Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Maritimes Region
Canadian Science Advisory Secretariat
Science Response 2015/035

SUPPORT FOR DELINEATION OF INNER BAY OF FUNDY SALMON MARINE CRITICAL HABITAT BOUNDARIES IN MINAS BASIN AND CHIGNECTO BAY

Context

In April 2014, the Fisheries and Oceans Canada (DFO) Species at Risk Management Division (SARMD) in the Maritimes Region requested information from DFO Science to assist with the delineation of boundaries for critical habitat (CH) being considered for Inner Bay of Fundy (IBOF) Atlantic Salmon within Chignecto Bay and Minas Basin, specifically: to assist with the delineation of the boundary between estuarine and marine habitat for several large, tidal estuaries (i.e., Petitcodiac River, Avon River, Salmon River Colchester, Shubenacadie River estuary and Cumberland Basin).

DFO Science had previously provided advice on the characteristics and general location of important marine and estuarine habitat for IBOF salmon (DFO 2008; DFO 2013); however, additional information was requested to assist in delineating the precise boundaries of important marine habitat within Chignecto Bay and Minas Basin in order to subsequently propose, describe and map these as CH within an amended Recovery Strategy for IBOF salmon. Once identified in the Recovery Strategy, measures will be taken to protect this marine CH under the *Species at Risk Act* (SARA).

This Science Response Report results from the Science Response Process of 11 July 2014 on Support for Delineation of Inner Bay of Fundy Salmon Marine Critical Habitat Boundaries.

Background

The inner Bay of Fundy populations of Atlantic salmon (*Salmo salar*) are listed as Endangered under the *Species at Risk Act*, and SARA requires the identification of CH for endangered species within a Recovery Strategy (or Action Plan). Atlantic salmon are an anadromous species and, therefore, require both freshwater and marine (including estuarine) habitats to complete their life cycle. Freshwater CH was identified in the Recovery Strategy for IBOF Atlantic Salmon published on the Species at Risk Public Registry in May 2010 (DFO 2010). The rivers identified as containing freshwater CH are the Big Salmon, Upper Salmon, Point Wolfe, Economy, Portapique, Great Village, Folly, Debert, Stewiacke, and Gaspereau rivers. The Recovery Strategy contains further details on the identified freshwater CH, including its geographical location and biophysical components (i.e., features, functions and attributes). Marine and estuarine CH for IBOF salmon are being considered for identification in an amended Recovery Strategy. This Science Response is intended to inform a specific component of this work as outlined below.

Previous Science Advice

Science advice on important marine and estuarine habitat for IBOF salmon was developed at a DFO science advisory meeting in November 2012 (DFO 2013). At this meeting, important marine and estuarine habitat for IBOF salmon was proposed as the tidal portions of 19 inner Bay of Fundy salmon rivers and the entire Bay of Fundy outward to the northern Gulf of Maine and the Canada/U.S. boundary, southward to latitude 43°46'51.

This large area was further subdivided into eight smaller areas of the Bay of Fundy (Figure 1) to help describe the spatial distribution of important functions by life-history stage, and the features and associated attributes that support these.

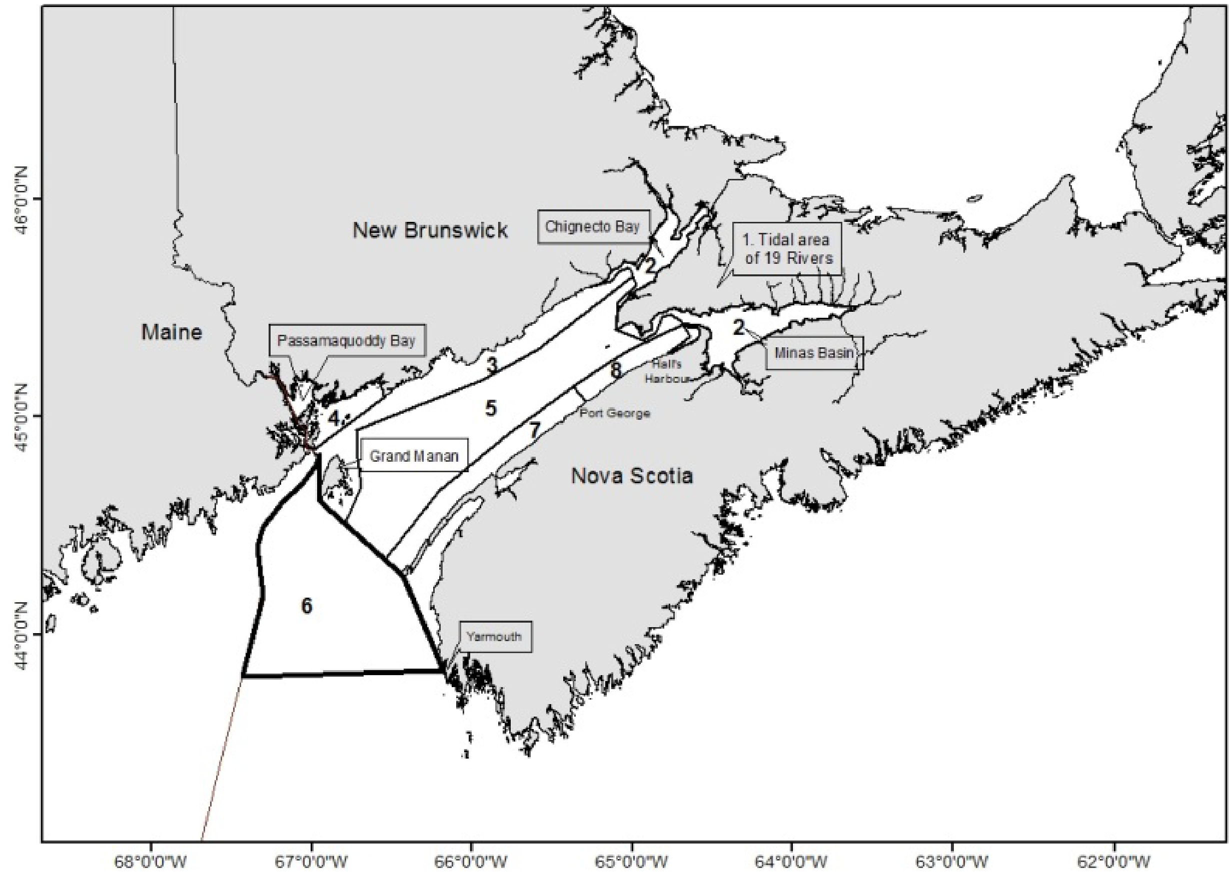

Figure 1. Areas identified within the important habitat bounding box for IBOF salmon (from DFO 2013).

At the November 2012 science advisory meeting, Minas Basin and Chignecto Bay (Area 2) was identified as important habitat for the migration of post-smolts, adults, and kelts; feeding of post-smolts and kelts; and staging of adult IBOF salmon (DFO 2013). While it was referred to as estuarine habitat, the distinction between estuarine and marine habitat was not discussed at this meeting except in general terms (i.e., estuaries were considered to be ≤30 practical salinity units (psu)).

At this meeting, the characteristics of Minas Basin and Chignecto Bay of importance for the different life-history stages of IBOF salmon were described, including temperature, salinity, depth/volume, predator abundance, and prey availability (Table 1). However, precise boundaries for Area 2 (e.g., geographic coordinates) were not provided.

Table 1. General summary of the biophysical functions, features and attributes necessary for required biological functions of inner Bay of Fundy salmon in Minas Basin and Chignecto Bay (DFO 2013).

