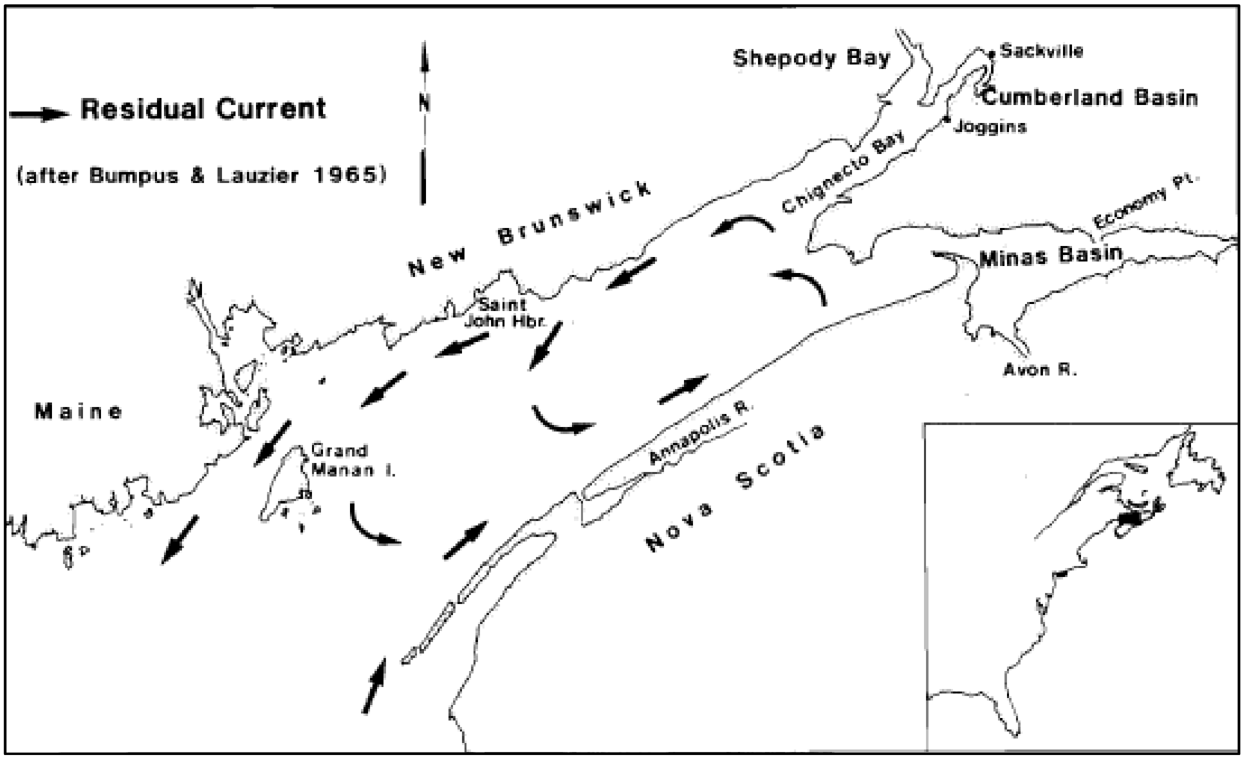

Figure 5a: Bay of Fundy showing residual current structure (from Dadswell et al. 1983, based on Bumpus and Lauzier 1965).

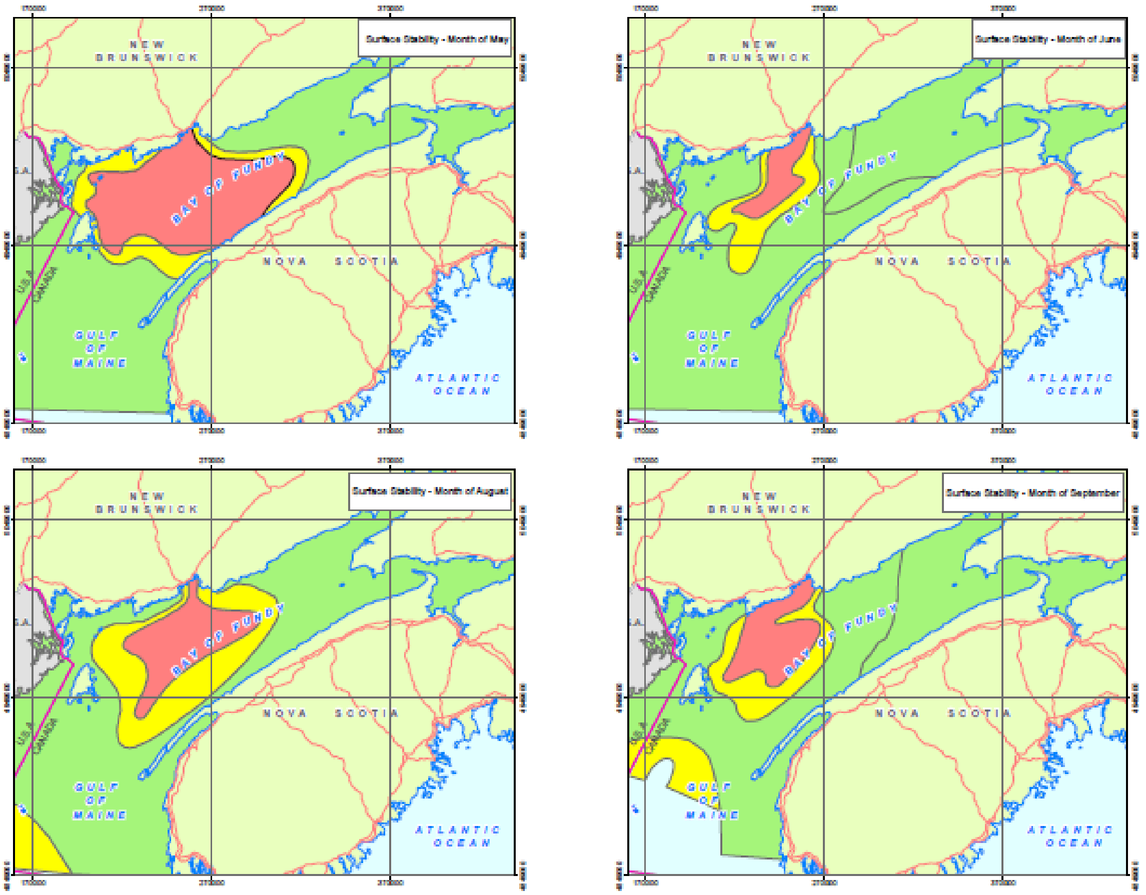

Figure 5b: Influence of the Saint John River discharge (red and yellow areas) on the surface stability (stratification) in the Bay of Fundy in May (upper left), June (upper right), August (lower left) and September (lower right). Legend: red is 'stratified', yellow is 'frontal' and .green is 'well mixed' waters of the Bay (Figure 5.12 in Jacques Whitford 2008).