Life Stage	Function	Timing	Features	Attributes
Post-smolt	Migration to outer Bay of Fundy	May –June	Migration Corridor	**Secondary** • Temperature • Salinity (increasing to 31 ppt) • Predator abundance
	Feeding	June-Sept	Food availability	**Primary** • Key forage species (not known for this area)
Adult	Migration to freshwater	May-Oct	Migration corridor	**Primary** • Temperature (<14˚C while Salmon await appropriate river discharges) **Secondary** • Salinity (decreasing) • Predator abundance
	Staging	June-Oct (River Specific)	Estuaries	**Primary** • Temperature (<14˚C) while Salmon await appropriate river discharges **Secondary** • Salinity (decreasing)
Kelt	Migration to Bay of Fundy	Winter/ spring	Migration Corridor	**Primary** • Salinity (increasing) **Secondary** • Depth/volume • Predator abundance
	Feeding	Winter/ spring	Food availability	**Primary** • Forage species including juvenile herring, white hake, winter flounder, and adult and juvenile three spine sticklebacks (Minas Basin)

Scope of This Assessment

Of the eight areas identified in Figure 1, three are being considered by SARMD as priorities for identification as marine/estuarine CH in the forthcoming amended Recovery Strategy:

1. the tidal portions of the rivers identified as containing freshwater CH (listed above and consistent with the 10 rivers identified in the Recovery Strategy as containing freshwater CH);
2. Minas Basin and Chignecto Bay (Area 2 in Figure 1); and
3. coastal Southwest Nova Scotia: Port George to Hall's Harbour (Area 8 in Figure 1).

This Science Response deals only with Area 2 (Minas Basin and Chignecto Bay) and is intended to provide additional guidance in defining the marine/estuarine boundaries of five large, tidal systems (i.e., Petitcodiac River, Avon River embayment, Salmon River Colchester, Shubenacadie River estuary and Cumberland Basin) within these sub-basins of the Bay of Fundy.

Analysis and Response

Challenges with Defining Marine and Estuarine Habitat in the Bay of Fundy

Estuarine habitat can be defined as seawater that is measurably diluted with freshwater derived from land drainage. Using this definition, the Bay of Fundy itself can be considered a large estuary. In the Bay of Fundy, salinity varies throughout the estuary principally due to the outflow of the Saint John River, and salinity is generally lower than full strength seawater, even near the mouth (approximately 31-33 psu; Drinkwater 1987). Salinities throughout the offshore regions of the Bay of Fundy have been measured by DFO at least once a year during the summer research vessel surveys since 1970 and sporadically before then. Annual summaries of the data have been produced in a series of reports over the years (e.g., Drinkwater 1987; Page et al. 1997; Losier et al. 1999; Clark et al. 2010; DFO 2013). The salinities in the Bay of Fundy vary spatially and temporally by several psu, especially during the spring when river runoff is high, but they are generally greater than 29 psu.

A partial literature search suggests that, in general, salinity decreases from the Bay of Fundy inward and inland, through Chignecto Bay, Shepody Bay and up the Petitcodiac River. The salinity at the mouth of Chignecto Bay is about 31 psu (Keizer and Gordon 1985 as reported in Locke and Bernier 2000; Keizer et al. 1984) and about 25 to 29 psu at the mouth of Shepody Bay (Keizer and Gordon 1985 as reported in Locke and Bernier 2000). Interestingly, salinity within some areas of Chignecto and Shepody Bays during the winter, when large amounts of ice were present, was indicated to be substantially lower (ranging from 10 to 25 psu; Desplanque and Bray 1986 as reported in Locke and Bernier 2000) during a seasonal period when freshwater input is expected to be relatively low.

Ideally, the boundary between marine and estuarine habitat would be established using detailed knowledge of the salinity regime within and surrounding each estuary, to establish the transition between the typical salinity of the Bay of Fundy and the lowered salinity of the estuaries (approximately less than 31 psu). However, in most cases, there are major gaps in the data required to establish a boundary based on salinity. Furthermore, such a boundary is actually a transition, which changes with each tidal cycle, seasonally, and annually due to factors such as river discharge and changing land-use patterns.

Guiding Principles for Delineating Marine CH in the Bay of Fundy

Guiding principles for boundary delineation of IBOF salmon CH in the Minas Basin and Chignecto Bay (Area 2) were discussed during the Science Response Process of 11 July 2014 and included:

- Ensure that estuarine CH is continuous with marine CH (i.e., to ensure that salmon moving between marine and estuarine environments would not experience a gap in protection),
- Ensure that habitat characteristics important for IBOF salmon are captured in marine CH so that important life-history functions can be carried out. For IBOF salmon, this includes proximity to identified freshwater and estuarine CH for migration purposes, and
- Limit the likelihood that the boundaries would change soon after they have been identified.

Approaches to Delineating the Boundary Between Marine and Estuarine CH

Various approaches have been used to delineate CH for marine species in Canada, but no marine CH has yet been established for an anadromous species. Examples where boundaries have been established at the transition between estuarine and marine habitat, which would have been informative in developing an approach for IBOF salmon, are limited or have not been well documented. Given the lack of relevant examples to draw from, a number of different approaches for delineating the boundary between marine and estuarine habitat for IBOF salmon in the Bay of Fundy were explored.

Approach 1: Salinity Gradient

From a scientific perspective, the preferred approach for establishing a marine/estuarine boundary would be to use salinity data. The boundary between marine and estuarine habitat is potentially defined as a salinity equal to or less than 29 psu, beginning where there is a steep spatial gradient in salinity, as the marine salinity transitions relatively rapidly from offshore values of greater than 29 psu to much lower salinities.

To determine whether estuarine/marine boundaries for four large tidal systems in Minas Basin and Chignecto Bay could be established based on salinity, readily available oceanographic data were compiled. No new data were collected, nor were there new analyses performed using existing data. Salinity data were found that had the potential to inform boundary delineation for two of the large tidal systems: Petitcodiac River and the eastern extremity of Minas Basin at Salmon River Colchester. While similar data may exist for Cumberland Basin and the Avon River embayment, they were not available in time for inclusion in this Science Response.

Approach 2: Alternatives to Salinity Gradient

Three alternative approaches to estuarine/marine boundary delineation are also presented, which may be used to complement, or as an alternative to, the approach based on salinity. These alternative approaches are based on tidal penetration indicators or enduring features (e.g., tidal boundaries, enduring points of land, etc.) that are expected to be less dynamic and more easily identifiable from published data sources.

Approach 2a) Lowest Normal Tide

The penetration of salt water up into an estuary/river system is controlled by the tidal amplitude of the adjacent marine system and the volume and rate of freshwater entering the estuary. The locations of specific tidal marks can be used as an approximation of marine penetration. The lowest normal tide (LNT) provides an estimate of the minimal penetration of marine water up into an estuary. The LNT was drawn as a line beginning at the furthest upstream location of the continuous extension of the lowest normal tide mark, running perpendicular to the direction of the channel; that is, the upper boundary of an area that is always wet with a psu value greater than zero. This approach is advantageous in that it can be derived from readily available Canadian Hydrographic Service (CHS) charts and could be standardized over all estuaries. How it relates to the salinity gradient will depend upon the characteristics of the estuary. The LNT line should give a better estimate of the transition between marine and estuarine habitat than the seaward headlands approach mentioned below, but it is not as accurate an estimate as the salinity gradient described above.

On the maps below, coarser scale CHS charts are used for visualization and, thus, the boundary may appear different than the edge of the LNT mark. It is unknown how well the LNT line corresponds to the region of rapid transition in salinity, which would indicate the transition between estuarine and marine habitat. In present usage, the LNT line is synonymous with lower low water mean tide (LLWMT), which is the average of all the lower low waters from 19 years of predictions.

Approach 2b) Channel Half Full

The Channel Half Full (CHF) boundary, another indicator of tidal penetration, is the first location downstream where the channel is half filled with water at low tide, running perpendicular to the direction of the channel. Advantages and limitations of this approach are similar to the LNT boundary in that it is relatively easy to delineate based on published data sources; however, its relationship to the salinity gradient will depend on the characteristics of the estuary. This approach would also be considered a better estimate than the headlands approach described below, but not as accurate as the salinity method described above. In general, the approach produces a boundary that is further downstream (i.e., more marine) than the LNT method described above.