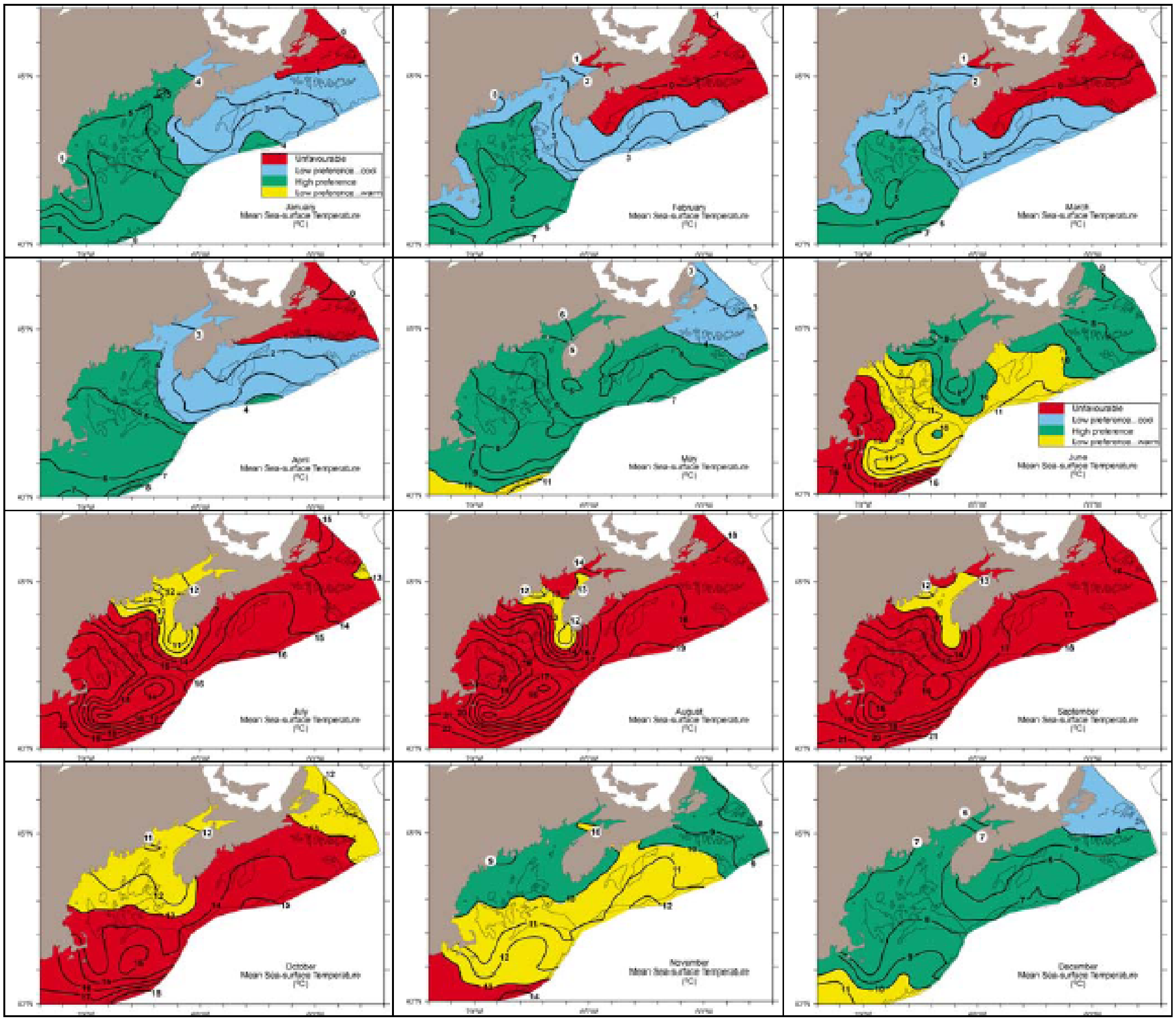

Figure 6: Average monthly SSTs for January (top right) through December (bottom left) as derived from satellite data, 1981-2000. Colour indicates the estimated temperature "preference" regions for salmon where red = unfavorable; blue = low preference (cold); green = high preference, and yellow = low preference (warm). Figure from DFO and MRNF (2008), but originally from figures 5-16 in Amiro et al. (2003).

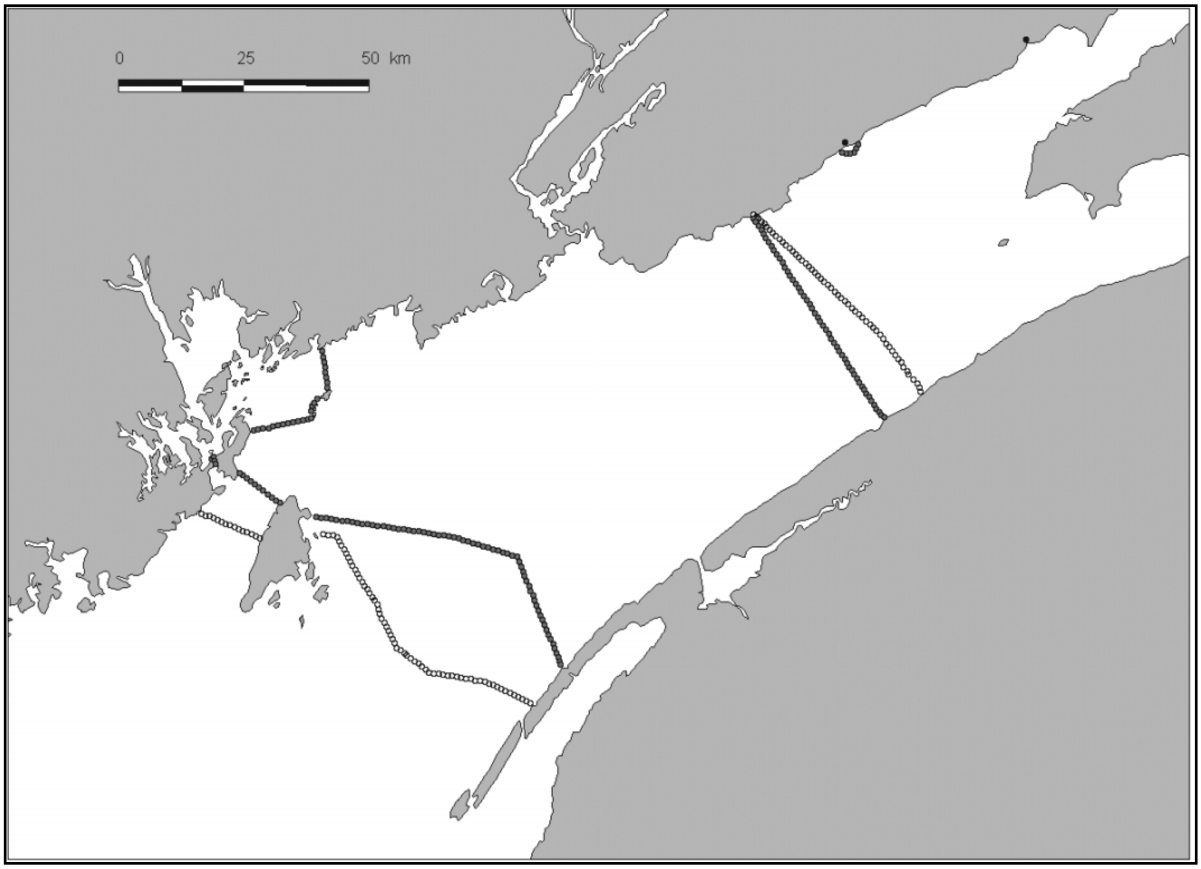

Figure 7: Map showing the location of receivers in marine arrays deployed in 2001 (shaded circles) and in 2002 (open circles) for monitoring the migration of post-smolts with transmitters (Lacroix 2008).