Approach 2c) Headlands

A headland-based boundary between marine and estuarine habitat is sometimes used when distinct coastline features exist, such as when the mouth of the estuary is bounded by a barrier beach. A headland in this context is an area along the coast surrounded by water on three sides (whereas a bay would be surrounded by land on three sides). Headlands and bays form on discordant coastlines, where bands of rock of alternating resistance run perpendicular to the coast. Headlands form where stronger (more resistant) rocks are less prone to erosion (such as chalk, limestone and granite). This difference in the rate of erosion is caused by differential erosion (Easterbrook 1999). Headlands can be useful when combined with knowledge of the general oceanography and hydrology of the area. Headlands do not work as well in macro-tidal environments, such as the Bay of Fundy, and when the coastline lacks distinct mouths of rivers or estuaries. As such, this approach may be appropriate in certain cases when a distinct feature exists or no salinity or other data is available. This approach has the advantage in that it is consistent with the description of the tidal portions of IBOF rivers presented in DFO (2013) and, hence, equivalent to the boundary approach being considered for estuarine CH for the 10 IBOF rivers identified in the Recovery Strategy as containing freshwater CH.

For the 10 IBOF rivers that have been identified in the Recovery Strategy as containing freshwater CH (DFO 2010), estuarine CH is being considered as the lower reaches of each river, between the high tide mark and a line drawn between the headlands. This is based on an approach typically used to define the boundary of a watershed rather than to define a boundary between marine and estuarine habitat; however, it is deemed appropriate for these smaller rivers with distinctive headlands. In the larger, more tidally-dominated river systems flowing into Chignecto Bay and Minas Basin (Cumberland Basin, Avon River embayment, Petitcodiac River, and the eastern extremity of Minas Basin at Salmon River Colchester), headlands are not always as obvious and/or are not expected to correspond with the transition from marine to estuarine habitat as defined by salinity.

Caveats

For the four different approaches, each boundary was extended to the mean high water mark established from the provincial coastlines (DNR 2005; Service Nova Scotia 2012a). The location of mean high water on provincial coastlines is interpreted from aerial photographs and is updated on a 10 year cycle (I. Holmes, Nova Scotia Geomatics Centre, pers. comm.). On the maps below, this coastline is not shown and, thus, boundaries may not appear to touch the coastline.

It is not expected that a single approach will satisfy each unique area under consideration. In addition, it is not expected that these approaches will define a standardized method for delineation of CH boundaries in other estuaries or for other species. Other approaches could be used depending on data and resource availability. For other cases, there could be different time constraints, data available, and/or considerations.

There are other habitat attributes important for IBOF salmon in Minas Basin and Chignecto Bay, in addition to salinity, that need to be considered when determining the boundary of CH for IBOF salmon within this area (Table 1). Although accurate boundaries for each habitat attribute are unlikely to be established, it may be possible to ensure that, generally, the boundary of CH proposed for Minas Basin and Chignecto Bay includes the attributes of importance for IBOF salmon. For example, while it may not be possible to delineate a boundary separating habitat that is less than 14°C from habitat that is greater than 14°C, it may be possible to identify the habitat that is generally less than 14°C at a time when this is important for salmon staging and migration.

Geographic coordinates for the boundaries/areas identified using each approach have not been provided. It is possible that a text description could be used instead of, or in conjunction with, coordinates to delineate these areas.

Petitcodiac River

The Petitcodiac River flows into Shepody Bay at the northeastern extremity of Chignecto Bay. Although the Petitcodiac River has been identified by DFO Science as one of the 19 rivers containing important estuarine habitat for IBOF Salmon (DFO 2013), its freshwater areas were not identified as containing CH in the published Recovery Strategy (DFO 2010) as it is not one of the 10 rivers included in the species short-term recovery goal. The Petitcodiac River system is, therefore, not currently being considered as containing estuarine CH in the forthcoming amended Recovery Strategy. One of the reasons for this is that the Petitcodiac does not currently contain a residual native population of Atlantic Salmon (DFO 2010), which was one of the top science-based criteria outlined in in the Recovery Potential Assessment to guide the selection of priority rivers (DFO 2008). However, it does contain juvenile salmon that were released from the IBOF Live Gene Bank (LGB) program (but not as one of the three target rivers). This management decision has relevant implications for defining the appropriate estuarine/marine boundary for the Petitcodiac River system.

The gates of the Petitcodiac Causeway in Moncton, N.B. have been open since spring 2010 (associated with the 'Petitcodiac Causeway Project'). During the initial Causeway construction, and subsequent years while in operation, it was estimated that 130 x 10^6 m^3 of sediment were deposited in the Petitcodiac River system (van Proosdj et al. 2009; Figure 2). Approximately 76 x 10^6 m^3 of this sediment has been displaced since the gates have been open on a continuing basis (AMEC Environment and Infrastructure 2012). Sediment (approximately 65 x 10^6 m^3) is now moving seaward and out of the river system, with an additional 5 x 10^6 m^3 moving further up into the river system past the Causeway structure (AMEC Environment and Infrastructure 2013). Prior to gate-opening operations associated with the 'Petitcodiac Causeway Project', the lower Petitcodiac River and estuary contained large amounts of suspended sediment with concentrations that reached as high as approximately 200 g/L (Curran et al. 2004); a number that was sufficient for fluid mud formation. The large amount of suspended sediment also reduced the width of the river channel near Moncton. Since commencement of the 'Petitcodiac Causeway Project', this is considered a transition period for sediment redistribution, and the use of this area by IBOF salmon may change as the system evolves (AMEC Environment and Infrastructure 2013).

In the Petitcodiac River system, fluid mud formation was shown to cause density inversions where colder, saltier water overlayed warmer fresh water due to the high concentration of suspended sediment forming fluid mud layers near the river bed (Curran et al. 2004). This may be an important influence on the portion of the water column used by salmon during migration, if fluid mud remains under the evolving sedimentary conditions of the system. Although untested, it is possible the suspended sediment concentrations could remain too high for salmon migration near the river bed. Although fluid-mud flows have been recognized as a significant mode of sediment transport, limited information regarding the internal structure of these flows exists.

Four different methods for delineating the marine/estuarine boundary for the Petitcodiac River system are described. These include boundaries based on salinity, the LNT, CHF, and the headlands (Figure 2). As mentioned previously, each boundary was extended to the mean high water mark established from the provincial coastlines. A limitation of this approach in the

Petitcodiac River system is the possible migration of the shoreline since the opening of the causeway gates in 2010.

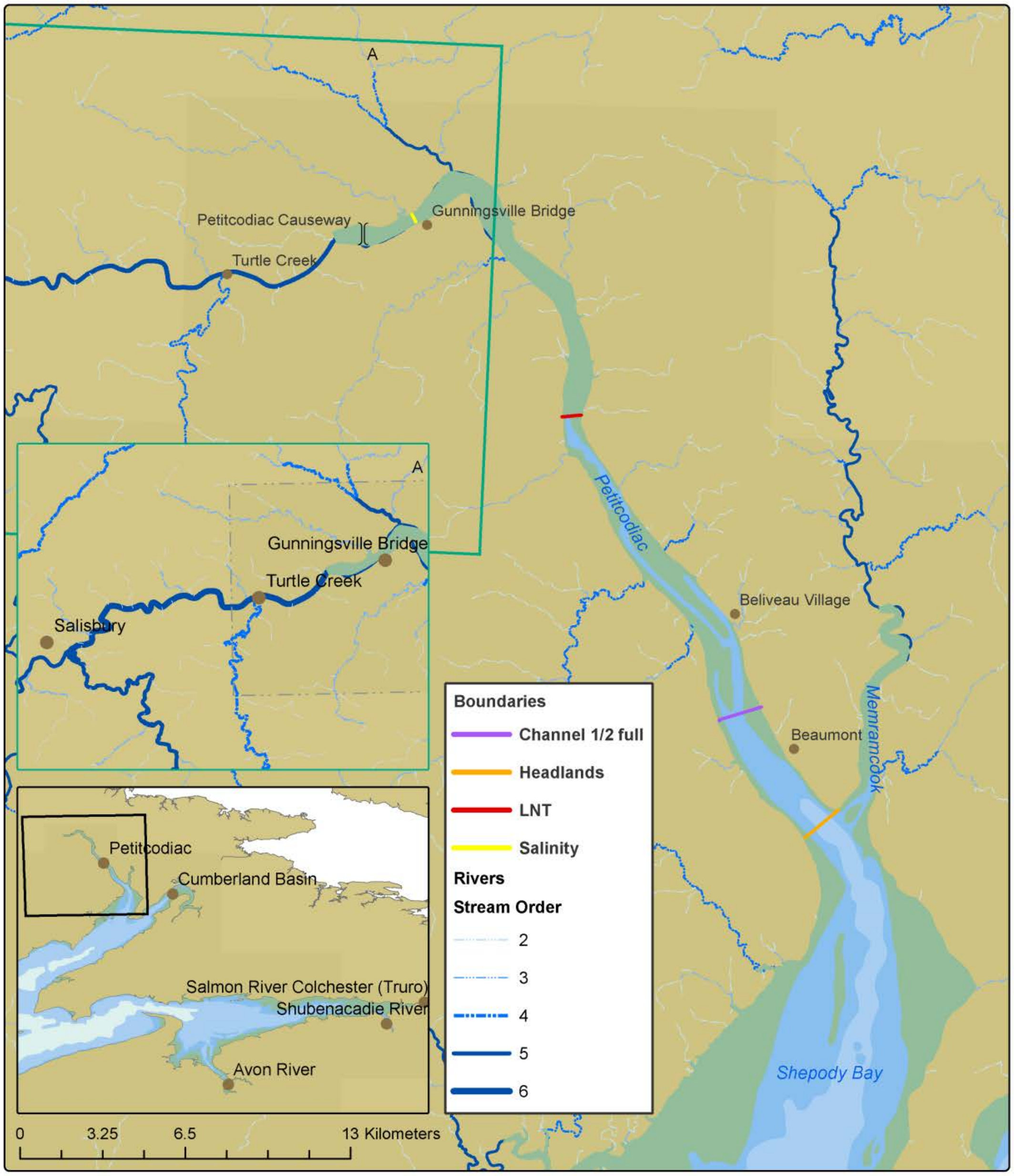

Figure 2. Four approaches to delineating the estuarine/marine boundary for the Petitcodiac River system. LNT = the line beginning at the furthest upstream location of the continuous extension of the lowest normal tide (LNT) mark, running perpendicular to the direction of the channel. Channel Half Full = the first location downstream where the channel is half filled with water at low tide (LNT), running perpendicular to the direction of the channel. Headland = a line between two headlands. A headland in this context is an area along the coast surrounded by water on three sides (Easterbrook 1999). The Canadian Hydrographic Service (CHS) maps shown are at a coarser scale than the charts used for boundary development; thus, the LNT boundary may appear different from the edge of the LNT mark. Electronic Navigation Chart (ENC) chart numbers 246241, 276312, and 276311 are shown on the map. River layers for New Brunswick and Nova Scotia are provided from the DNR (2013) and Service Nova Scotia (2012b), respectively.

Approach 1: Salinity Boundary

In response to the gates opening in the Petitcodiac River, various organizations have collected salinity information to monitor the associated environmental change. In 2012, AMEC (2013) collected water samples along the Petitcodiac River in three separate sampling periods: spring (May 7, 2012), summer (August 8, 2012), and fall (October 18, 2012). Samples were collected during both the flood and ebb tides to represent a range of average tidal conditions. A total of five replicate water samples were collected from 0.20 m below the water surface at each station for a given tide condition, with two stations upstream of the causeway (Turtle Creek, Salisbury Railway Bridge Crossing) and two downstream of the causeway (Gunningsville Bridge and Belliveau Village).

AMEC (2013) suggests that the maximum range of salt intrusion in the Petitcodiac River occurs during flood high tides when saline water makes its way up to Salisbury (Figure 2), which is approximately 22 km upstream of the Petitcodiac River Causeway at Moncton. Salt intrusion during ebb low tides occurs at about Turtle Creek, which is 5 km upstream of the Causeway. There is variability in salt intrusion between spring and summer (Figure 3), with more fresh water flow occurring in the spring; thus, reducing salt intrusion further up the river. Generally, the river approaches marine conditions of salinity for most of the year at Belliveau Village, which is approximately 17-18 km seaward of the Petitcodiac River Causeway. Salinity values are greater than 20 psu and closer to 30 psu at Belliveau Village during most of the year (Figure 3).

Environment New Brunswick (1980; as reported in Locke and Bernier 2000) reported that before the causeway was built, historical data suggested the salinities upstream of Moncton in summer were at least 28.5 psu, except under freshet conditions, with the salinities at Salisbury being between 0.26 to 11 psu (Elson 1961 as reported in Locke and Bernier 2000).

The recent measurements from AMEC demonstrated consistently high salinities at Belliveau Village near the mouth of the Petitcodiac River and consistently low salinities in Salisbury and at Turtle Creek (Figure 3). The salinities at Gunningsville Bridge were seasonally variable.

This information suggests that the gradient in salinity and, hence, the inland boundary for marine water varies seasonally. In the spring, the boundary is somewhere between Gunningsville Bridge and Belliveau Village, and, in the summer, the boundary is further upstream between Gunningville Bridge and Turtle Creek. Given the seasonal variability and the lack of sampling between Gunningsville Bridge and Belliveau Village, a reasonable estimate of an average position is proposed as Gunningsville Bridge (yellow line in Figure 2).

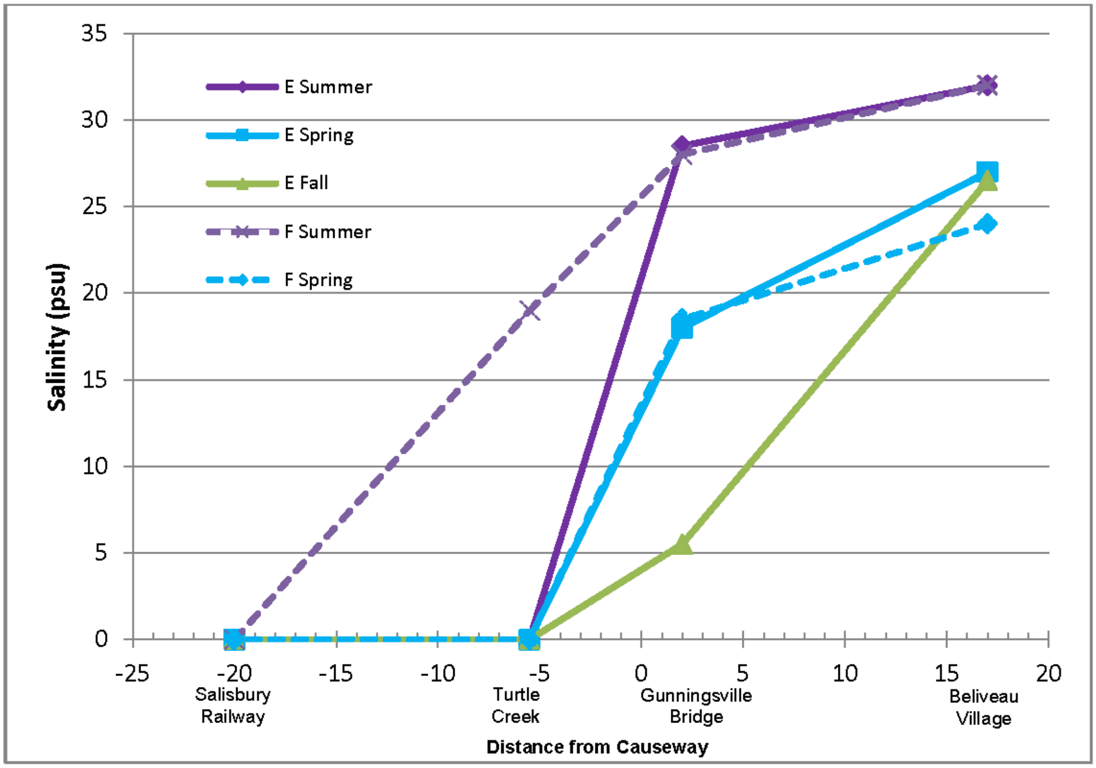

Figure 3. E - Ebbing low tide and F – Flooding high tide salt intrusion in the Petitcodiac River. Graph was recreated from information provided by AMEC Environment and Infrastructure (2013).

Approach 2a: Lowest Normal Tide Boundary

The LNT boundary in the Petitcodiac River system is shown as a red line in Figure 2. This line was derived from CHS chart number 413001. This line is located between Gunningsville Bridge and Beliveau Village, which is close to the expected transition between marine and estuarine habitat based on salinity data, although it does not vary seasonally. This line is considered to be appropriate for defining a marine CH boundary for Chignecto Bay (Area 2).