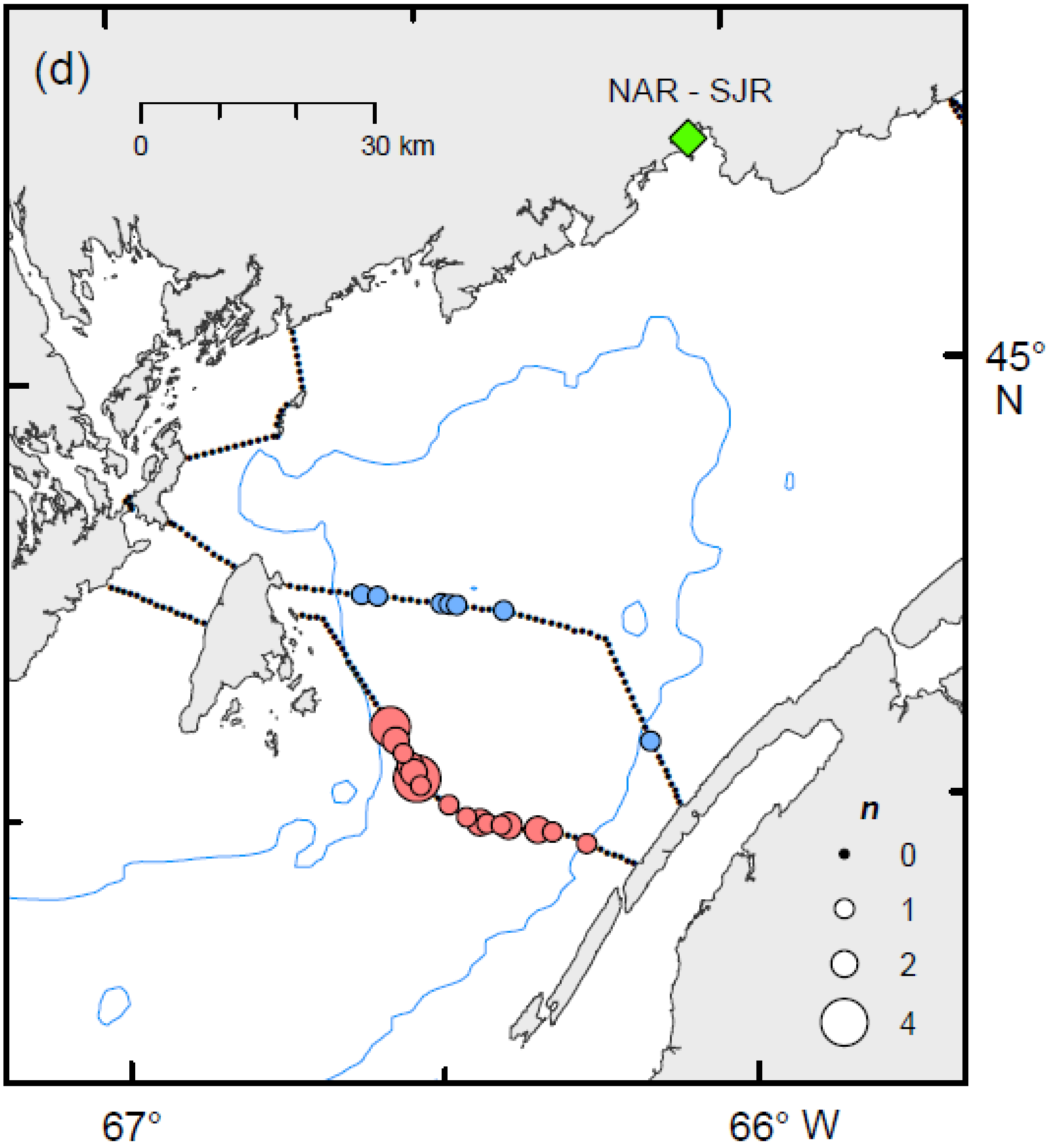

Figure 8: Distribution of migrating Atlantic Salmon (Salmo salar) post-smolts of wild and hatchery origin, from the Nashwaak (NAR) and Saint John River (SJR), tagged with acoustic transmitters in 2001 (graded blue circles) and 2002 (graded red circles) based on site of first detections on receiver arrays bounding the OBoF (Lacroix 2012).