Approach 2b: Channel Half Full Boundary

The Channel Half Full boundary for the Petitcodiac River system is shown as a purple line in Figure 2. It was derived from CHS chart number 413001. Based on available salinity data, this line does not appear to reflect the location of the transition between marine and estuarine habitat.

Approach 2c: Headlands Boundary

A headland boundary for the Petitcodiac River system, based on topography, is shown as the orange line in Figure 2. This line is the furthest seaward of the four proposed approaches. Using this approach to identify the boundary of marine CH for IBOF salmon in Chignecto Bay, there is a risk that habitat important for the staging of adult salmon and migrating smolts would be excluded. The use of this approach for the Petitcodiac River system would be consistent with the approach being considered to identify the estuarine CH of the 10 rivers identified in the Recovery Strategy as containing freshwater CH. However, the Petitcodiac River is not currently identified as containing freshwater CH for IBOF salmon (DFO 2010).

Eastern Extremity of Minas Basin at Salmon River Colchester

Salmon River Colchester and Shubenacadie River estuary are two of the many river systems flowing into the Cobequid Bay portion of Minas Basin, and the river locations are at its most eastern extremity. Although the Salmon River Colchester has been identified by DFO Science as one of the 19 rivers containing important estuarine habitat (DFO 2013) for IBOF salmon, it is not currently identified as containing freshwater CH in the published Recovery Strategy, so it is not being considered as containing estuarine CH in the forthcoming amended Recovery Strategy.

The Recovery Strategy for IBOF salmon currently identifies six rivers flowing into the Minas Basin as containing freshwater CH (Stewiacke, Debert, Folly, Great Village, Portapique, and Economy), and the estuaries of these rivers are being considered as containing estuarine CH in the forthcoming amended Recovery Strategy. As noted previously in the Background section, headlands boundaries are being considered as the estuarine/marine boundaries for these river systems. The Shubenacadie River estuary is being considered as containing estuarine CH for IBOF salmon in the forthcoming amended Recovery Strategy since salmon must migrate through the Shubenacadie River estuary in order to reach the freshwater CH of the Stewiacke River.

Four approaches for delineating the estuarine/marine boundary for IBOF salmon CH where Salmon River Colchester enters the Minas Basin were explored. These include boundaries based on the salinity, LNT, CHF, and Headlands approaches (Figure 4). The challenge in this area is to select boundaries that exclude what is strictly the estuarine habitat of the Salmon River and Shubenacadie River estuary, includes the entire marine habitat of the Minas Basin, but also provides connectivity with the estuarine CH being proposed for the freshwater CH rivers listed above.

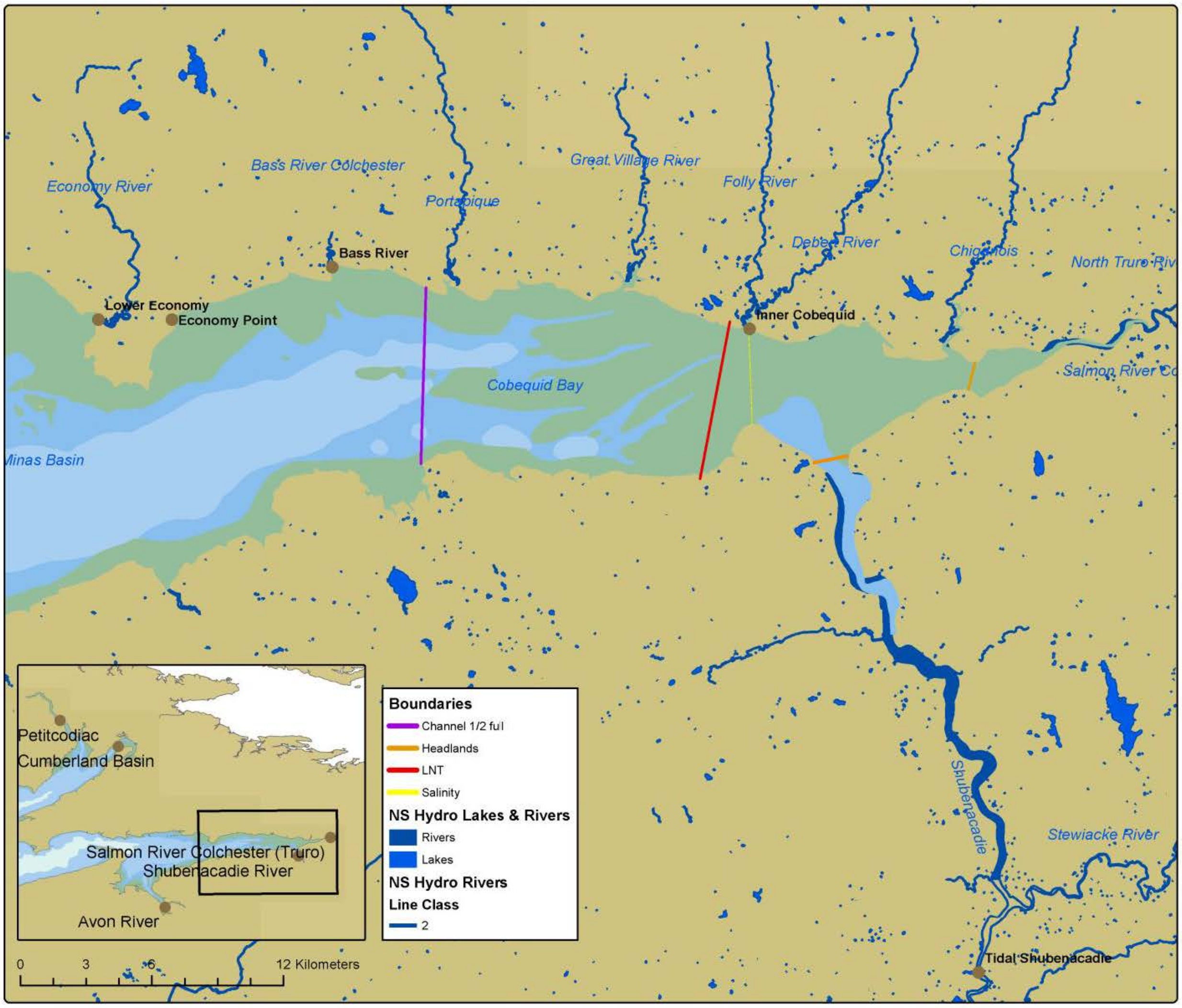

Figure 4. Four approaches to delineating the estuarine/marine boundary for the eastern extremity of Minas Basin at Salmon River Colchester. Salinity = LNT = the line beginning at the furthest upstream location of the continuous extension of the lowest normal tide (LNT) mark, running perpendicular to the direction of the channel. Channel half full = the first location downstream where the channel is half filled with water at low tide (LNT), running perpendicular to the direction of the channel. Headland = a line between two headlands. A headland in this context is an area along the coast surrounded by water on three sides (Easterbrook 1999). The provincial coastlines are not shown on this map and, thus, boundaries may not appear to touch the coastline. In addition, the Canadian Hydrographic Service (CHS) maps shown are at a coarser scale than the charts used for boundary development; thus, the LNT boundary may appear short or long of the edge of the LNT mark. Electronic Navigation Chart (ENC) chart numbers 246241, 276312, and 276311 are shown on the map. River layers for New Brunswick and Nova Scotia are provided from the DNR (2013) and Service Nova Scotia (2012b), respectively.

Approach 1: Salinity Boundary

Surface water temperatures, salinities, and turbidity have been measured for seven sites along the north shore of the Minas Basin and Cobequid Bay several times per year, usually late July-early September (Bradford et al. 2012). The approximate locations of the sites are shown in Figure 5. This sampling begins in Parrsboro, about 3 hours before predicted high water at Parrsboro, and then proceeds towards the inner portion of Cobequid Bay. The Bass River and

Inner Cobequid sites are usually sampled within 30 minutes of local high water. The 'tidal Shubenacadie' site (actually five sites within close proximity; Figure 5) is sampled on the day before or after the other sites. Efforts are made to avoid the tidal bore at this location.