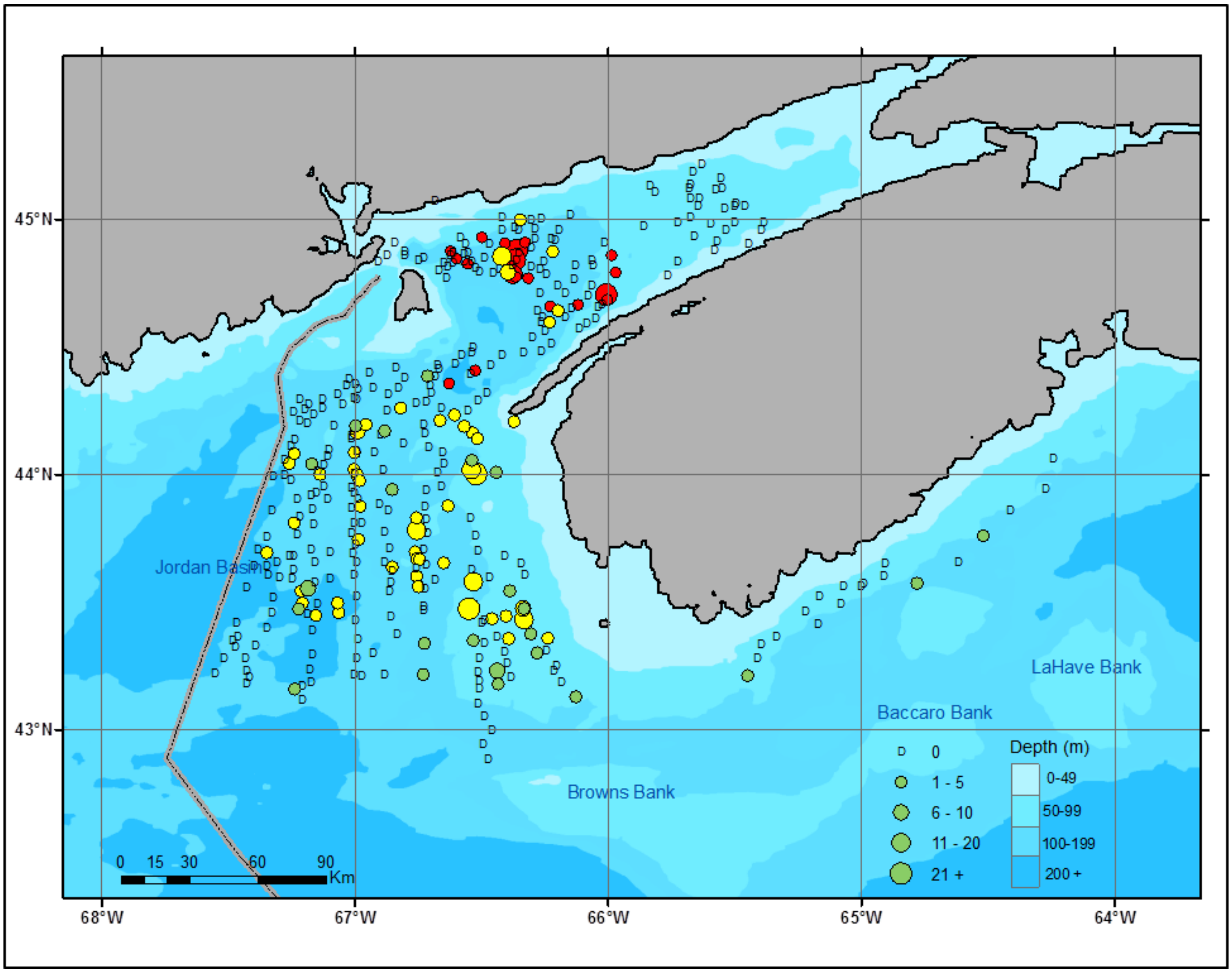

Figure 9a: Distribution of Atlantic Salmon (Salmo salar) post-smolts captured during surface trawling surveys in the Bay of Fundy and Gulf of Maine in 2001 (red circles), 2002 (yellow circles), and 2003 (green circles). Figure provided by Lacroix (pers. comm.).

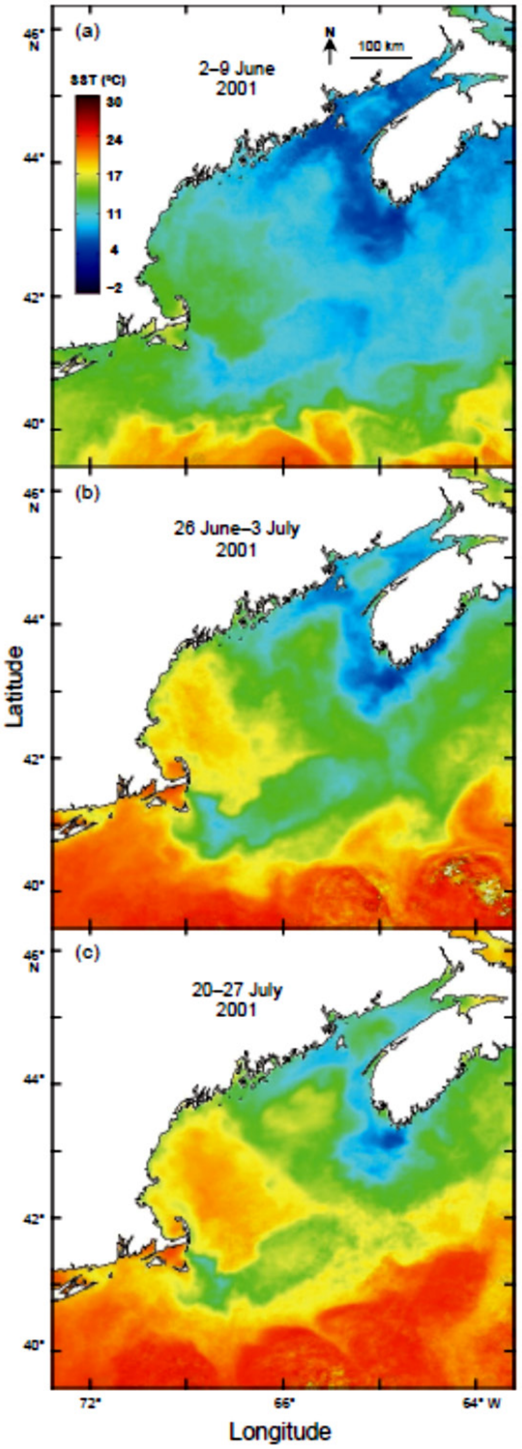

Figure 9b: Maps of SST (mean corrected 8-day composite) in the Bay of Fundy and Gulf of Maine during (a-top panel) 2–9 June, (b-middle panel) 26 June–3 July, and (c-bottom panel) 20–27 July of 2001, when Atlantic Salmon post-smolts were in the Bay of Fundy and Gulf of Maine. Satellite images are from the School of Marine Sciences, University of Maine (Lacroix 2012).

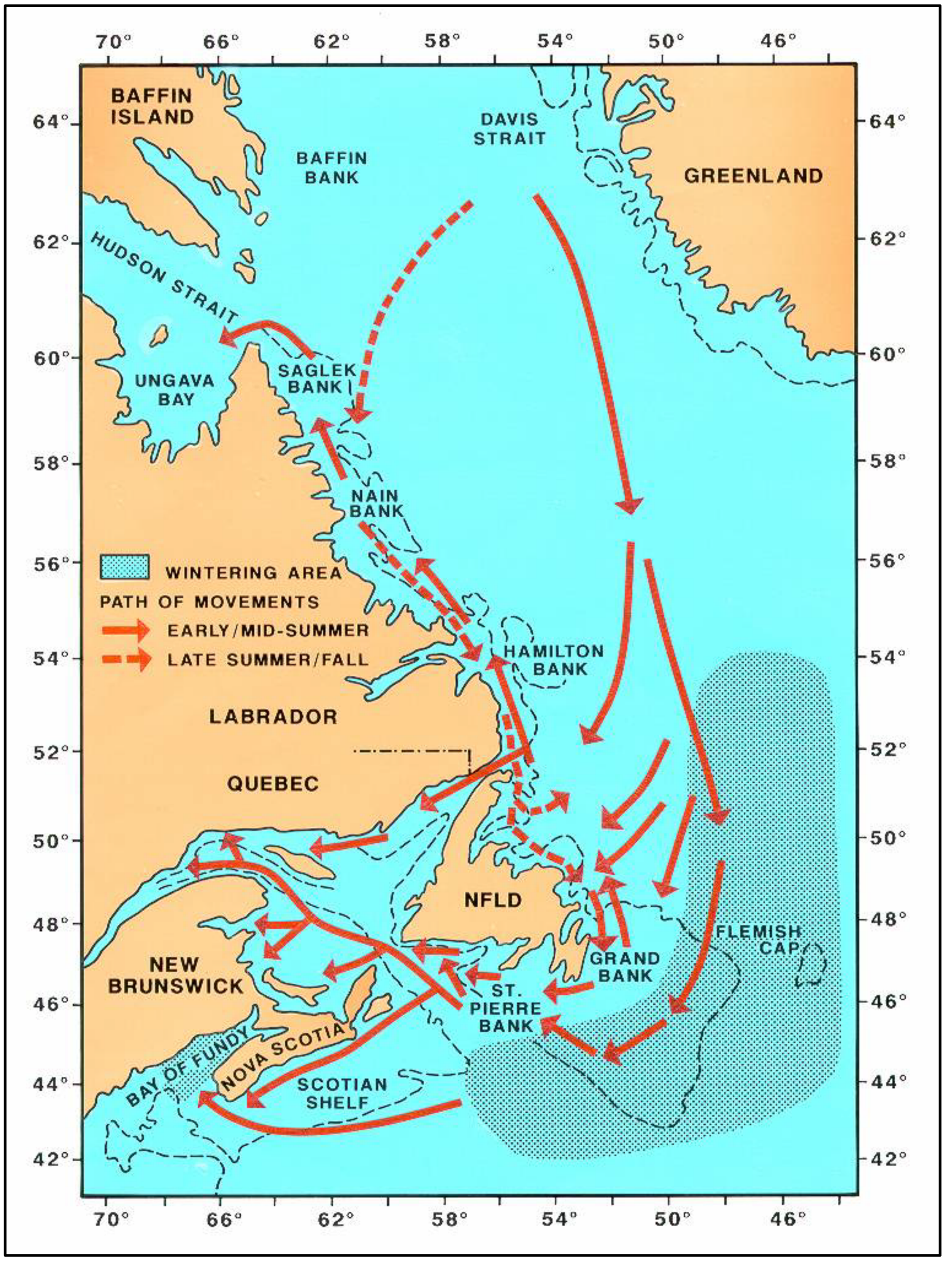

Figure 10: Migration of Atlantic Salmon from the Labrador Sea and west Greenland area to home waters reproduced from Reddin (2006).

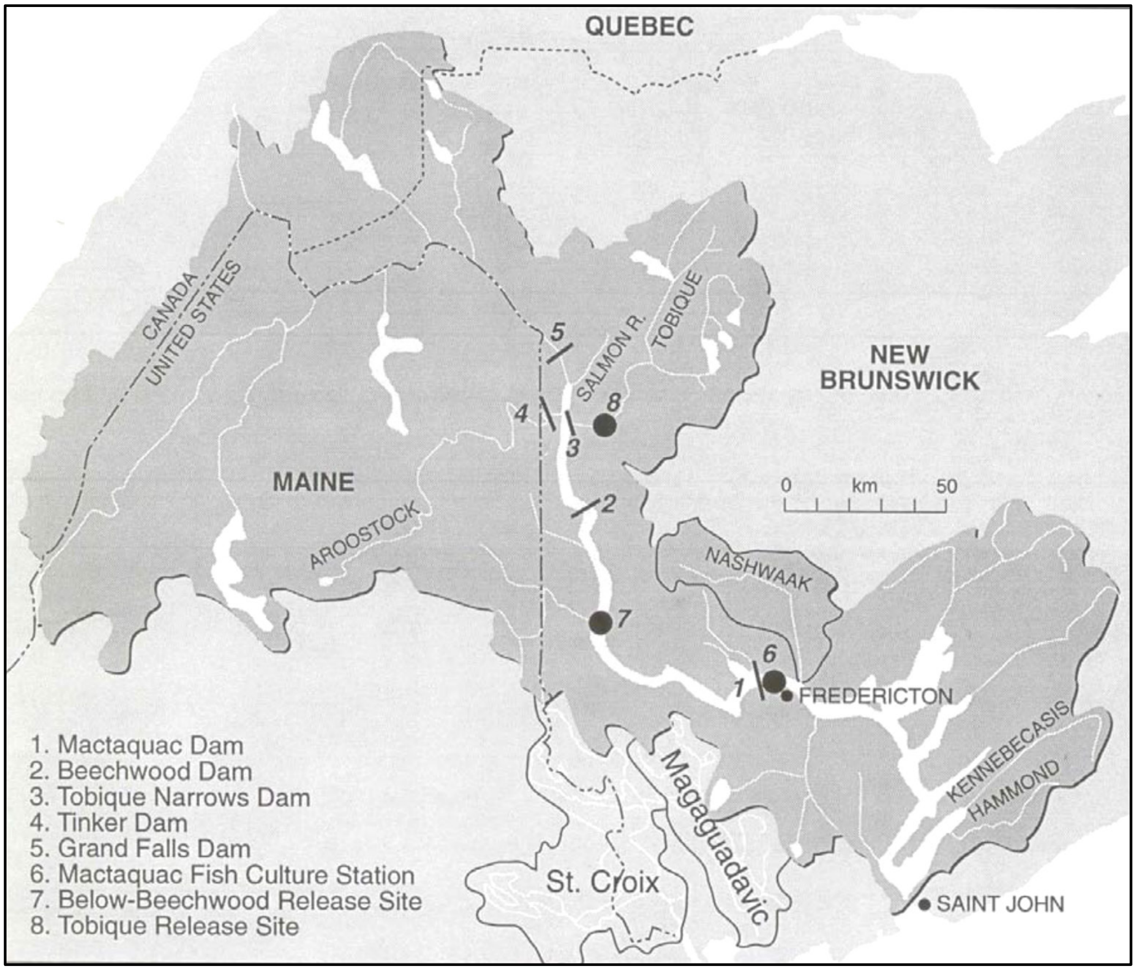

Figure 11: Map of the Magaguadavic, St. Croix and Saint John River drainages including Tobique and Nashwaak rivers and other major tributaries, dams, and principal release sites for Atlantic Salmon upriver of Mactaquac Dam. (Mactaquac Fish Culture Station is now referred to as the Mactaquac Biodiversity Facility).