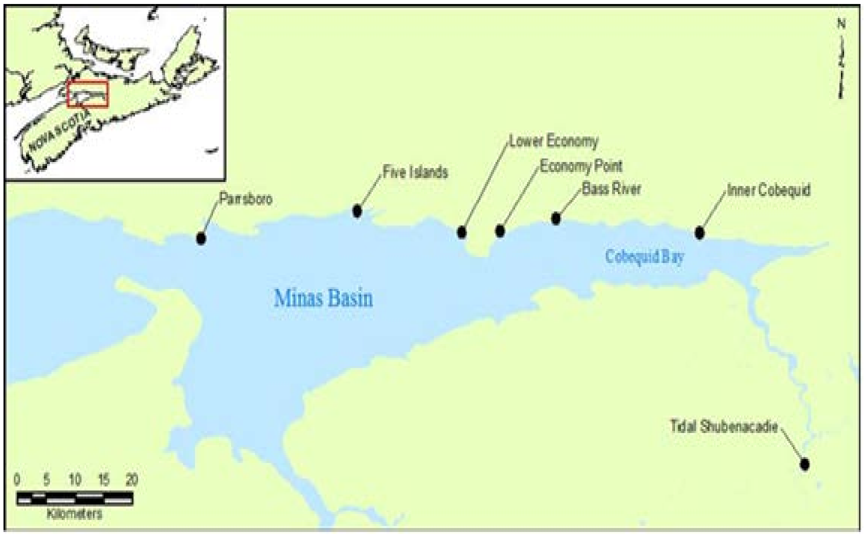

Figure 5. Salinity sampling locations in Minas Basin, Cobequid Bay and Tidal Shubenacadie, referenced in Table 2.

Results of the sampling are shown in Table 2 and Figure 6. These samples show average salinities between 25-31 psu, generally decreasing towards Salmon River Colchester. From these data, there is no clear transition between marine and estuarine conditions along the north shore of Minas Basin and Cobequid Bay. The average salinity at Inner Cobequid was 25.7 psu. An approximate 25 psu line was added to Figure 4 as the yellow dashed boundary, although it is unknown when a steep spatial gradient in salinity actually begins.

Table 2. The salinity conditions of sampling locations in Minas Basin, Cobequid Bay and Tidal Shubenacadie.

Area	Site	Avg. Salinity	Count	Min Year	Max Year
Minas Basin	Partridge Island	30.13	38	2000	2013
Minas Basin	Five Islands	28.14	40	2000	2013
Minas Basin	Lower Economy	28.94	40	2000	2013
Cobequid Bay	Economy Point	27.44	37	2000	2013
Cobequid Bay	Bass River/Saints Rest	28.35	41	2000	2013
Cobequid Bay	Inner Cobequid/Little Dyke	25.66	31	2001	2013
Tidal Shubenacadie	Boat Launch	13.10	2	2002	2002
Tidal Shubenaadie	Pine Tree	9.00	11	2001	2004
Tidal Shubenacadie	Shubie 102	8.08	40	2000	2013
Tidal Shubenacadie	Fish House	5.05	2	2001	2001
Tidal Shubenacadie	Palliser	0.30	1	2001	2001
Cobequid Bay	Maitland	27.40	1	2001	2001
Cobequid Bay	Anthonys Park	27.70	1	2002	2002
Cobequid Bay	Noel Bay	28.40	2	2001	2002

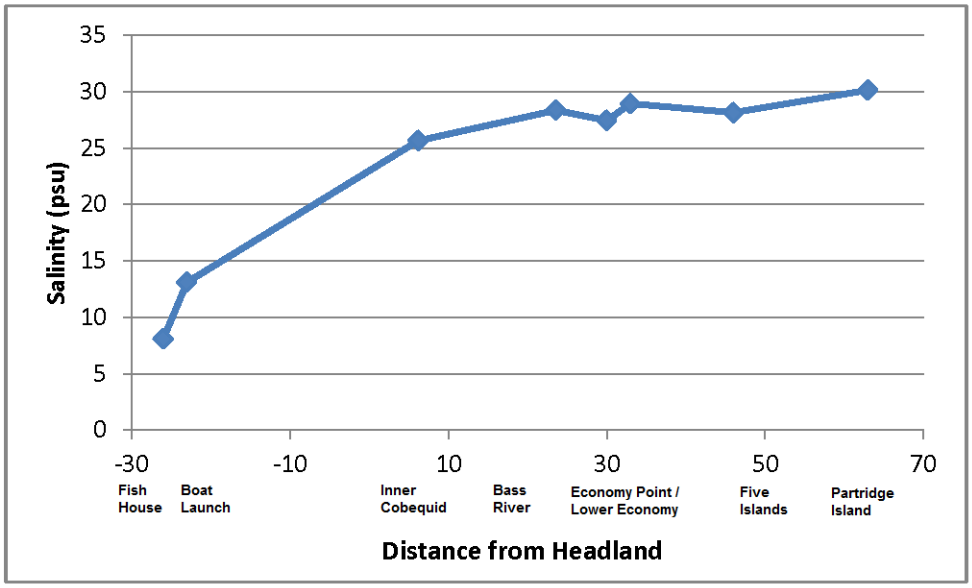

Figure 6. The salinity conditions at sampling locations in Minas Basin, Cobequid Bay and Tidal Shubenacadie.

As with the other rivers in the Bay of Fundy, there is salt water intrusion well up into the Salmon and Shubenacadie rivers. The above results are consistent with Parker et al. (2007; and references therein), which demonstrate contour lines of near surface summer salinities measured in 1958 in Minas Basin and Cobequid Bay, which suggests that the steepest salinity gradient transitioning high marine to low freshwater salinities occurs near the head of Cobequid Bay – in the region southeast of the Inner Cobequid label shown on Figures 4 and 5. This is similar to the pattern shown in the Shubenacadie River (Table 2).

From other work conducted in this area (B. Law, pers. comm.), it would appear that there is a sill between Minas Basin and Cobequid Bay that leads to more estuarine conditions, with greater sediment loads, in Cobequid Bay than in Minas Basin.

The salinity boundary, in this case, is not considered a useful way to establish a boundary between marine CH in the Minas Basin and the Salmon River Colchester system. Using this salinity boundary would create a disconnect between marine CH in the Minas Basin and estuarine CH proposed for the Shubenacadie.

Approach 2a: Lowest Normal Tide Boundary

The LNT boundary relevant for the eastern extremity of Minas Basin at Salmon River Colchester is shown as the red line in Figure 4. It was derived from CHS chart number 401002. This line falls well into the middle of Cobequid Bay, and important habitat for IBOF salmon would likely be excluded if this were used as the boundary for marine CH in Minas Basin. Moreover, this boundary falls short of the outflow of rivers identified as containing freshwater CH (Stewiacke, Folly and Debert rivers), and which are also being proposed as containing estuarine CH. It also falls short of the estuarine CH being considered for Shubenacadie River that will be included within the forthcoming amended Recovery Strategy. Thus, using the LNT approach to define a boundary for marine CH in the Minas Basin would result in a disconnect between the habitat used by IBOF salmon for migration between rivers previously identified as containing freshwater CH, additional estuarine habitat being considered as containing CH, and the marine CH being considered in the Minas Basin.

Approach 2b: Channel Half Full Boundary

The CHF boundary relevant for the eastern extremity of Minas Basin at Salmon River Colchester is shown as the purple line in Figure 4. It was derived from CHS chart number 401002. This boundary is the furthest seaward of the four approaches presented and falls far into Cobequid Bay, which would typically be considered marine habitat. Moreover, this boundary prevents connectivity with more rivers identified as containing freshwater CH (Stewiacke, Debert, Folly, Great Village, and Portapique rivers). Using this approach to define a marine CH boundary at this location would result in a wide disconnect between habitats used by IBOF salmon for migration between previously identified freshwater CH rivers and the marine CH being considered in the Minas Basin.