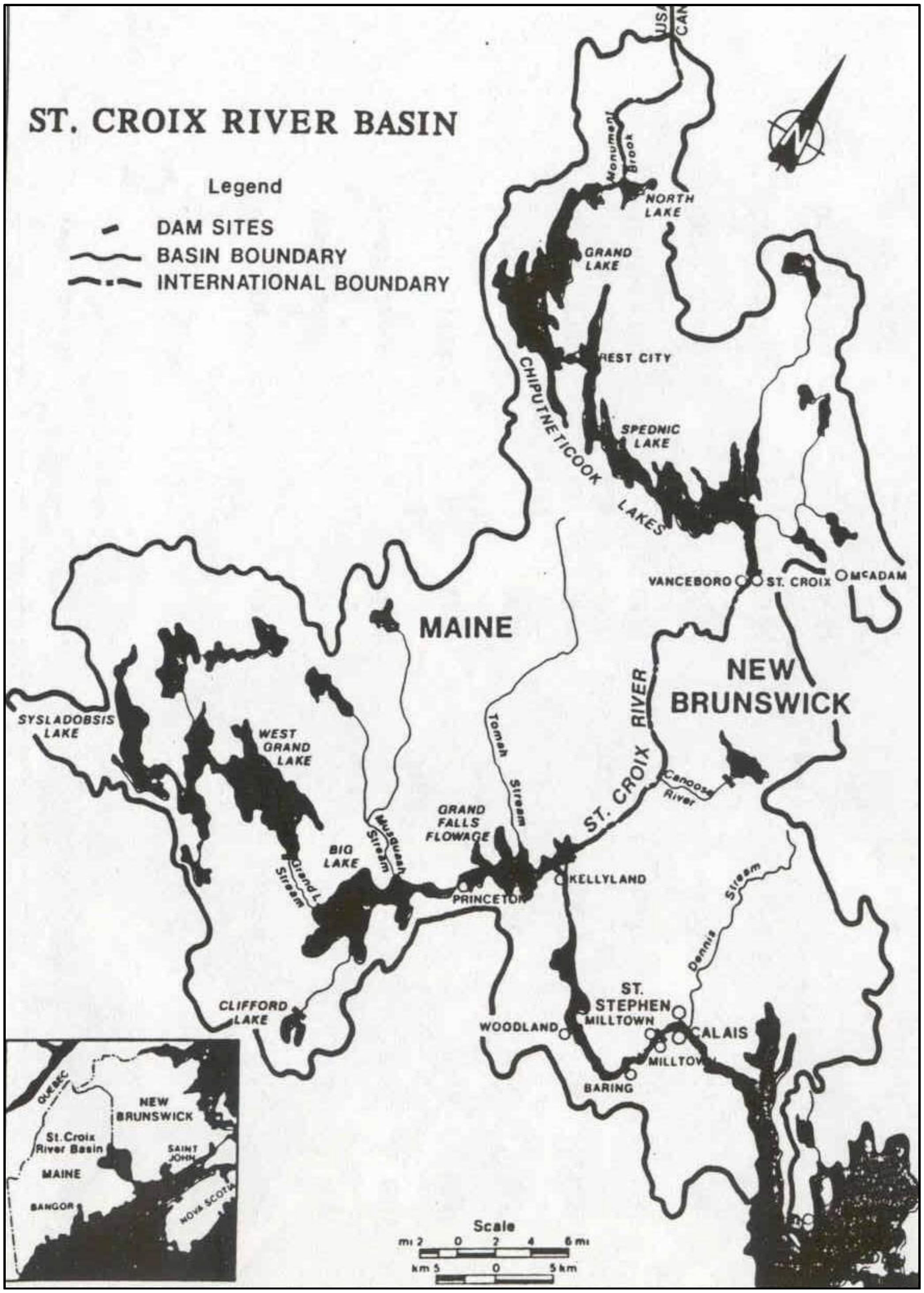

Figure 12: Map of St. Croix River watershed including Milltown, Woodland and Grand Falls (Kellyland) hydroelectric dams.

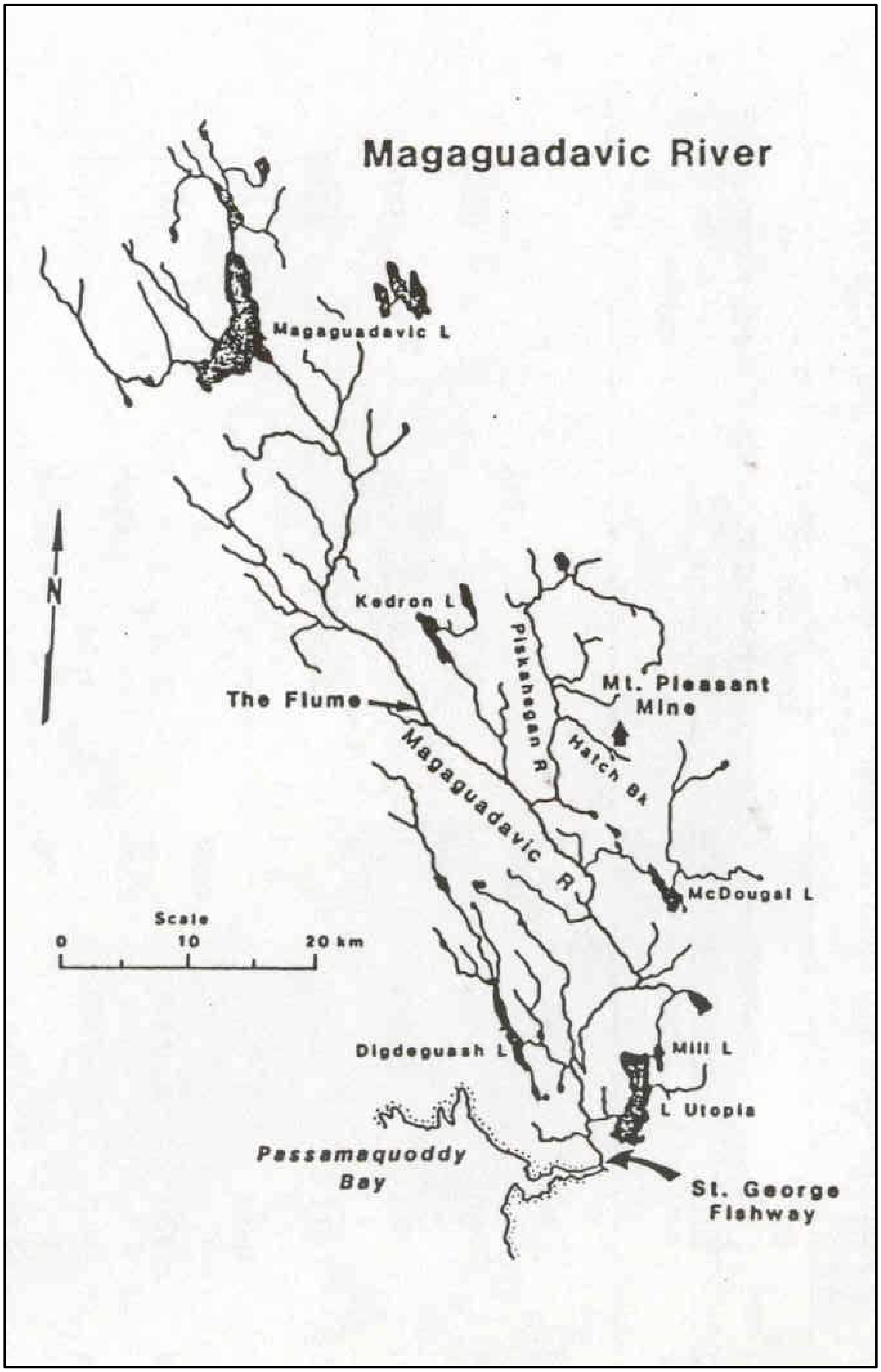

Figure 13: Map of Magaguadavic River, including St. George Fishway (hydroelectric dam).

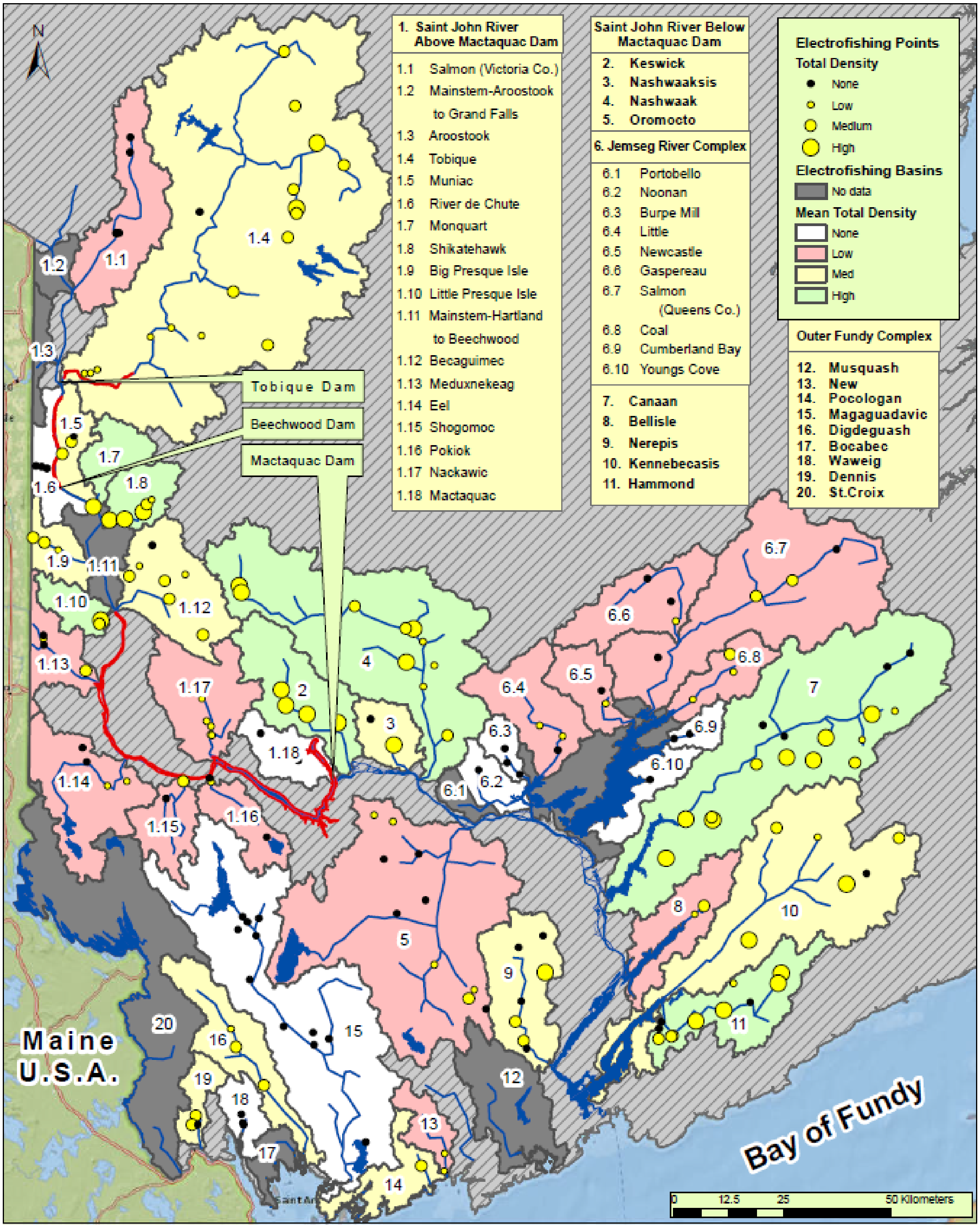

Figure 14: Densities of wild juvenile salmon at each site electrofished in DU 16 in 2009 (Jones et al. 2014). Mactaquac, Beechwood and Tobique headponds shown in red.

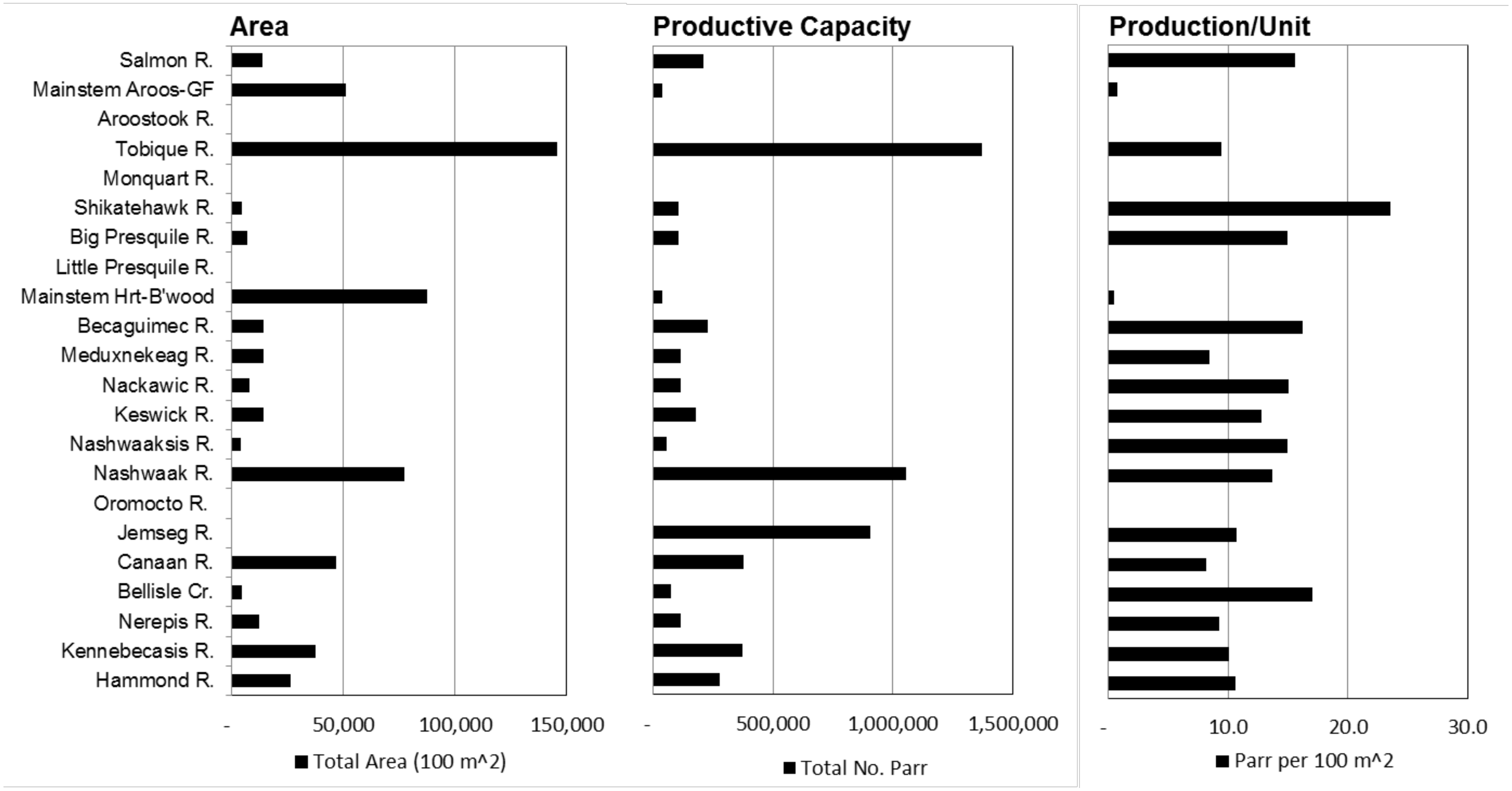

Figure 15: Wetted area, productive capacity of age-1+ and older Atlantic Salmon parr and production of parr per unit area for 22 OBoF rivers determined using grade (measured from ortho-photo maps) as a proxy for habitat quality for stream reaches (Peter Amiro, retired DFO biologist, pers. comm.; based on Amiro 1993).