Approach 2c: Headlands Boundary

A Headlands Boundary for the eastern extremity of Minas Basin at Salmon River Colchester, based on an evaluation of the topography, is shown as an orange line in Figure 4 (a Headlands Boundary is also shown for the Shubenacadie River estuary). For Salmon River Colchester, this line would be considered most likely to capture the full extent of important marine habitat. Using this boundary would best ensure habitat connectivity for IBOF salmon migrating from their marine habitat through proposed estuarine CH and into freshwater CH for the Stewiacke, Debert, Folly, Great Village, Portapique, and Economy rivers, as well as encompassing habitat used by salmon migrating into the estuary of the Shubenacadie River, which is being considered to contain CH.

Cumberland Basin

Cumberland Basin (Figure 7) is an inlet at the northeastern most part of the Bay of Fundy and is connected to Chignecto Bay. The Recovery Strategy for IBOF salmon does not currently identify any rivers flowing into the Cumberland Basin as containing freshwater CH. The Maccan River, which flows into the Cumberland Basin, has been identified by DFO Science as one of the 19 rivers containing important estuarine habitat (DFO 2013); however, the estuarine habitat of this river is not currently being considered for prioritization for identification as CH given it has not been identified as containing freshwater CH in the published Recovery Strategy (DFO 2010).

The limited salinity data available at the time of drafting this Science Response indicates that salinity within Cumberland Basin is about 30 psu (Keizer et al.1984). Given the limited data and lack of recent data at hand to fully evaluate a boundary based on salinity for Cumberland Basin, emphasis is placed on the other three approaches for delineating the boundary between estuarine and marine habitat for IBOF salmon at this location. These include boundaries based on the LNT, CHF, and the headlands (Figure 7).

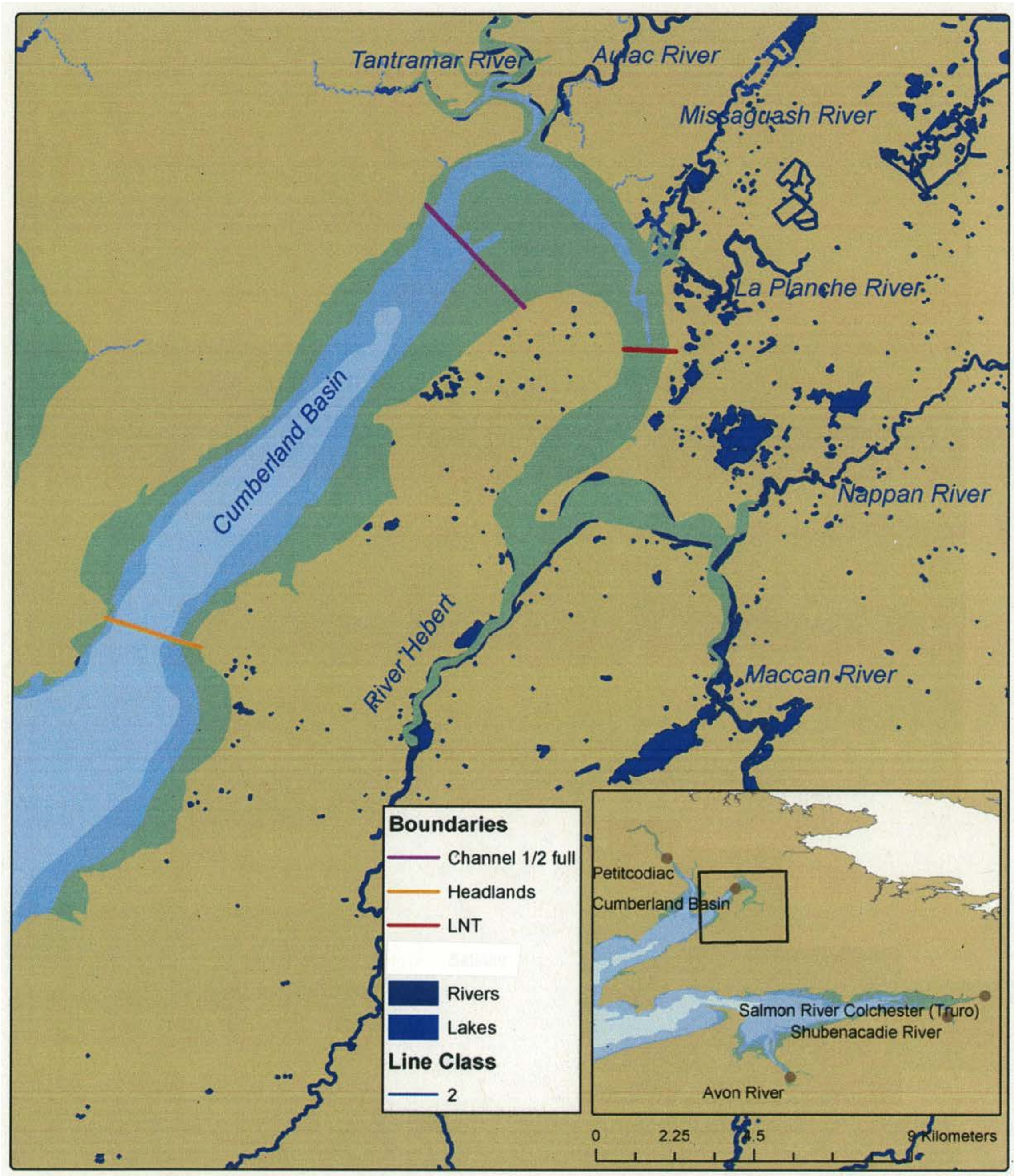

Figure 7. Three approaches to delineating the estuarine/marine boundary for Cumberland Basin. LNT = the line beginning at the furthest upstream location of the continuous extension of the lowest normal tide (LNT) mark, running perpendicular to the direction of the channel. Channel Half full = the first location downstream where the channel is half filled with water at low tide (LNT), running perpendicular to the direction of the channel. Headland = a line between two headlands. A headland in this context is an area along the coast surrounded by water on three sides (Easterbrook 1999). The Canadian Hydrographic Service (CHS) maps shown are at a coarser scale than the charts used for boundary development; thus, the LNT boundary may appear short or long of the edge of the LNT mark. Electronic Navigation Chart (ENC) chart numbers 246241, 276312, and 276311 are shown on the map. River layers for New Brunswick and Nova Scotia are provided from the DNR (2013) and Service Nova Scotia (2012b), respectively.

Approach 2a: Lowest Normal Tide Boundary

The LNT boundary for Cumberland Basin is shown as the red line in Figure 7. It was derived from CHS chart number 413001. This line is the furthest upstream of the three options provided, and it likely captures most of what would be considered important marine habitat for IBOF salmon as described in the Background section of this report.

Approach 2b: Channel Half Full Boundary

The CHF boundary for Cumberland Basin is shown as the purple line in Figure 7. It was derived from CHS chart number 413001. This line is expected to exclude important marine habitat that may be used by adult Atlantic Salmon (especially hatchery-origin salmon), which are known to stray into adjacent rivers when they are trying to find their natal river (Jonsson et al. 2003).

Approach 2c: Headlands Boundary

The Headlands boundary for the Cumberland Basin is relatively easy to define based on the topography, as there is an obvious narrowing of the estuary at this point. However, this line is expected to exclude an even larger portion of what may be considered important marine habitat for IBOF salmon. As none of the rivers flowing into the Cumberland Basin are currently identified as containing freshwater CH or being considered as containing estuarine CH, providing continuity with freshwater or estuarine CH is not a concern in this area.

Avon River Embayment

The Avon River system is a large embayment that flows into the southwestern part of Minas Basin and into which flow several IBOF salmon rivers. It has a causeway with tidal gates (without fish passage) at the Town of Windsor, Nova Scotia.

The Recovery Strategy for IBOF salmon does not currently identify the Avon River (or any of the rivers flowing into the Avon River embayment) as containing freshwater CH (DFO 2010); thus, the Avon River estuary, and the estuaries of the rivers flowing into it, are not being considered as containing estuarine CH in the forthcoming amended Recovery Strategy. However, the Avon River embayment is adjacent to the Gaspereau River (Figure 8), which has been identified as containing freshwater CH and for which estuarine CH is being considered. Adult Atlantic Salmon are known to stray into adjacent rivers when they are trying to find their natal river (Jonnson et al. 2003). Given the proximity of the mouth of the Gaspereau River to the Avon River embayment, straying of IBOF LGB Gaspereau River salmon into the Avon River embayment below the causeway is considered to be very likely.