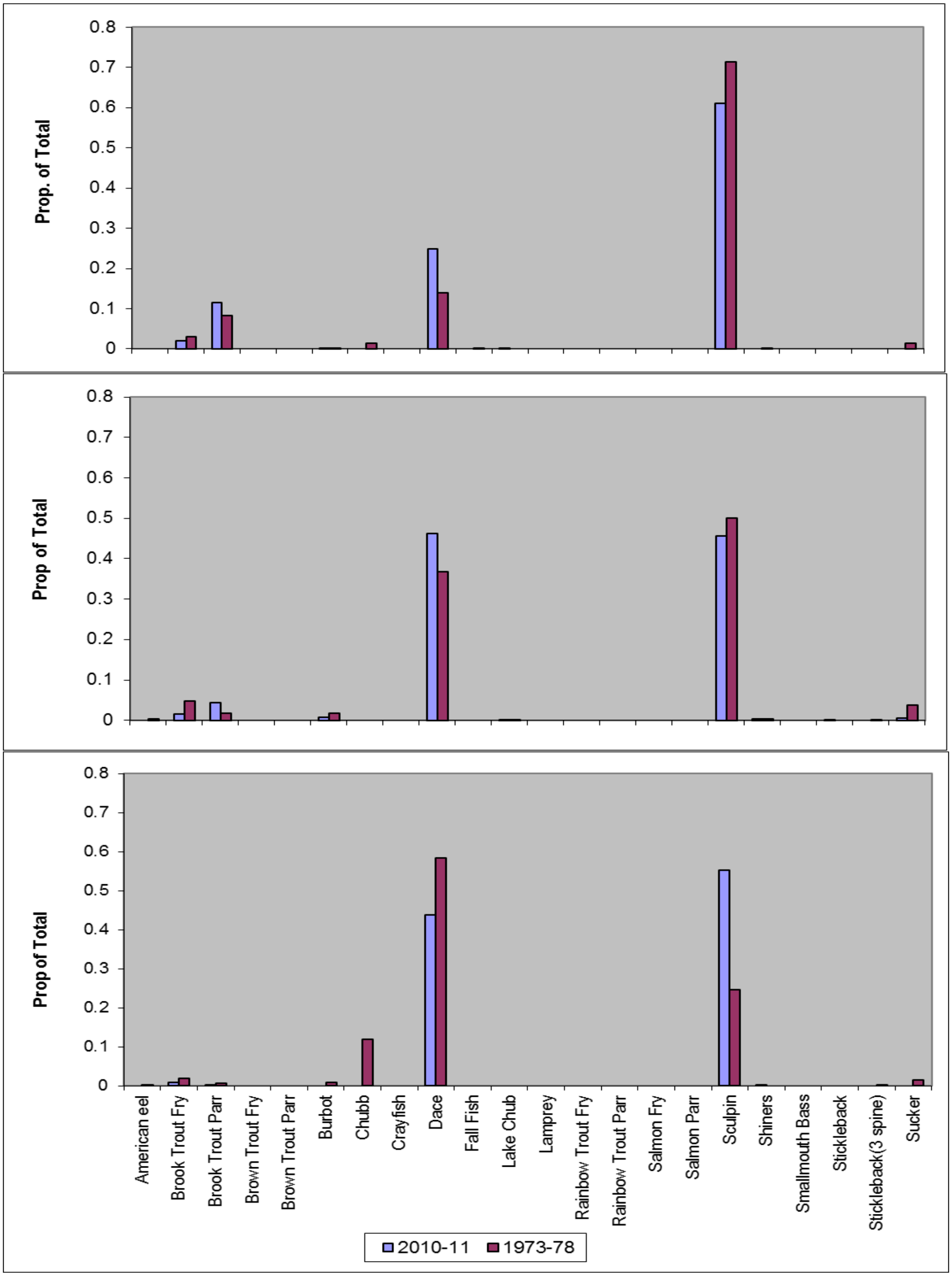

Figure 16: Relative frequencies of occurrence of non-salmon species captured by electrofishing in 12 sites (3 in stream order 3 [top panel], 7 in stream order 4 [middle panel], and 2 in stream order 5 [lower panel]) on the Tobique River tributary, 1973-1978 (Francis 1980) and 2010-2011.

APPENDICES

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.

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APPENDIX 2

Methods Used in Estimating Productive Salmon Habitat in DU 16

The estimates of spawning and rearing habitat area for the majority of the rivers within DU 16 are those reported in Marshall et al. (1997). These estimates, primarily on the tributaries within Saint John Watershed, are based on length measurements from ortho-photographic maps and width measurements from air photos (Amiro 1993). The habitat is partitioned into productive (>0.12%) and non-productive based on stream gradient (Amiro 1993). Using the productive habitat area estimate is consistent with the approach used for documenting freshwater habitat for the IBoF population (Amiro et al. 2003). Where ortho-photo/air photo calculations were not available for a particular watershed, previously documented habitat estimates were used (Baum 1982; Anon. 1978a, 1978b). Furthermore, if no previous habitat estimates could be found then the following calculation was used as per Anon. (1978a):

$$\begin{array}{c}\text{Productive Rearing}\\ \text{Area (m}^2\text{) of}\\ \text{unsurveyed river}\end{array} = \begin{array}{c}\text{Drainage Area (km}^2\text{)}\\ \text{of unsurveyed river}\end{array} \times \frac{\text{Productive Rearing Area of Surveyed River (m}^2\text{)}}{\text{Drainage Area of Surveyed River (km}^2\text{)}}$$

The surveyed river (proxy) was a nearby river with similar habitat characteristics. Drainage areas were calculated using either New Brunswick Department of Natural Resources current data shapefiles or online information hosted by the University of Southern Maine for international boundary waters:

Whenever possible the spawning and rearing habitat area estimates are categorized as accessible or non-accessible (i.e., dam with no upstream fish passage or impassable falls). Since a number of rivers are located within the United States of America, the proportion of habitat within Canada is calculated based on drainage area estimates.

For the rivers west of the Saint John River in DU 16, habitat area estimates for the St. Croix, Magaguadavic, Digdeguash and ‘other rivers’ were reported in Anon. (1978a, 1978b). The ‘other rivers’ habitat estimate of 2,350 units (100 m^2) was prorated by drainage area among the New, Pocologan, Bocabec, Waweig and the Dennis Stream. Although the estimate for the Pocologan River includes the whole river (26 km), salmon only utilize the first 9. km of the river from its mouth (Carr and Whoriskey 2003). Dalziel (1956) described the area above Pocologan Station as poor spawning grounds but rather ideal speckled trout habitat although access to this section is not impeded by Keyhole falls (2 km downstream of Pocologan Station) in normal to high water conditions. Likewise, the New River estimate includes the whole drainage area although salmon would only use the first 7 km as upstream habitat is marshland (Carr and Whoriskey 2003). While the Dennis Stream is a subwatershed of the St. Croix River, its habitat was not included in the St. Croix estimates. The Dennis Stream is categorized as an “other river” and the estimate of habitat is prorated as per drainage area. The Fletcher and Meister (1982) and Havey (1963) both report 836 units (100 m^2) of salmon habitat for the Dennis which is greater than this report presents. As a clear outline of which rivers are included in the “other rivers” presented in several documents was not forthcoming, these estimates remain uncertain.

The St. Croix River productive habitat area was updated from the previously reported 30,790 units (100 m^2) (Anon. 1988). Previous estimates were based on the assumption that salmon are not encouraged to develop standing populations above St. Croix (Vanceboro) on the East Branch or on the West Branch. Fletcher and Meister (1982), Anon (1988) and Havey (1963) report accessible rearing habitat above Vanceboro (East Branch) and for several sections in the West Branch (Tomah Stream, West and East Branch Musquash Stream, and Grand Lake

Stream). These habitat estimates were added to the previously reported productive area presented. It is important to note that spawning and rearing habitat of the West Branch is intensely managed for its Landlock Salmon and warmwater sport fisheries by the Maine Department of Inland Fish and Game although anadromous Atlantic Salmon are not denied access to the West Branch (Fletcher and Meister 1982). The presented productive area estimate can be further divided into: 29,097 (International), 7,308 (Maine USA) and 1,634 units (New Brunswick, Canada).

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