Salinity information may be available but was not obtained in time for the drafting of this Science Response; therefore, only the three other approaches for delineating the boundary between estuarine and marine habitat for IBOF salmon are presented for the Avon River embayment. These include boundaries based on the lowest normal tide, the location at which the channel is half filled with water at low tide, and the headlands (Figure 8).

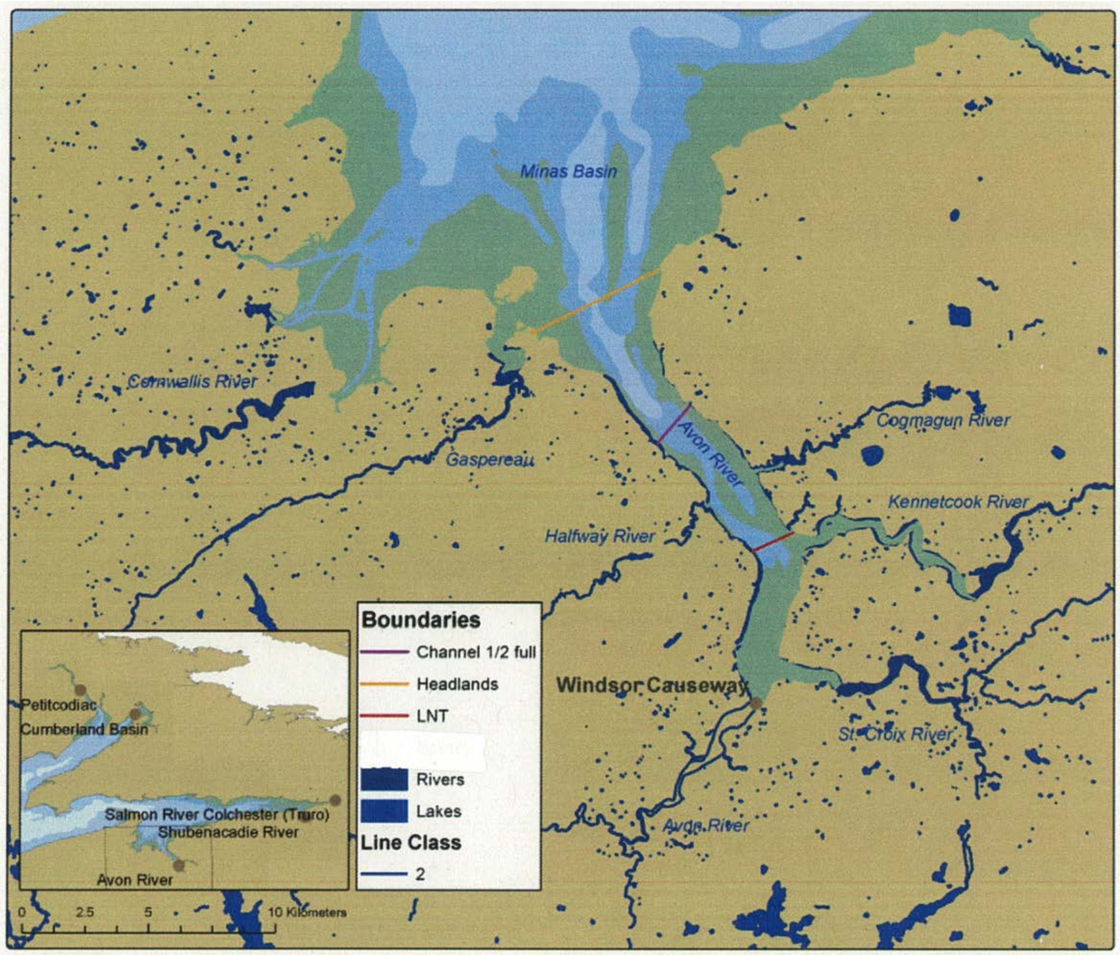

Figure 8. Three approaches to delineating the estuarine/marine habitat for the Avon River embayment. LNT = the line beginning at the furthest upstream location of the continuous extension of the lowest normal tide (LNT) mark, running perpendicular to the direction of the channel. Channel half full = the first location downstream where the channel is half filled with water at low tide (LNT), running perpendicular to the direction of the channel. Headland = a line between two headlands. A headland in this context is an area along the coast surrounded by water on three sides (Easterbrook 1999). The Canadian Hydrographic Service (CHS) maps shown are at a coarser scale than the charts used for boundary development; thus, the LNT boundary may appear short or long of the edge of the LNT mark. Electronic Navigation Chart (ENC) chart numbers 246241, 276312, and 276311 are shown on the map. ENC chart numbers 246241, 276312, and 276311 are shown on the map. River layers for New Brunswick and Nova Scotia are provided from the DNR (2013) and Service Nova Scotia (2012b), respectively

Approach 2a: Lowest Normal Tide Boundary

The LNT boundary for the Avon River embayment is shown as the red line in Figure 8. It was derived from CHS chart number 414001, which is a finer scale chart than is shown in the figure. This is why the LNT line does not coincide exactly with the contours shown in the figure. This line is the furthest up the river of the three options provided. As noted above, the Avon River and none of the rivers flowing into it contain freshwater CH or are being considered as containing estuarine CH, so using this boundary would not result in a disconnect between areas of identified CH. In addition, this boundary is the most likely to capture what would be considered important marine habitat for IBOF salmon.

Approach 2b: Channel Half Full Boundary

The Channel Half Full boundary for the Avon River embayment is shown as the purple line in Figure 8. It was derived from CHS chart number 414001. This line may exclude a portion of what is considered important marine habitat for IBOF salmon, including salmon straying from the adjacent Gaspereau River.

Approach 2c: Headlands Boundary

For the Avon River embayment, there is not a single obvious choice for the selection of a Headlands boundary. One possible choice based on topography is drawn in orange in Figure 8. This line is expected to exclude a portion of what may be considered important marine habitat for IBOF salmon, including salmon straying from the adjacent Gaspereau River. In addition, even without salinity data to review, it is considered unlikely to represent the transition between marine and estuarine habitat.

Conclusions

Given the guiding principles outlined above in this Science Response, and the fact that the tidal portions of:

- the Petitcodiac,
- several rivers draining into the Cobequid Bay (i.e., Salmon River Colchester, North (Colchester), Chiganois, Debert, Folly, Great Village, Portapique, and Shubenacadie rivers),
- the Maccan River (which drains into the Cumberland Basin), and
- the Gaspereau River (which has been identified as containing freshwater CH and drains into the Minas Basin in proximity to the Avon River embayment),

were all identified as containing important estuarine habitat, were among the highest priority areas identified by DFO (2013), and are all part of the long-term recovery target for IBOF salmon (DFO 2010), an inclusive approach to the delineation of marine habitat boundaries in proximity to these rivers (i.e., one that leads to the greatest amount of identified marine CH) is recommended.

Specifically, the following approaches are recommended for use in the delineation of IBOF Salmon marine habitat related to four large tidal estuaries in the Minas Basin and Chignecto Bay:

- The LNT boundary represents the most inclusive boundary for the Cumberland Basin and the Avon River embayment.
- The Headlands boundary of the Salmon River Colchester and Shubenacadie River estuary represents the most inclusive approach for the eastern extremity of Minas Basin.
- While the salinity boundary would be the most inclusive for the Petitcodiac River, the LNT boundary is recommended as a more reproducible (more easily defined) approach.

Additional salinity data might refine the salinity boundaries or provide for the establishment of a salinity boundary for those sites where data was lacking (i.e., Cumberland Basin and Avon River embayment), which could be considered in future boundary refinements if required. However, even with more refined salinity information, an approach that takes into account other management considerations would still be appropriate.

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Date: July 29, 2015

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ISSN 1919-3769
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Correct Citation for this Publication:

DFO. 2016. Support for Delineation of Inner Bay of Fundy Salmon Marine Critical Habitat Boundaries in Minas Basin and Chignecto Bay. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/035.

Aussi disponible en français :

MPO. 2016. Soutien pour définir les limites de l'habitat marin essentiel du saumon de l'intérieur de la baie de Fundy dans le bassin Minas et la baie Chignecto. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2015/035.